EFFECTIVENESS OF ORGANIC AND REDUCED INORGANIC FERTILIZERS ON YIELD AND FODDER QUALITY IMPROVEMENT OF MAIZE IN WESTERN KENYA

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A THESIS SUBMITTED TO THE SCHOOL OF AGRICULTURE AND BIOTECHNOLOGY IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF DEGREE OF MASTER OF SCIENCE IN AGRONOMY, UNIVERSITY OF ELDORET, KENYA

2025

DECLARATION

Declaration by the student

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Declaration by the supervisors

This thesis has been submitted for examination with our approval as university supervisors.

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DEDICATION

I dedicate this work to farmers, agronomists, soil scientists, family, friends and all interested in the field of agronomy.

ACKNOWLEDGEMENTS

First, I give thanks to almighty God for the gift of life, knowledge and good health throughout the entire study period and perseverance to accomplish this work. Special thanks go to my supervisors, Dr John Ngeno and Dr Ruth Njoroge of the Department of Department of Seed, Crop and Horticultural Sciences and Department of Soil Science, respectively, in University of Eldoret for their patience, understanding, supervision and cordial support throughout this study. Their unfailing specialized guidance, comments and timely input made the completion of the research work possible. I am grateful to the lecturers and technical staff of the School of Agriculture and Biotechnology for their guidance. I sincerely thank my fellow students at the postgraduate computer lab for their encouragement and assistance during research and writing of this thesis.

I express my sincere gratitude to the University of Eldoret for giving me the opportunity to undertake my postgraduate studies and realize my academic dreams.

Lastly, I express deep gratitude to my entire family for the love, concern, encouragement and financial support.

ABSTRACT

Maize remains a vital staple in Kenya, providing food for over 90% of the population and serving as the backbone of both food security and livestock nutrition. Despite its importance, maize production has declined in recent years, largely due to soil fertility depletion. This study, therefore, adopts the Integrated Soil Fertility Management (ISFM) principle of combining inorganic and organic P amendments to improve soil health and increase maize yields. The study leverages pressmud, a nutrient-rich residue from sugarcane processing that remains largely untapped in East Africa, despite its potential to improve soil health. Field trials were set up using a randomized complete block design to evaluate effect of sole application of pressmud in combination with cattle manure and reduced doses of P inorganic fertilizers in enhancing soil fertility, maize performance (grain yield and forage quality) and economic returns in two agro-ecological zones of western Kenya- Bungoma (LM2) and Kisumu (LM3). Soil samples were collected before and after the season to monitor changes in pH, organic carbon, nitrogen, phosphorus and potassium. Agronomic data, including plant growth, grain yield, forage quality and cost-effectiveness, were also recorded and analyzed using ANOVA. The results showed that pressmud applied at 30 kg P ha^{-1} (PM30) improved soil pH, available phosphorus and organic carbon, while cattle manure was more effective at boosting nitrogen content. The combination of 15kg Pha^{-1} from both organic and inorganic sources (TSP15+PM15 or TSP15+CM15) consistently resulted in grain yields exceeding 4.4 tons per ha, improved plant growth, crude protein in fodder and showed superior profitability while forage dry matter yields peaked under TSP10+PM10+CM10 in Bungoma and TSP22.5+PM7.5 in Kisumu. While not all treatments enhanced every aspect of forage quality most improved digestibility and maintained acceptable fiber levels but however, fodder from Bungoma showed slightly inferior acid detergent fiber (ADF) content. Based on these findings, farmers in similar regions are encouraged to use PM30 for improving phosphorus availability or CM30 for boosting nitrogen. To maximize grain yields and profitability, TSP15+CM15 (75kgTSP+3.06 t per ha of cattle manure) is recommended which also supports better fodder quality. Further research is needed in other agro-ecological zones and to better understand the factors behind reduced fodder quality.

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ANOVA	Analysis of Variance
CM	Cattle Manure
C-N	carbon-to-nitrogen ratio
DAP	Diammonium Phosphate
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization Corporate Statistical Database
KALRO	Kenya Agricultural and Livestock Research Organization
MLN	maize lethal necrosis
PM	Press Mud
TSP	Triple Super Phosphate

CHAPTER ONE

INTRODUCTION

1.1 Background to the study

Maize is one of the most important staple cereal crops grown by farmers globally. On the global scale, maize production reached 1,241.6 million metric tons in 2023 (FAOSTAT, 2025). North America, particularly the United States, leads in maize production, contributing to over 30% of the global output (Purewal *et al*, 2022). In Africa, maize is a major cereal crop, with Ethiopia, Nigeria, Egypt and South Africa, being the main producers (Benjamin *et al*., 2024)-. In Eastern Africa, maize is extensively cultivated in Kenya, Uganda, Tanzania, and Ethiopia, serving as a primary staple food for majority of the region's population (Were, 2021). Maize remains one of the most important cereal food crops in Kenya, where it a staple food for over 90% of the population (de Jong, Selten, Gitata-Kiriga, Peters & Dengerink, 2024). The crop is grown in high-potential areas mainly by smallholder farmers in the North Rift and parts of Western Kenya (Wanyama, Mighty, Sim & Koti, 2021; de Jong *et al.*, 2024). The average per capita consumption of maize is estimated at 0.103 t, translating to 36% of the country's calorie intake (Aguk, Onwonga, Chemining'wa, Jumbo & George, 2021). The crop is also utilised for livestock feed and fodder, hence supporting the livestock sector in Kenya. Nutritionally, maize grain comprises 72% starch, 10% protein, 4.8% oil, 8.5% fiber, 3% sugar, and 1% ash (Purewal *et al*., 2022), which provides a significant source of energy and protein in livestock feed formulations (Amanjyoti, Sowdhanya, Rasane, Singh, Ercisli, Verma & Ullah, 2024 (Palamarchuk, Krychkovskyi, & Skakun, 2024). Moreover, maize fodder is a highly nutritious source of crude protein and digestible dry matter, favorable to ruminant livestock (Aguk *et al*., 2021; Rangasami, Purnima, Pushpam & Ajaykumar, 2024). Maize is, therefore, indispensable for both human and livestock diets in Kenya (Dejene, 2018; Meenakshi, Sahitya, & Ali, 2024).

In Kenya maize production has fluctuated over the years (Mang'eni, 2022; Shilwatso, Simiyu, & Rutto, 2024). The estimated average grain yield of maize in Kenya is about 1.6 t/ha, against the potential production of 5.8 t/ha (2021-2023, FAOSTAT 2025), reflecting a yield gap of more than 4.2 t/ha, which is attributed to food insecurity affecting 34.5 and 28.6% of the inhabitants of Kenya and Eastern Africa and hence, there is need for intervention to meet the deficit.

Among the factors limiting maize production, the key ones include edaphic factors, pests and diseases, and low soil fertility (Yokamo, Jiao, Gurmu, Atinafu, Alemu, & Jiang, 2022). Climate change and land degradation remain major constraints (Saik *et al.*,2024). The areas suitable for maize production are under continuous production and hence deteriorate in terms of soil fertility due to nutrient depletion, potentially explaining the decline observed in maize production in Kenya up to 2019 (Chen, Li, Zhao, Li, Wei, Ma, & Tan (2024). The importance of maize for food, feed, and fodder calls for either increasing acreage or intensifying available production approaches that includes intensified fertilizer application (Brandt, Yesuf, Herold & Rufino, (2020); Wanyama *et al.*, 2021; Wamalwa, 2024) as an avenue towards improved production.

Low and declining soil fertility is a key drawback to maize production (Mutuku, Roobroeck, Vanlauwe, Boeckx, & Cornelis, 2020); Sime, Ballo, Abro, Gugissa, Mendesil,

& Tefera, 2024). Maize grain yields can be increased by between 200-500% when limiting nutrients are adequately supplied (Edmeades, Bänziger, & Ribaut, 2024). A soil investigation led by National Accelerated Agricultural Inputs Access Programme (NAAIAP, 2014), reported that in Kenya, between 88.7%, 71.5%, 62.5% and 19.4% of farms have low levels of C, N, P and K.

The use of inorganic and organic fertilizer inputs has proved beneficial in providing crops with the necessary nutrients deficient in the soil as evidenced by the studies done in western Kenya (Barasa, Ochuodho, Kebeney, & Barasa, 2022) in the recent past. Inorganic fertilizers are known to support high crop yields (Barasa *et al.*,2022), but contribute to enormous soil-related negative effects that include nutrient leaching, water and environmental pollution, nutrient toxicities to plants, soil acidity that lead to nutrient unavailability (Mutuku *et al.*, 2020; Radulov, & Berbecea, 2024). Industrial waste products like pressmud can also lead to environment pollution if not well managed (Lahori, Tunio, Ahmed, Mierzwa-Hersztek, Vambol, Afzal, & Muhammad, 2024; Sajid, Aslam, Hussain, Mumtaz, & Kousar, 2024).

In Kenya, pressmud is often disposed of in open dumpsites, contributing to air pollution and the contamination of ground and surface water (Nyonje, Njogu, & Kinyua, 2014; Srivastava, & Chakma, 2023). The sugar industry is the main source of pressmud, a by-product generated during the clarification and filtration of sugarcane juice. Kenya produces approximately 5.6 million metric tons of sugarcane annually (Statista, 2023), and studies indicate that pressmud accounts for about 3–4% of the cane processed. This translates to an estimated 168,000–224,000 tons of pressmud produced each year across the country’s major sugar mills, including Mumias, Nzoia, Chemelil, South Nyanza, and Transmara Sugar Companies.

Most of this pressmud remains underutilized and is often discarded near factory premises, despite its potential as an organic amendment rich in organic carbon, phosphorus, calcium, and micronutrients. If properly handled, pressmud and other sugar industry waste can serve as valuable organic fertilizers (Reganold, & Wachter, 2016; Arulazhagan, Muthaiyan, Murugaiyan, Uthandi, Alagirisamy, & Murugaiyan, 2024). Research findings show that pressmud and other sugar industry wastes can be used as organic fertilizers (Dotaniya, Datta, Biswas, & Meena, 2016; Khumla, Solomon, Manimekalai, & Misra, 2024).

Applying well-composted organic waste offers several benefits, such as reducing soil erosion and runoff, decreasing nitrate leaching, increasing soil carbon, and enhancing nutrient availability for plants (Szogi, Vanotti, & Ro, 2015; Hiranmai, Neeraj, & Vats, 2024; Seufert, & Ramankutty, 2017). Studies have demonstrated that using animal manure as the main organic source in agriculture increased biodiversity, improved soil and water quality, and enhanced profitability and nutritional value of food (Kumar, Ansari, Choudhary, Ravisankar, Singh, & Mehta, 2024).

Pressmud cake, constituting about 3% of the cane crushed in sugar processing, is a rich source of organic matter and plant nutrients and can be utilized profitably for crop production (Palanichamy, Kuppusamy, Suresha, & Prakash, 2024). It is acknowledged as a valuable organic manure and effective soil amendment (Sajid *et al*, 2024). Converting pressmud and other sugarcane processing waste into nutrient-rich organic manures addresses disposal and pollution problems while providing an alternative for soil replenishment, potentially reducing fertilizer costs for farmers (Selvamurugan, Doraisamy, & Maheswari, 2013; Lahori *et al.*, 2024).

Proper soil fertility management is essential for sustainable agriculture, resulting in increased yields while decreasing environmental and soil degradation (Oldfield, Bradford & Wood, 2019; Ndegwa, Gichimu, Mugwe, Mucheru-Muna, & Njiru, 2023). Therefore, research focusing on recycling sugarcane pressmud and blending it with cattle manure and/or synthetic fertilizers to improve maize yields and soil properties is necessary (Lahori *et al* 2024). The aim of this study is to fill the knowledge gap on the effectiveness of pressmud and cattle manure alone or blended with lower rates of inorganic fertilizer on soil fertility improvement, growth and yield of food and fodder maize in Western Kenya.

1.2 Statement of the problem

The depletion of soil fertility is a significant factor contributing to the decline of per capita food production in sub-Saharan Africa (Tefera *et al.*, 2024). Maize yields have been decreasing over the past decade (Kihara, Bolo, Kinyua, Nyawira, & Sommer, 2020; Kasera, Osure, Oloo, Odhiambo, Salu, & Oguna, 2024). In Kenya, maize yield averages 1.8 t/ha for smallholder farmers compared to the potential yield of 6.0 t/ha, translating to over 50% yield gap (Munialo, Dahlin, Onyango, Oluoch-Kosura, Marstorp & Öborn, 2020). This persistent yield gap has significant economic implications, as it directly affects household incomes, food affordability, and national food security targets. Low yields limit the profitability of maize farming, reducing farmers’ capacity to invest in soil improvement practices or purchase quality inputs, thereby perpetuating rural poverty. Low maize grain and fodder yields are primarily due to several constraints, with low soil fertility resulting from nutrient depletion, improper management of fertilizers, and climate change effects as the key contributors (Kugedera & Kokerai, 2024; Sharma, Kumar, Farooq, MeCarty, Kumar, Sharma, & Mehta, 2024) In Kenya, nutrient deficiencies are the primary reasons for low and declining maize yields (Kiboi, Ngetich, Mucheru-Muna, Diels, & Mugendi, 2021). Most agricultural soils in western Kenya are highly deficient in phosphorus (P) and nitrogen (N), which are crucial for optimal maize production (Otieno, 2021; Otieno *et al*., 2024). As a remedy the soil fertility problem, many smallholders' farmers resort to applying synthetic fertilizers such as diammonium phosphate (DAP) and NPK fertilizers (Manorama, Behera, & Suresh, 2024; Nasar, Ahmad, Gitari, Tang, Chen, & Zhou, (2024). However, these inorganic fertilizers often lack secondary nutrients (calcium, magnesium, and sulfur) and micronutrients like iron, copper, and zinc, which are essential for crop yield and quality (Dhaliwal, Dubey, Kumar, Toor, Walia, Randhawa, & Shivey, 2024). The continuous application of certain inorganic fertilizers can lead to increasing soil acidity, which reduce crop productivity, thereby creating food insecurity (Wato, Negash, Andualem, & Bitew, 2024; Wang, H., Yang, Yao, Feng, Wang, Kong, & Deng, 2024). Farmers can apply organic inputs to correct soil fertility. y. Presmud is an abundant organic resource presenting disposal challenges for the sugar processing industry, and can be used as an organic manure. However, its use as organic fertiliser has not been assessed for field crop production in Kenya, and this study will partially fill this knowledge gap.

1.3 Justification of the study

Maize is one of the leading cereal crops relied upon for human food, income, industrial raw material, and animal feed. Its production and productivity need to be enhanced and sustained. Maize, the preferred crop for this study, is the staple food and primary animal feed source in Kenya (Njoroge, Otinga, Okalebo, Pepela, & Merckx, 2018; Vučkovski &

Marina, 2024). Kisumu and Bungoma Counties are important areas for maize production in Kenya (Njagi, Riungu, Opiyo, Mwadime, & Aloo, 2024; Nzaka, Koech, Bett, & Owuor, 2024). These regions represent medium potential maize production areas, although maize yields in the two counties have remained below expectations for most of the improved varieties cultivated there (Kiprop, Kirwa, Ngotho, Mwungu, Wanjau, Otieno & Ghosh, 2024).

Integrated soil fertility management involving the combined use of organic manure and synthetic fertilizers has proved beneficial in improving maize productivity and produce quality in many studies compared to the application of manures or synthetic fertilizers alone (Barasa *et al*., 2022). Composting of industrial, or domestic solid waste is an effective strategy for solid waste management that provides opportunities for the conversion and recycling of organic materials. The organic materials in solid waste are decomposed and stabilized through composting, and the final compost products can be applied as a fertilizer, soil conditioner, or organic amendment (Jaffari, Hong & Park, 2024).

To ensure food security, addressing limiting factors contributing to low crop yields is crucial (Toromade, Soyombo, Kupa, & Ijomah, 2024). There is a need to reduce inorganic fertilizer application to alleviate the negative effects associated with their prolonged use and high application rates on soil characteristics and crop performance. Organic Manures are a suitable supplement to inorganic fertilizers and are beneficial for both soil nutrient and carbon (C) management (Barasa *et al*., 2022; Wato *et al.*,2024). However, they are not readily available in smallholdings. Due to limited supply, most smallholder farmers usually apply animal and green manure at very low rates, which makes minimal improvement on soil nutrient levels and crop performance, especially with the prevalent low inorganic fertilizer application (Kalibata, Thangata, Mutyasira, Nhlengethwa & Chirwa, 2024).

Kenya had 15 sugar milling companies with production capacity of 6 million tones. Average production of sugarcane in Kenya was 5.262 million per year, pressmud constitutes 2 to 4% of the weight of sugar cane processed. The 5,262 million can produce average of 105 to 210 million of pressmud (Mati & Thomas, 2019, Tiema, C., Ochung, A., & Omwoma, S. 2021), posing a serious waste management challenge in the absence of local options for recycling or conversion to useful by-products. Despite its abundant availability locally and demonstrated potential as a fertilizer elsewhere (Meghana & Shastri, 2020; Tiema *et al* 2024), there is limited use of sugarcane pressmud as a manure in Kenya.

There is a lack of information on the quality and effectiveness of pressmud as a fertilizer for maize production in Kenya to support its recommendation for bioconversion and application. Therefore, this study evaluated the potential of sugarcane pressmud as an alternative organic manure for maize production when applied as the sole nutrient source or in combination with cattle manure and/or synthetic fertilizers. The ultimate goal is to sustainably reduce the use of synthetic fertilizers and increase soil organic carbon by supplementation with organic sources in maize production. Therefore, replenishing soil nutrients in arable lands where maize is cultivated is required to reverse the decline in production.

1.4 Objectives

1.4.1 Broad objective

To contribute towards food security through application of affordable alternatives in managing soil quality for sustainable maize production.

1.4.2 Specific objectives

1. To assess the effect of integrated application of organic amendments and reduced inorganic fertilizer levels on soil properties.
2. To determine the effect of different organic amendments integrated with different inorganic fertilizer levels on maize growth and grain yield in lower midland semi-humid (LM3) and sub-humid (LM2) agro-ecological zones in western Kenya.
3. To evaluate the effect of organic amendments integrated with different inorganic fertilizer levels on the forage quality of maize in low midland semi-humid (LM3) and sub-humid (LM2) agro-ecological zones in western Kenya.
4. To assess the economic implication of using pressmud and cattle manure in maize production

1.5 Hypotheses

1. The soils in Kibos and Bumula are low in soil nutrients and the applied interventions are capable of supplying and improving the nutrients required for optimum crop performance.
2. There is increased soil nutrient availability and utilization by the maize crop when applied in the combined forms that positively impacts the crop performance.

3. The applied nutrients in combination improves the nutrients quality of maize forage and hence their nutritive value.
4. Pressmud and cattle offer similar economic benefits when used as organic amendments in maize cultivation.

CHAPTER TWO

LITERATURE REVIEW

2.1 Maize utilization and constraints to production

Maize (*Zea mays*) is one of the most grown and diversified crops in the world. It is used for various purposes, including food, animal feed, and industrial purposes. However, its growth is controlled by a series of limitations affecting yield and overall production.

There are many applications for maize, making it a very adaptable crop. Consumed in a variety of forms, including cornmeal, tortillas, popcorn, Kumar, Panwar, and polenta, it is an important staple food for human consumption globally (Mandal, Singh, Chaudhary, Kaur, & Kaushik 2023). It is the main source of protein and energy in cattle feed. The production of industrial goods such as adhesives, plastics, and biofuels (ethanol) is another application for it (Vallebueno-Estrada, Hernández-Robles, González-Orozco, López-Valdivia, Tham, Sánchez, & Montiel, 2023). In both traditional and modern agriculture, maize plays a vital role that affects economies and food security in several nations.

2.2 Maize production constraints in Kenya-

According to Kipkulei, Bellingrath-Kimura, Lana, Ghazaryan, Baatz, Matavel and Sieber (2024), maize is a crucial crop that is grown in a variety of agroecological zones, each with its own special traits and difficulties. According to Abate *et al*. (2015), these zones span from lowlands to upper highlands according to Abate *et al*. (2015) with transitional zones having the greatest potential for maize production. Among the problems affecting Kenyan maize production are drought, limited access to improved seeds, and maize lethal necrosis (MLN) (Gressel, Mbogo, Kanampiu, & Christou., 2024). Other limiting factors that significantly impact crop performance and, in turn, yields include weeds, pests, diseases, and inadequate soil fertility (Wu, Chen, Dou, Liao, Li, An, & Dong., 2024). In the humid transitional and high tropics, stem borers, foliar and stalk/ear rot diseases, and others cause significant losses (Hossain, Muthusamy, Bhat, Zunjare, Kumar, Prakash & Mehta., 2022). Access to credit and financing for small-holder farmers has been found to be a major obstacle to maize production in all agro-ecological zones (Ogunleye, Akinloye, Kehinde, Ajayi, & Wongnaa., 2024). Biofertilizers and integrated nutrient management have been promoted as remedies for soil fertility issues, but farmers have not adopted them extensively. By enhancing soil nutrient content and microbial activity, these techniques increase crop growth and resilience against environmental constraints, resulting in higher and more sustainable crop yields (Mutegi, Hendriks, Jones, Okori, & Siambi, 2015; Xing *et al*., 2024).

2.2.1 Soil fertility constraints and their management

Among other things, farmers in western Kenya list decreasing soil fertility as the main obstacle to maize production, which results in yield losses of 20–80% and, in extreme situations, total crop failure (Omondi, Aila, Ombok, Obange & Dida., 2024). Crop productivity is severely hampered by declining soil fertility, especially due to deficiencies in phosphorus (P) and nitrogen (N). Soil degradation is a result of ongoing cereal monoculture and insufficient nutrient replenishment (Musa, Samuel, Adams, Abdulsalam, Nathaniel, Maude, & Tiamiyu, 2024). Maize yields can be considerably increased by increasing soil organic carbon and improving soil fertility through integrated nutrient management (Vanlauwe, Bationo, Chianu, Giller, Merckx, Mokwunye, & Sanginga, 2006; Kigara, Mugo, & Wekesa, 2016; Wang *et al*., 2024). More sustainable maize production results from these techniques, which also increase soil organic matter, decrease erosion, and improve water retention (Fidelis, de Figueiredo, Oliveira, da Silva, & Pereira, 2020).

Research indicates that combining organic and inorganic fertilizers can significantly improve maize yields and soil health (Imran, 2024). The use of locally available organic materials, such as compost and manure, can provide a cost-effective solution for smallholder farmers (Ayinde *et al*., 2016).

2.2.2 Use of inorganic fertilizers in managing soil fertility

The use of fertilizers has significantly boosted crop production, meeting the food supply needs of the growing human population (Penuelas, Coello, & Sardans, 2023). However, agricultural intensification, which involves the use of fossil fuels for machinery, chemical pesticides, herbicides, synthetic fertilizers, and other agro-chemicals is harmful to the agro-ecosystem health and balance, interfering with its proper function (Sarkar, Jaswal & Singh, 2024; Padmavathy & Poyyamoli, 2011; Hermani, 2020).

The use of mineral fertilizers by smallholder farmers in Sub- Saharan Africa is essential towards improving crop production, however; several studies shown that the application of NPK fertilizer without amendments among smallholder farmers in Western Kenya, has contributed to low soil productivity (Balah, Thomas & Ogallo, 2024; Barasa *et al.*, 2022; Otieno, 2024). The resultant low crop yields are likely to lead to reduced farmer’s income and food insecurity in the region. (Roobroeck, Palm, Nziguheba, Weil, & Vanlauwe, 2021). Sai and Paswan, 2024 confirmed that applying NPK fertilizer application at the recommended rate does not lead to significant yield increases.

The use of synthetic and organic fertilizers has become indispensable in agriculture, enhancing the supply of essential nutrients that support plant growth, (Imran, 2024). The rapid increase in the global human population has prompted a tremendous rise in the demand for food (Fróna, Szenderák & Harangi-Rákos, 2019; Ghosh, Kumar & Biswas, 2024). Statistics indicate that 40 to 60 percent of crops are cultivated using various types of fertilizers to improve nutrition and crop performance (Chen, Luo, Li, Zhang, Peng & Wang 2018; Ludemann, Wanner, Chivenge, Dobermann, Einarsson, Grassini & Tubiello, 2024). Over 50 percent of the human population relies on crops fertilized with synthetic fertilizers for their food supply (Crews, & Peoples, 2004; Penuelas *et al*., 2023). While this meets the food supply demand, the long-term detrimental effects of intensive synthetic fertilizer application are often overlooked (Govil, Long, Escribà-Gelonch & Hessel, 2024).

Excessive use of synthetic fertilizers can alter soil fertility by increasing its acidity (Qiao, Miao, Han, Li, Jiang & Zhao, 2018; Pahalvi, Rafiya, Rashid, Nisar & Kamili, 2021; Teketel, 2024). To mitigate this, soil testing every three years is recommended to monitor nutrient needs and ensure the correct amount and type of fertilizers are applied (Penuelas *et al*., 2023).Synthetic fertilizers not only alter pH levels but also in high or continuous doses diversity drops, beneficial communities weaken, soil health declines (Aguilera, Lassaletta, Gattinger, & Gimeno, 2013; Wei, Xie, Wan, Song, Zhong, Xin & Song, 2024).

Nitrogen and other chemicals in fertilizers can contaminate ground and surface water, leading to health concerns (Nath, Bhuyan, Gogoi, & Deka, 2023). Health hazards associated with exposure to air, water, or food contaminated with fertilizers include heart disease, thyroid disorders, hypertension, respiratory conditions, and cancers (Mahurpawar, 2015; Ahmed, Mehmood, & Imran, 2017; Penumantra, Shirbhate, Tiwari, & Narkhede, 2024). While fertilizers contribute to high food security, their continued application has serious environmental and health implications (Penuelas *et al.*, 2023). Despite these dangers, synthetic fertilizers remain indispensable in modern agriculture due to their role such as providing nutrients readily available to plant use, this improves plant growth and production increase, farmers can manage amount and timing according to the plant they are targeting, farmers can correct deficiency of the soil and choose the nutrient to apply, in case of poor soil by using inorganic you can restore yield very fast while organic still buildup.

2.2.3 The use of organic amendments in managing soil fertility

Organic amendments improve soil structure and increase soil organic carbon content, thereby enhancing the soil's ability to retain nutrients and moisture. This, in turn, promotes plant growth, health, and productivity. Additionally, organic soil amendments like compost and animal manure can immobilize potentially toxic elements from the soil (Ahmad, Lee, Lee, Al-Wabel, Tsang & Ok, 2017; Ghani, Nawab, Khan, Khan, Ahmad, Ali, & Dinelli, 2024). Pressmud, a plentiful industrial waste in Kenya, could be used as compost to supplement synthetic fertilizers in the cultivation of maize for improved yield.

Exploiting the use of pressmud as an organic fertilizer input provides an avenue for waste recycling for a cleaner environment and resource utilization to replenish soil organic matter with the benefit of improving maize yields towards sustainable agriculture. Recycling organic waste as a crop fertilizer as opposed to its disposal in landfills would reduce greenhouse gas emissions as noted by Kiehbadroudinezhad, Merabet & Hosseinzadeh-Bandbafha (2024) who indicated that it helps reduce air and soil pollution that contributes to clean environment. Organic manure provides crops with the essential macro and micronutrients necessary for healthy growth as pointed out in the study by Emendu, Chinweuba & Chinedu (2021) and Dhaliwal *et al*. (2024) and beyond nutrient supply, it also improves the soil's physical, chemical and biological qualities enhancing its structure and texture (Singh, Malhi, Kaur, Singh & Jatav, 2022). By stimulating biological activity organic manure helps release nutrients deeper in the soil and reduces moisture loss through evaporation (Miller, 2000; Jiang, Dong, Bian, Zhang & Wang, 2024) with among the various ways to use organic matter for soil enrichment being composting which is considered the most effective as acknowledged by a research study by Manea, Bumbac, Dinu, Bumbac & Nicolescu (2024). Compost is produced through the controlled aerobic decomposition of organic residues such as yard waste, kitchen scraps and crop residues resulting in a humus-like nutrient-rich product teeming with beneficial microorganisms whose process enhances soil fertility, water retention and structural stability (Bremaghani, 2024).

Traditional organic amendments like animal manure are rich in organic matter and minerals such as nitrogen, phosphorus and potassium boosts soil fertility and stimulates microbial activity (Verma, Pradhan, Singh, & Kushuwaha, 2024) while cultivating certain crops typically legumes and ploughing them back into the soil as green manure also contribute to soil fertility increasing organic matter which strengthens soil structure and adds nitrogen since leguminous plants can fix atmospheric nitrogen into a form plants can use (Dotaniya *et al*., 2016; Huang, 2024).

Biochar (a stable carbon-rich material) produced when organic matter is heated in low oxygen conditions a process known as pyrolysis (Afshar & Mofatteh, 2024). When applied to soil, biochar therefore improves water retention, enhances fertility and sequesters carbon in the soil. Its porous structure and large surface area make it particularly effective at holding nutrients and moisture, making it a long-lasting organic amendment (Ruan, Zhang, Lambers, Xie, Zhang, Xie & Wang, 2024).

Furthermore, the application of biochar has shown promise in alleviating heavy metal toxicities and improving soil nutrient content. (Kuppusamy, Thavamani, Megharaj, Venkateswarlu & Naidu, (2016) demonstrated that biochar application in contaminated soils reduced heavy metal availability and enhanced nutrient retention, promoting healthier plant growth and improved soil fertility.

The nutrient composition of organic amendments can differ greatly depending on the source materials and the methods used for composting or processing whose variation makes it difficult to determine exact application rates for crops (Dotaniya *et al*., 2016; Meena, Aggarwal, Meena & Rathore, 2024). For example, animal manure must be thoroughly composted to eliminate harmful pathogens including *Salmonella* and *Escherichia coli* (Rizwan *et al*., 2024).

In comparison with synthetic fertilizers, organic amendments generally contain lower levels of nutrients. Meeting crop nutrient requirements therefore often demands larger amounts of material, which can present practical challenges in handling and application (Rizwan *et al*., 2024; Chen *et al*., 2024). Additionally, nutrients are released gradually as the organic matter decomposes. While this slow-release process can improve soil fertility over time, it may not supply sufficient nutrients for fast-growing crops that require immediate nutrient availability (Miller, 2000; Govil *et al*., 2024).

Crops may experience a nitrogen shortage if organic amendments with a high carbon-to-nitrogen (C) ratio, like straw or wood chips, momentarily immobilize nitrogen as soil microbes break it down. The C ratio can be balanced by adding a small amount of nitrogen fertilizer (Miller, 2000; Xu, Yao, Chen, Liu, Teng, Huang & Gao, 2024). The preparation, transport, and application of organic amendments can be labor-intensive and costly, especially for large-scale farming operations. Although the benefits of improved soil health and reduced input costs may offset these expenses over time, initial investments can be significantly high (Conway, & Barbier, 2013); Toor, Yang, Das, Dorsey, & Felton, 2021). Organic materials in solid waste can be biodecomposed and stabilized by composting, and the final products applied to the field as a soil conditioner or fertilizer (Dukić, Marks & Llenas, 2020). Composting produces a transient thermophilic phase followed by a cooling period, resulting in stable, hygienic, humus-like compost that retains beneficial mineral elements for soil and plants (Karimi, Raza & Mechri, 2024). If done properly, composting effectively destroys weed seeds and pathogens through the heat generated by microorganisms during the process (de Bertoldi, 2013).

Composting relies on aerobic microorganisms to break down organic materials, yielding simpler organic and inorganic compounds that are more available as plant nutrients (Aronsson, 2024). Composting of pressmud is known to improve its physical structure and lower the C- N ratio by breaking down more than 16% of the waxy components (MDiaz, 2016). Raw pressmud from the sulphitation process of sugar processing contains 35-37% organic carbon, 1.0-1.5% nitrogen, 2.5-3.5% phosphorus, and 0.5-0.8% potash (Conway & Barbier, 2013; Sajid, Aslam, Hussain, Mumtaz & Kousar, 2024), making it a rich nutrient source when composted. According to MDiaz (2016) and Sajid *et al*. 2024), comparison of the nutrient value between sulphitation- and carbonation-processed pressmud cakes revealed presenece of higher in N, P and K content in pressmud from the sulphitation process. The nitrogen, phosphorus, and potassium contents in sulphitation-processed pressmud were 2.43%, 2.95%, and 0.44%. In contrast, carbonation-processed pressmud cake contained 0.88%, 0.93%, and 0.53% of N, P, and K, respectively. According to Dotaniya *et al*. (2016), the organic carbon content of pressmud obtained from the carbonation process was lower (15.07%) than that from sulphitation processing (26.0%). Nitrogen, phosphorus, and potassium contents of sulphitation filter cake were 2.38%, 2.62%, and 0.62%, respectively, whereas carbonation process filter cake contained 0.86%, 1.02%, and 0.60% N, P, and K, respectively.

During composting, mesophilic microorganisms initially decompose available simple sugars, generating heat and raising the temperature to the thermophilic range (40-70°C) (Durán-Valle & López-Coca, 2024). Another group of organisms with ability to degrade polymers and utilize intermediate products of fermentation becomes active during the thermophilic period (Meng, Liang, Wang & Ren, 2024). Nitrogen in the organic compounds is converted to ammonium ions through the high-temperature aerobic fermentation process (Yang, Zhang, Du, Gao, Cheng, Fu, & Wang, 2024). The elevated temperatures during composting kill pathogens and weed seeds, reducing disease incidence and weed pressure in subsequent crops (de Bertoldi, 2013, Kushal *et al*., 2024). A proper composting process should provide conditions for adequate oxygen transfer inside the compost heap to produce good-quality compost from organic waste (Goldan, Nedeff, Barsan, Culea, Panainte-Lehadus, Mosnegutu, & Irimia, 2023; Lalthlansanga, Pottipati, Mohanty & Kalamdhad, 2024; Wang, Feng, Wang, Wang & Wang, 2024).

Soil organic carbon is a vital component of soil fertility, influencing nutrient availability, water retention, and soil structure (Khan & Kwot, 2024). Continuous cultivation without adequate organic matter replenishment leads to a decline in soil organic carbon content, negatively impacting soil health. A study by Lal. (2015) emphasizes the role of organic amendments, such as crop residues and cover crops, in enhancing soil organic carbon levels and improving soil structure.

Similarly, other studies (Six *et al*. 2018 and Francaviglia, Almagro & Vicente-Vicente, 2023) demonstrated that adopting conservation agriculture practices that promote organic matter accumulation, including minimal tillage and residue retention, significantly increased soil organic carbon content and improved soil aggregation. These practices contribute to better soil structure, water retention and resilience against erosion, supporting long-term soil fertility and agricultural productivity.

Organic amendments supply essential nutrients necessary for plant growth. For instance, compost typically contains about 1-3% nitrogen, 1-2% phosphorus, and 1-2% potassium (Panday, Bhusal, Das & Ghalehgolabbehbahani, 2024). These nutrients are gradually released, providing a steady supply for plants (Asadu, Ezema, Ekwueme, Onu, Onoh, Adejoh & Emmanuel, 2024). The addition of organic amendments improves soil structure by increasing soil aggregation, which enhances aeration, water infiltration and root penetration. Compost, for instance, helps create a crumbly soil texture that facilitates root growth and water movement (Aluvihara, Weerawardena, Gunaratne, Deniyapahala & Kumari, 2024).

Organic matter significantly increases the soil's water holding capacity, crucial in areas prone to drought. The improved soil structure allows better water infiltration and retention, reducing the need for frequent irrigation (Diaz, 2016; Ray, & Majumder. 2024). Organic amendments stimulate microbial activity, essential for nutrient cycling and organic matter decomposition. Increased microbial activity leads to the formation of humus, a stable form of organic matter that enhances soil fertility (Filipović, *et al.*,2024). Using organic amendments can reduce dependence on chemical fertilizers, promoting sustainable agriculture. Green manures and composts, for example, can supply a significant portion of the nutrients required by crops, minimizing the need for synthetic inputs (Zhao, Bai, Han, Yao, Liu, Hao & Wang, 2024; Jin, Jin, Wang, Li, Liu, Liu, Z & Yu, 2022). However, organic fertilizers should not be considered an ultimate solution to immediate high crop yields owing to their slow release of the contained crop nutrients to meet the immediate crop needs (Govil *et al*.,2024). Hence the need for their combination with the inorganic fertilizers for improved and immediate nutrients availability.

2.2.4 The combined use of inorganic and organic fertilizers in managing soil fertility

Inorganic fertilizer sources as a major soil fertility management option may not be sustainable, as continued application leads to soil deterioration and environmental pollution (Henryson *et al*., 2018; Stewart *et al.*, 2020, Srivastav *et al*., 2024). A remedy to this problem is to limit the sole use of chemical fertilizers through combination with organic fertilizers; this has proved beneficial in sustaining soil fertility as compared to applying chemical or organic fertilizers alone Pei *et al*., 2021 Wang *et al*., 2024). A recent study in western Kenya (Barasa *et al.*, 2022) has confirmed that inorganic fertilizers when combined with organic fertilizer application improves soil physical and chemical properties, besides promoting plant growth and yield. Combined application of organic and inorganic fertilizer inputs has shown to increase soil organic matter, total nitrogen content of the soil and soil microenvironment in wheat/maize fields (Song, Yang, Liang, Yang, Song & Li, 2024). Another study (Lu, Hao, Ma, Gao, Fan, Guo, & Zhou, 2024), found that under the same nutritional conditions, organic fertilizer can enhance soil available nutrients such alkali-hydrolytic nitrogen, available phosphorus, available potassium, and soil organic matter while lowering the quantity of conventional fertilizer needed by wheat. He, Peng, Hou, & Li. (2024) suggested that variations in SOC stock are influenced by fertilization mechanisms. To improve soil fertility and SOC stocks in wheat fields, it is advised to utilize organic fertilizer instead of conventional fertilizer or reduced chemical and substitute it with organic fertilizer. (Xu, *et al*2025), found that soil undergoing organic fertilization treatments had larger OC stocks and distribution ratios in both the passive portion and the pool. The maximum OC in the passive pool and carbon management index (CMI) under nitrogen, phosphorus, potassium with manure (NPKM) demonstrated that adding manure together with chemical fertilizers was a successful method of enhancing soil OC stability and sequestration. Zhao, Khan, Yin, Song, & Nie (2024) found that physico-chemical characteristics of the soil were enhanced by partially replacing inorganic fertilizer with organic fertilizer, which raised the production of rice grains in the following seasons. Another study conducted by Wei, Xie, Wan, Song, Zhong, Xin, & Song (2024) reported that microbial fertilizers greatly increase the diversity and richness of soil microorganisms, which is essential for preserving the microecological balance of the soil and enhancing the soil environment. Microbial fertilizers promote plant growth and improve the uptake and use of vital nutrients like nitrogen (N), phosphorus (P), and potassium (K) by secreting a variety of secondary metabolites, proteins, enzymes, and plant hormones. Chemical fertilizer reduction combined with organic fertilizer application meets the requirements for green ecology which is becoming crucial in environmental protection especially in low fertility soils like those of Kibos and Bumula sites of Western Kenya.

It has been demonstrated that combining pressmud with synthetic fertilizers may significantly increase crop yields. For instance, a research conducted in 2005 by Shankaraiah and Murthy showed that, in comparison to utilizing chemical fertilizers alone, applying a constant rate of pressmud together with different amounts of synthetic fertilizers greatly enhanced cane and sugar yields by up to 21%. Farmers were able to reduce the cost of synthetic fertilizers by up to 50% by using half the recommended rate of pressmud-blended synthetic fertilizer. The findings underscore the economic advantage of reducing dependence on costly synthetic fertilizers by integrating them with organic nutrient sources. Singh, Singh, and Rao (2013) reported that the use of pressmud alongside inorganic nitrogen, applied either individually or together, increased sugarcane yields by 12.9% to 65.6% compared with untreated controls. Similarly, pressmud improved maize and wheat yields by 129.4% and 62.2%, respectively, illustrating the substantial gains achievable through combined fertilization practices. Despite these promising results, Kenya has not yet undertaken studies to evaluate the potential of pressmud in enhancing the production of staple food crops. This study therefore explored crop performance when pressmud is applied alongside bovine dung, a commonly available organic resource on Kenyan farms.

Supporting the benefits of integrated fertilization, Manna, Swarup, Wanjari, Mishra, and Shahi (2018) found that combining farmyard manure (FYM) with inorganic fertilizers increased yields of wheat and maize while improving soil fertility, contributing to long-term soil health. Similarly, Mandal, Patra, Singh, Swarup, and Masto (2019) observed that rice yields rose by 25% when FYM was applied together with synthetic fertilizers, compared with the use of inorganic fertilizers alone. These studies collectively highlight the potential of integrating organic and inorganic inputs to sustain high crop productivity and preserve soil quality over multiple growing seasons. When compared to using only inorganic fertilizers, the authors results showed that combining FYM with synthetic fertilizers increased rice output by 25% which also improved soil health by increasing microbial activity and soil organic carbon levels. The rise in soil organic carbon is especially beneficial for enhancing soil structure and water holding capacity both of which are critical for crop development especially in regions that are prone to drought. While Alam, Islam, Rahman and Bhuiyan's (2020) studied the effects of mixing poultry manure with inorganic fertilizers on soil properties and tomato yield found that tomato yield and soil nutrient content were significantly increased by the integrated approach. This approach is beneficial for high value crops like tomatoes because the increased nutrient content in the soil promotes robust plant development and higher yields.

Mucheru-Muna, Mugendi, Kung'u& Mugwe, (2014) assessed the impact of integrating *Tithonia diversifolia* green manure with inorganic fertilizers on maize yield on Kenyan soils. The findings revealed that the combined application significantly increased maize yield compared to the sole use of inorganic fertilizers. The integrated approach also enhanced soil fertility by increasing nitrogen availability. This is particularly relevant for smallholder farmers in Kenya who seek sustainable methods to improve crop productivity without relying solely on expensive chemical fertilizers. In another study, Mutegi *et al*. (2015) investigated the impact of integrated soil fertility management (ISFM) practices on maize production in Kenya. The study found that combining organic and inorganic fertilizers resulted in higher maize yields and improved soil nutrient balance. ISFM practices help mitigate nutrient deficiencies and enhance soil fertility, providing a sustainable solution for smallholder farmers.

There are several advantages to using both organic and inorganic fertilizers together. In the first place, it increases agricultural yields by providing a balanced supply of nutrients that enhance crop growth and productivity. For instance, it has been shown that pressmud greatly boosts the yields of cane, maize, and wheat when combined with synthetic fertilizers (Shankaraiah & Murthy, 2005; Singh *et al*., 2013). This balanced nutrient delivery ensures that crops receive the essential macro and micronutrients needed for optimal development, while also boosting soil fertility (Wang *et al*., 2024Long-term soil fertility maintenance is aided by organic fertilizers such as pressmud, FYM, and calf manure, which add organic matter and boost microbial activity. This improves the availability of nutrients and the structure of the soil (Manna *et al*., 2018; Mandal *et al*., 2019). The addition of organic matter by these fertilizers helps to build soil organic carbon, which is necessary to maintain soil yield and health. Pal and Poddar (2024).

Utilizing organic fertilizers also lessens the negative effects that synthetic fertilizers have on the environment, including greenhouse gas emissions and nutrient leaching (Verma *et al*., 2024). According to Alam *et al*. (2020), organic fertilizers enhance soil health and lessen the requirement for chemical inputs. By lowering chemical inputs, more sustainable farming methods are encouraged and the detrimental environmental impacts of excessive fertilizer usage are lessened.

2.3 Effect of integrated nutrient management on maize growth and grain yield

2.3.1 Maize growth

Using organic matter improves plant height and leaf area by increasing micronutrient availability and improving root growth (Ayoola & Makinde, 2019, Dhaliwal *et al*., 2024). In recent years, it has been demonstrated that integrated nutrient management, which includes inorganic fertilizers, pressmud, and cow dung, greatly increases maize production and growth. In comparison to utilizing inorganic fertilizers alone, research have demonstrated that combining these organic elements improves plant height, leaf number, leaf area index (LAI), stem girth, and shoot dry weight yield. The application of prescribed NPK in conjunction with cow dung, pressmud, and vermicompost, for example, significantly increased plant height, leaf count, and shoot dry matter production, as shown by Kaur *et al*. (2023). In a similar vein, Yadav *et al*. (2024) found that adding 75% of the suggested NPK to farmyard manure composed of cow dung enhanced growth traits including plant height, LAI, and shoot biomass. Yemata & Mengistu (2024) verified that, in comparison to a non-fertilized plot, the application of synthetic fertilizers and cow dung following plant nutrient removal significantly increased plant height, LAI, stem girth, and shoot dry matter production.

2.3.2 Grain yield and quality

The combined use of organic and inorganic manure enhances maize yield and grain quality more effectively than using either type of fertilizer alone (Chen *et al*., 2024). Abd El-Gawad and Morsy (2017) highlighted that the integrated application of farmyard manure (FYM) and chemical fertilizers significantly improved maize yield attributes, including the number of grain rows, ear length, ear weight, and the weight of 100 grains. This demonstrates the complementary benefits of organic and inorganic fertilizers in soil fertility management. Combination of pressmud compost with urea resulted in the highest maize grain yield, with compost enhancing soil organic matter and microbial activity, and urea providing essential nitrogen for plant growth (Iqbal *et al*., 2017; Ashenafi, Gebre Selassie, Alemayehu, & Berhani 2023. Some studies have also shown that biochar improves soil moisture retention and nutrient availability thus leading to higher maize yields when used alongside chemical fertilizers (Major *et al*., 2017; El-Syed, Helmy, Fouda, Nabil, Abdullah, Alhag, & Elrys, 2023). Combining organic and inorganic fertilizers not only increased maize yields but also improved the nutritional quality of the grains in majority of cereal crops. Sharma and Subehia (2020) reported that the use of vermicompost alongside inorganic fertilizers significantly enhanced both maize output and grain quality. In this combination, the inorganic fertilizers supplied readily available nutrients for immediate plant growth while vermicompost provided a steady release of nutrients and supported soil microbial activity.

Similarly, Shafi, Bakht, Khan, Khan and Raziuddin (2016) found that integrating chicken manure with urea led to higher maize yields and improved grain quality compared with using urea alone in their study. In this case, urea supplied the nitrogen needed for optimal growth whereas poultry manure enriched the soil with organic matter and additional nutrients. Walia and Kaur (2019) also observed that combining chemical fertilizers with green manure crops in particularly legumes substantially increased maize productivity. The symbiotic relationship between nitrogen-fixing bacteria in legumes and artificial fertilizers further enhances nutrient availability, reinforcing the benefits of integrated fertilization strategies.

These studies underscore the importance of integrating organic and inorganic amendments to optimize maize yield and quality. Each combination offers unique benefits, and selecting the appropriate amendments should consider specific agro-ecological zones and soil conditions for the best results. Critical evaluation and comparison of different amendment combinations are crucial for developing sustainable and efficient fertilization practices for maize production. (Kumar *et al*. 2021) found that crop yield and soil health were significantly enhanced by integrated fertilization with FYM. By modifying the microbial population and soil enzymatic activities, integrated fertilization by FYM improves yield parameters and nutrient (N, P, and K) availability.

2.4 Effect of integrated nutrients management on forage quality of maize

Using a combination of organic and inorganic manures can lead to better forage quality outcomes than using either type of fertilizer alone (Sher, Adnan, Sattar, Ul-Allah, Ijaz, Hassan, & El Askary, 2022). Choudhary, Garg, Reddy, Meena, Mondal, Tuti, & Rajawat, (2024) demonstrated that the integrated use of organic and inorganic fertilizers increased the absorption of nitrogen (N), phosphorus (P), and potassium (K) in plant leaf tissue, leading to better plant health and higher yields. Together with Sher, Adnan, Sattar, Ul-Allah, Ijaz, Hassan, & El Askary (2022), Azraf-ul-Haq Ahmad & Mahmood (2007) discovered that mixing these fertilizers in sorghum greatly enhanced fodder output by increasing the number of leaves per plant, plant height, and leaf area. By supplying a balanced mix of nutrients, integrated fertilization supports optimal plant growth and higher yields. Harischandra, Premalal and Wicramasinghe (2015) recommended combining urea (100 kg/ha), muriate of potash (MOP, 62.5 kg/ha) and organic manure (15,000 kg/ha) to maximize fodder yield in sorghum. In a separate investigation, Essilfie, Darkwa and

Asamoah (2024) examined the effects of inorganic fertilizers and chicken manure on maize and found that applying both together produced the highest fodder yields compared with using each fertilizer individually. Similarly, Jalal, Ahmed, Ashraf, and Ali (2016) reported that compost combined with inorganic fertilizers enhanced maize protein content and overall forage quality. Darabi, Heidari, Khalesro and Jahani Azizabadi (2025) further demonstrated that combining chemical fertilizers with pelleted chicken manure increased maize yields improved yield components and produced fodder with higher crude protein and lower NDF fiber content thus a nutrient-dense forage that contribute to better animal performance and overall nutrition.

Sher *et al*. (2022) also noted that the nutritional density and digestibility of the feed were enhanced in maize production when organic and inorganic fertilizers were used. While artificial fertilizers guaranteed a balanced supply of vital nutrients, organic additions enhanced soil microbial activity and nutrient availability, resulting in higher-quality fodder. These studies highlight how crucial it is to apply a balanced fertilization strategy in order to maximize yield and quality. Farmers may improve fodder quality and yields by combining organic and inorganic fertilizers, which will increase productivity and promote agricultural sustainability overall.

A number of quality parameters including as nutritional content, digestibility, fiber composition and general palatability are used to evaluate maize fodder (Cueva Welchez, 2024). Maize forage quality is shaped by agronomic practices, harvest timing and the type of soil amendments used whether organic or inorganic. Nutrient content is the main factor influencing quality with maize valued for its high energy from carbohydrates (Narayan, 2024; Duma & Sulendre, 2025). Nitrogen-rich fertilizers, including manure, compost, and synthetic sources, can increase protein levels in maize fodder (Khan, Khan, Ali, Bashir & Noor, 2018; Weiss, 2019). Organic amendments further enhance mineral availability improving calcium and phosphorus content essential for bone and metabolic health (Mupambwa & Wakindiki, 2019; Shah Faisal *et al*. (2013; Jalal, Ahmed, Ashraf, and Ali, 2016; Walia and Kaur, 2019).

Another important characteristic of maize forage is digestibility, which determines how well nutrients are absorbed and broken down by animals. The amount of neutral detergent fiber (NDF) and acid detergent fiber (ADF) in the feed has a significant impact on this. NDF measures the total amount of cellulose, hemicellulose, and lignin in the cell wall. Lower NDF readings indicate better digestibility and higher forage consumption. Forage fiber decreases as plant nitrogen levels increase, claim Karimi, Sayfzadeh, Pazoki, Hadidi Masouleh, & Zakerin (2025) and Mertens & Grant (2020). For high-producing dairy cows, maize fodder is more suitable since it typically has a lower NDF than other forage crops (Ballard, Thomas, Tsang, Mandebvu, Sniffen, Endres, & Carter, 2015; Karnatam, Mythri, Un Nisa, Sharma, Meena, Rana, & Sandhu, 2023Higher energy availability and better digestibility are indicated by lower ADF values, which quantify the amount of cellulose and lignin (Kung, Shaver, Grant, & Schmidt, 2018). Organic amendments can assist maintain reduced lignin levels in maize feed by enhancing soil health and encouraging better plant development (Wang, Yan, Xu, Wang & Hu, 2020).

Palatability, or the willingness of animals to consume the forage, is influenced by its texture, aroma, and taste. High-quality maize forage is typically more palatable, encouraging higher intake rates and better overall animal performance. (Norman, H. C., & Masters, D. G. 2023) The application of fertilizers plays a crucial role in enhancing forage quality by improving nutrient content, which can positively affect the aroma and taste, making the forage more appealing to animals (Santos, Monteiro, Voss, Komora, Teixeira, & Pintado, 2021). However, excessive use of certain fertilizers, particularly nitrogen, can sometimes lead to undesirable changes in texture or taste, potentially reducing palatability (Revilla, Plaza & Palacios, 2021). Ensuring good palatability involves not only proper harvesting, handling, and storage practices to prevent spoilage and maintain forage quality but also the careful management of fertilizer application to optimize both yield and palatability (Gaikwad, Rautela, Kedare, Sarkar, Pal, & Sharma, 2024).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the study area

The soil fertility study was carried out during the long rains of 2021 at Kiboss representing lower midland semi-humid zones (LM 3) in Kisumu county and Bumula representing lower midland sub-humid zones (LM2) in Bungoma county. Figure 1 shows a map of the study site.

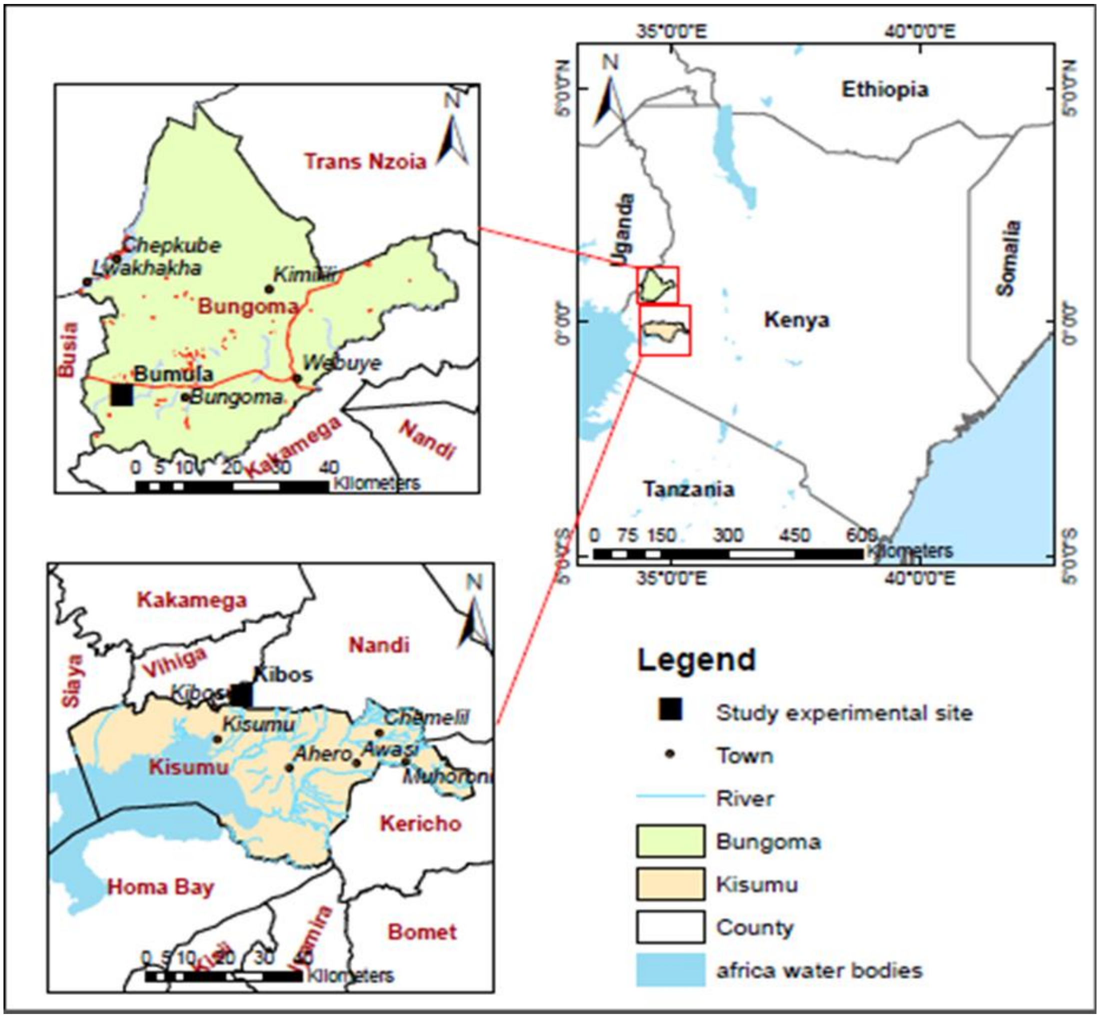


Figure 3.1. A map of study area

The organic inputs that included sugarcane pressmud(PM) and cattle manures (CM) were initially composted as described in section (3.1.1) and mixed with TSP fertilizer in various proportions which were later tested on soil fertility and crop performance and maize forage at the study sites.

The study sites are located in low soil fertility regions of western Kenya (Table 1). This formed the basis for the fertility study on inorganic and organic inputs as an avenue for soil fertility and crop improvements. The area experiences warm and wet climatic conditions with bimodal rainfall and generally low soil fertility as presented in Table 1.

***Table 1**: Climatic conditions of the study site*

Study site	Eco-Zone	Soil Type	Soil pH	Altitude m.a.s. l	Rainfall (mm)	Mean Temp. (^{O}C)	Latitude	Longitude
Kibos Kisumu County	LM3	Orthic Acrisols	6.07	1224	450-600	21-22.7	0.0393°N	34.8162°E
Bumula Bungoma County	LM2	Acrisols	5.55	1493	1500	21 -25	0.5742°N,	34.4420°E

Source: Jaetzold, *et. al,* (2012)

3.2 Composting and preparation of organic soil fertility inputs

Raw pressmud and cattle manure were composted using the Berkley hot composting method (Raabe, UCDavis Vegetable Center). This is a rapid composting procedure that can be concluded within 14-21 days depending on the type of organic material and various physical factors. For this study, composting was carried out for a period of up to 30 days, since pressmud is known to take long to decompose. The process was managed as described below for optimal degradation of the organic sources.

3.2.1 Compost C: N adjustment

Before composting, the starting materials were divided into two parts. One part was sun-dried for carbon enrichment while the other part was maintained fresh. The two portions were then mixed to obtain a C:N ratio of about 25-30:1, which is suitable for the efficient nutrient use and multiplication of the bacteria responsible for the composting process.

3.2.2 Compost heap

A compost heap measuring roughly 1.3 meters in height and 2 meters in width was prepared using pressmud and cattle manure for effective decomposition and retain heat while preventing the material from drying out too quickly. After construction, the compost piles were left undisturbed for four days to allow heat to build up.

3.2.3 Aeration

The compost heaps were turned every two days to ensure sufficient oxygen reached the microorganisms and to promote even decomposition of the organic material After the initial four days. Aeration is essential for aerobic composting requiring at least 5% oxygen during the bio-oxidative phase with a maximum of 10% as the process progresses. Regular turning was maintained to ensure adequate oxygen levels to support continued aerobic decomposition as microbial populations grew and also to prevent foul odors and sustained effective breakdown of the compost material (Meng, Liu, Shi, Wu, & Xu, 2013).

3.2.4 Temperature

The temperature was monitored on a weekly basis and maintained between 40°C to 65°C throughout the thermophilic phase of composting (Mohammad, Alam, Kabbashi & Ahsan, 2012), as this range is considered as the most favorable for the process. Maintaining the optimum temperature range was critical for aerobic composting. Throughout the process, the temperature of the pile indicated the metabolic status of the microbial population and the progression of the decomposition process. If the temperature rose above the optimum, it was regulated by turning and temporarily spreading the piles for short periods to avoid further heating of the compost (above 75°C), which could be lethal to the decomposing bacteria. Achieving and maintaining temperatures of 55°C to 65°C was targeted to kill pathogens and weed seeds, ensuring a clean final compost.

3.2.5 Moisture

The compost heap moisture was maintained at 45 to 60%, which is considered optimal for the composting process (Paul, 2014). Low moisture content reduces the rate of decomposition due to dehydration and overheating, while excess moisture (>60% RH) causes waterlogging and suffocation of the aerobic decomposers. Moisture was measured at two-day intervals using a moisture meter and adjusted by adding water to the compost or allowing for partial dehydration.

3.2.6 pH

The pH of raw pressmud and cattle dung was usually below 4.5. A pH varying between 6.0 to 7.5 is suitable for the survival and activity of bacterial decomposers, while a pH range of 5.5 to 8.0 is favorable for fungal decomposers (Kalamdhad, Khwairakpam, & Kazmi, 2012). At a pH above 7.5, gaseous loss of ammonia was likely to occur during composting, reducing the nitrogen content of the final product. Therefore, the pH was measured during the turning of the compost to determine the changes following the decomposition of the material. Composting was terminated at a pH below 7.5 to avoid nutrient nitrogen loss.

3.3 Soil sampling for initial site characterization

Soil samples were taken from the two sites of Kibos and Bumula study sites. Laboratory soil tests based on some selected soil chemical properties of the soil samples from the two sites were later carried out.

Soil sampling involved six soil samples (0.5 kg each) from each of the study sites as mentioned above. In each site, soil sampling was done by the zig-zag technique by auguring the soil at two different soil depths (0-15 and 15-30) cm. The soil samples from the same depth and at different points of each of the selected s sites were respectively bulked to form composite samples to eliminate unnecessary variability. From the composite samples, 100 g of soil sample was drawn for further laboratory analysis. Soil parameters measured included: (pH, P, N, organic carbon and K determination as described in Table 4

3.3.1 Nutrient content of materials used in the field experiments

The fertilizers used and their nutrient contents are presented in table 2.

***Table 2**: Nutrient Contents of pressmud and cattle manure used in field trials as determined at 30 days of composting*

Chemical parameter	**Organic Amendment**	
	Pressmud (PM)	Cattle manure (CM)
Organic Carbon	24.4	25
Total Nitrogen	0.6	1.5
Total Phosphorus	0.7	0.5
Total Potassium	0.4	0.8

3.3.2 Soil sampling and laboratory analyses

a) Soil sampling procedures

Soil sampling was three-fold running from prior to the onset of the field experiments at both study sites. First sampling was done to characterize the soils at the study sites prior to planting. The second sampling was done at the flowering stage of the maize crops and the third sampling was done at the maize crop harvesting time.

The laboratory soil analysis procedures used in determining selected soil fertility properties at the two-site included**;** Soil pH (Glass electrode method), organic carbon (Walkley & Black method); total nitrogen (Kjeldahl method) and available phosphorus (Olsen method), as outlined in the Laboratory Manual by Okalebo *et al*., 2002.

b) Determination of soil pH (H_2O) 1:2.5

Fifty (50) ml of distilled water was added to 20 g air-dried (2mm) soil. The mixture was stirred for two minutes and allowed to stand for 30 minutes. Thereafter the soil suspension was stirred for two minutes, and pH was measured using the pH meter.

c) Total organic carbon (%) content of soils

Walky and Black (1934) oxidation method as described by Okalebo *et al., (*2002) was used to determine soil total organic carbon. This procedure involves complete oxidation of organic carbon by an acid (H_2SO_4) dichromate solution. Excess or unreacted dichromate (Nelson and Sommers, 1975) was determined by titration using ferrous ammonium sulfate. The colour change from greenish to brown forms the end point and the titer is then used to calculate organic carbon after making the blank correction.

d) Olsen Extractable phosphorus (mg.kg^{-1})

Phosphomolybdate method, (Olsen *et al.,* 1954) as described by Okalebo *et al.,* 2002 was used in extraction of soil available P. Phosphate and ammonium molybdate forms a complex in this method, that is reduced with ascorbic acid to produce a blue colour complex in a solution whose intensity (the absorbance) is measured using a spectrophotometer at a wavelength setting of 880 nm. Phosphorus concentration (ppm) in soil solution is calculated by plotting absorbance versus concentration from which sample concentration is read off from the graph and ppm P is calculated.

d) Total nitrogen (%) and phosphorus in plant samples

Total nitrogen concentration was determined based on the Kjeldahl procedures as described by Okalebo *et al.,* 2002. Total P was determined from the plant tissues after digestion with concentrated sulphuric acid in the presence of a catalyst. The principle involved is the oxidation of organic materials to inorganic soluble P components (phosphate). Phosphate is then measured using the phosphomolybdate colorimetric method in which the absorbance (blue colour intensity) is measured at a spectrophotometer wavelength setting of 880 nm. Blank correction is made by subtracting the mean blank reading from the sample reading. A graph of absorbance against standard P concentrations is plotted from which solution P concentration for the samples is determined. These nutrient concentrations were then used to determine the amount of nutrients contained in the plant tissues.

e) Exchangeable (potassium) (cmol.kg^{-1})

The exchangeable potassium was extracted from a soil sample using an excess of 1M NH_4OAc (ammonium acetate) solution where the maximum exchange occurred between NH_4 and the cations originally on the soil exchange sites on the soil surface. The amount of the exchangeable metal cation in the soil extract was then determined using atomic absorption spectrophotometry at specific metal wavelengths.

3.3.3 Treatments used in the field experimental study

Thirteen treatments consisted of decomposed pressmud (PM) and cattle manure (CM) in various combinations with or without inorganic fertilizer (TSP) at calculated rates of the organic manure (Table 3).

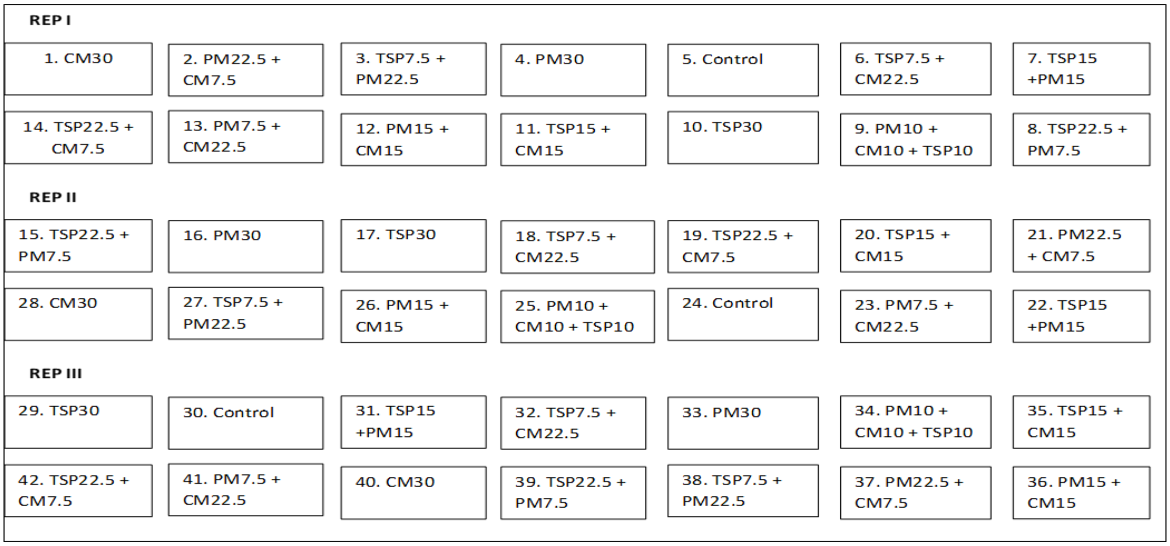
Treatments were: 1. Absolute zero (control) without any fertilizer input, while Treatment 2 was. NPK fertilizer at the full recommended rate of 100 kg N/ha, 30 kg P/ha, and 60 kg K/ha (Samuel, Abigael, Ruth, & Ernst, 2019). Other treatments consisted of reduced NPK fertilizer at various combinations with decomposed pressmud and cattle manure at a calculated rate that fulfilled NPK nutrients requirement for maize production. The quantity of manure applied was calculated based on P_2O_5 to supply the full rate of P.

***Table 3**: Treatments tested in the field study*

Soil amendments	Description	Organic fertilizer quantity (t/ha^{-1})
Control	No nutrients applied	
Triple Super Phosphate (TSP)	30 kg P/ha^{-1}, full inorganic P	
Press Mud (PM)	30 kg P/ha^{-1}, full organic P	4.225
Cattle Manure (CM)	30 kg P/ha, full organic P	6.123
TSP 15 + PM 15	15 kg P/ha^{-1} TSP + 15 kg P/ha PM (half rate each)	2.113
TSP 22.5 + PM 7.5	22.5 kg P/ha^{-1} TSP + 7.5 kg P/ha PM (2/3 TSP + 1/3 PM)	1.056
TSP 7.5 + PM 22.5	7.5 kg P/ha^{-1} TSP + 22.5 kg P/ha PM (1/3 TSP + 2/3 PM)	3.169
TSP 15 + CM 15	15 kg P/ha^{-1} TSP + 15 kg P/ha CM (half rate each)	3.061
TSP 22.5 + CM 7.5	22.5 kg P/ha^{-1} TSP + 7.5 kg P/ha CM (2/3 TSP + 1/3 CM)	1.531
TSP 7.5 + CM 22.5	7.5 kg P/ha^{-1} TSP + 22.5 kg P/ha CM (1/3 TSP + 2/3 CM)	4.592
PM 15 + CM 15	15 kg P/ha^{-1} PM + 15 kg P/ha CM (half rate each)	2.113 + 3.061
PM 22.5 + CM 7.5	22.5 kg P/ha^{-1} PM + 7.5 kg P/ha CM (2/3 PM + 1/3 CM)	3.169 + 1.531
PM 7.5 + CM 22.5	7.5 kg P/ha^{-1} PM + 22.5 kg P/ha CM (1/3 PM + 2/3 CM)	1.056 + 4.592
TSP 10 + PM 10 + CM 10	10 kg P/ha^{-1} TSP + 10 kg P/ha PM + 10 kg P/ha CM (1/3 each)	1.409 + 2.041

3.3.4 Experimental design and field layout

The experimental units were laid out in a randomized complete block design in three replications in a fine tilth-prepared field. The treatments consisted of decomposed pressmud and cattle manure combined with or without inorganic fertilizer at calculated rates of the organic manure. The treatments were arranged in a randomized complete block design with three replicates (Figure 2).



REP I						
1. CM30	2. PM22.5 + CM7.5	3. TSP7.5 + PM22.5	4. PM30	5. Control	6. TSP7.5 + CM22.5	7. TSP15 +PM15
14. TSP22.5 + CM7.5	13. PM7.5 + CM22.5	12. PM15 + CM15	11. TSP15 + CM15	10. TSP30	9. PM10 + CM10 + TSP10	8. TSP22.5 + PM7.5
REP II						
15. TSP22.5 + PM7.5	16. PM30	17. TSP30	18. TSP7.5 + CM22.5	19. TSP22.5 + CM7.5	20. TSP15 + CM15	21. PM22.5 + CM7.5
28. CM30	27. TSP7.5 + PM22.5	26. PM15 + CM15	25. PM10 + CM10 + TSP10	24. Control	23. PM7.5 + CM22.5	22. TSP15 +PM15
REP III						
29. TSP30	30. Control	31. TSP15 +PM15	32. TSP7.5 + CM22.5	33. PM30	34. PM10 + CM10 + TSP10	35. TSP15 + CM15
42. TSP22.5 + CM7.5	41. PM7.5 + CM22.5	40. CM30	39. TSP22.5 + PM7.5	38. TSP7.5 + PM22.5	37. PM22.5 + CM7.5	36. PM15 + CM15

***Figure 3.2**: Layout of the treatment combinations in the field*

3.4 Planting and management of the crop in the field experiment

The maize crop was planted at a spacing of (0.75 m between rows x 0.25 m within rows), resulting in a total plant population of 150 plants per plot. Two maize seeds were sown per hill, and the seedlings thinned to one per hill one week after emergence. The treatments were applied at sowing, and topdressing was done 8 weeks after planting. Inorganic nitrogen was supplied in a split application in the form of urea, while phosphorus and potassium were applied as triple superphosphate (TSP) and muriate of potash, respectively, at planting. Other agronomic procedures for maize production, such as weeding, topdressing, and pest and insect control, were appropriately followed after planting.

3.4.1 Test crop

Maize variety H520 is a hybrid developed by the Kenya Seed Company for medium-altitude ecological zones, with a rainfall range of 800-1500 mm and a growth temperature range of 12°C to 30°C. The hybrid has a yield potential of 32 bags of 90 kg per acre. Its grains are very sweet and good for roasting, and the dry kernels are not easily attacked by weevils after harvesting. This variety of maize is tolerant to turcicum leaf blight and grey leaf spot (GLS).

3.4.2 Data collection

To investigate the effect of different organic fertilizer sources integrated with inorganic fertilizer on maize growth and yield, data were collected on plant height, number of leaves, leaf area index and biomass yield. The N, P, and K content in the maize tissues were also analyzed at flowering and maturity. Maize forage quality attributes measured included crude protein (%), dry matter yield, neutral detergent fiber (NDF), acid detergent fiber (ADF), and *In Vitro* Digestibility.

3.4.3 Maize growth and yield

Leaf Area Index (LAI) was calculated by measuring the leaf area and determining the number of leaves per unit ground area. For growth measurements, nine plants were tagged in each plot. Starting two weeks after emergence, plant height was measured in centimeters using a meter ruler or tape measure. The number of leaves on each plant was counted, and these measurements were recorded at two-week intervals until the first tassel appeared.

To estimate the leaf area, the length and maximum width of each leaf were measured. The leaf area for each leaf was calculated using the formula:

Leaf Area (LA) = Leaf length X Leaf Width X 0.75

The factor 0.75, as described by Francis, Rutger, and Palmer (1969), accounts for the leaf's shape, providing a more accurate estimation of its actual area.

The total leaf area for a plant was then calculated by summing the areas of all leaves on that plant. The Leaf Area Index (LAI) was determined by dividing the total leaf area of the plants by the ground area they occupied, using the formula:

$$LAI = \frac{Total\ leaf\ area}{Ground\ Area}$$

This approach provides a precise measure of the plant canopy's density and its ability to capture sunlight for photosynthesis. Leaf Area (LA) = Leaf length X Leaf Width X 0.75

For consistency, leaf area measurements were based on the uppermost fully expanded leaf at each sampling stage. Specifically, from the second stage onwards, this corresponded to the seventh leaf of the plant. The measurements were done at five growth stages: stage 1 when the plant had 6 leaves, stage 2 when the plant had 12 leaves, the silking stage, the filling stage, and the physiological maturity stage (Sun, Gao, Wang, Hu, Zhang, Bao, and Fan, 2019).

After harvesting and drying, maize from each treatment was threshed and weighed for yield and yield component determination. The data were used to compare the treatments. Harvesting of maize for yield estimation was done by discarding two outer rows per plot and two plants at the ends of each row. Thus, four inner rows per plot were harvested from an effective area of 13.5 m^2. In the harvest area, the total weights of unshelled maize carbohydrates were determined. The maize was shelled by hand and grain weights were recorded for each plot. The stovers were cut at ground level, and their fresh and dry weights were measured. A random sampling of sub-samples consisting of 6 stalks per plot was taken and chopped into small pieces of 3-5 cm in length and mixed thoroughly. These were then weighed and the fresh weights recorded. The chopped stover samples were sun-dried to obtain dry stover weight.

3.5 Forage sampling and quality determination

3.5.1 Forage harvesting

Sampling and sample preparation for forage yield and quality determination were done as described by Nazli *et al*. (2016). Ten randomly selected plants from the four center rows of each experimental plot were harvested by cutting at a height of 10 cm above the ground at the black layer stage (R6), considered optimal timing for high nutritional quality of forage (Bal *et al*., 1997).

The fresh forage biomass obtained from the sampled plants was weighed to determine forage yield. To make a composite sample for quantifying dry matter, fiber, and nutrients (NPK), the whole maize plants with cobs were chopped into small pieces (2-3 cm), oven-dried at 65°C to constant weight, and finely ground in a grinding mill (RAS Mill Series II, Romer, USA) to pass through a 1 mm screen. The sieved samples were stored in airtight polyethylene bags in a dry place until they were needed for chemical analysis to assess their nutritional variation among the treatments applied in the field.

3.5.2 Forage post-harvest processing

The percentage of dry matter (DM) and moisture was determined using AOAC official method No. 934.01. Chopped whole plant samples were packed in paper bags or envelopes and placed in sunlight. Once the DM reached up to 50%, the samples were then dried to constant weight by placing them in a hot air oven at 65°C overnight. Finally, the moisture content of each sample was determined as the difference in weights before (W1) and after (W2) drying, and percent moisture was calculated using the equation below:

$$Moisture\ (\%) = \frac{W1 - W2}{Weight\ of\ Sample}\ X\ 100$$

$$Dry\ Matter\ (\%) = 100 - Moisture\ (\%)$$

Dry matter (DM) yield was calculated using the fresh and dry weights by multiplying the green herbage yield and the dry matter percentage as follows:

$$DM\ Yield = Fresh\ Biomass\ X\ \%\ DM$$

3.5.3 Crude protein (CP*) content determination*

The percentage of crude protein was quantified using the micro-Kjeldahl procedure following AOAC official method No. 954.01. Two grams (2g) of ground and homogenized dry samples were taken into a micro-Kjeldahl digestion flask. About 5 grams of digestion mixture (100g K_2SO_4 + 10g $CuSO_4$ + 5g $FeSO_4$) were added along with 40 mL of concentrated sulfuric acid (H_2SO_4). The flask was placed on a heater set to medium temperature for digestion. The digestion was carried out for 3-4 hours until the solution became clear. The contents of the flask were cooled and transferred to a volumetric flask to make a dilution up to 1 liter with distilled water. A 10 mL aliquot of this dilution was transferred into a micro-Kjeldahl distillation apparatus along with 10 mL of 40% sodium hydroxide (NaOH) solution and boiled for distillation. The liberated ammonia was condensed and collected into a beaker containing 2% boric acid. In a 100 mL conical flask containing 2-3 drops of mixed indicator (0.1% BCG and 0.1% methyl red in 95% alcohol), 50 mL of ammonia condensate was added. The ammonia condensate was titrated against

0.01 M HCl, and a light pink color was recorded as the end point to determine the total nitrogen content in the forage sample. The crude protein was calculated using the following formula:

$$Nitrogen\ (\%) = \frac{N\ X\ T\ X\ 250\ X\ 0.0014}{Weight\ of\ Sample}\ X\ 100$$

Crude protein (CP) content was determined by multiplying total nitrogen by the constant 6.25, based on the assumption that all protein contains 16% nitrogen as follows:

$$Crude\ Protein\ (\%) = Nitrogen(\%)\ X\ 6.25$$

3.5.4 Determination of neutral detergent fiber content

The percentage of neutral detergent fiber (NDF) was determined by the AOAC official method No. 989.03. An amount of 1.5 g of ground and homogenized sample was transferred to a conical flask and mixed with 0.5 g of sodium sulfide (Na_2S). For digestion, 100 mL of NDF solution was added, and the flask was heated on a plate until the contents started boiling. The Neutral Detergent Fiber (NDF) solution used for digestion typically consists of sodium lauryl sulfate (SDS) as the primary detergent to solubilize cell contents and hemicellulose while leaving behind fibrous components like cellulose, hemicellulose, and lignin. It also contains EDTA (ethylenediaminetetraacetic acid) as a chelating agent to bind divalent cations, preventing the formation of insoluble complexes, along with sodium borate (borax) and sodium phosphate (Na_2HPO_4) as buffering agents to maintain the solution’s pH. Additionally, octanol is included to reduce foaming during the boiling process. This composition is designed to effectively digest plant material for fiber analysis. The flask was then covered with another small flask to condense the steam produced and enhance the digestion process. Digestion took 1½ hours. The solution was then filtered through ordinary cloth with the help of a suction pump. The residue on the cloth was washed with hot water. The collected sample was dried in an oven at 105°C for a few hours until the weight became constant. The sample was reweighed, and the percentage of NDF was calculated using the following formula:

$$NDF(\%) = \frac{W2 - W1)}{Weight\ of\ Sample}\ X\ 100$$

3.5.5 Quantification of acid detergent fiber content

To determine acid detergent fiber (ADF), 1.5 g of the dried sample was placed in a 500 mL conical flask. About 100 mL of acid-detergent solution was added, and the flask was covered with a 250 mL inverted conical flask. The mixture was heated to boiling for five to ten minutes, then the heat was reduced to prevent foaming. Once boiling, the sample was refluxed for 60 minutes with periodic shaking to prevent material from sticking to the flask walls. After refluxing the contents were swirled and filtered using hot water and any remaining traces of the ADF solution were removed by washing the residue with acetone and the residue was then collected in a previously weighed crucible (W1) dried to a constant weight and then weighed again (W2) to determine the final ADF content. The ADF was calculated using the following formula:

$$ADF(\%) = \frac{W2 - W1)}{Weight\ of\ Sample}\ X\ 100$$

3.5.6 Quantification of acid detergent lignin (adl) content

Acid Detergent Lignin (ADL) determination is a method used to quantify the lignin content in plant materials, which helps in understanding the fiber composition. The process involves first extracting Acid Detergent Fiber (ADF) from the sample by treating it with an acid detergent solution to remove hemicellulose and other non-lignin components, leaving behind lignin and cellulose. The remaining material is then subjected to a strong acid, such as sulfuric acid, which dissolves the cellulose and isolates the lignin. The lignin residue is filtered, washed, dried, and weighed to determine its content. This method, which may not have been detailed in Chapters 2 and 3 of the manuscript, is crucial for analyzing the fibrous content of plant materials, and its methodology should be clearly documented in the methods section or any updates to the study to ensure accurate and reproducible results.

3.5.7 In vitro dry matter digestibility (IVDMD) analysis

The In Vitro Dry Matter Digestibility (IVDMD) methodology involved preparing forage or feed samples by drying them to a constant weight and then grinding them to a fine powder. The ground samples were incubated with a buffer solution and digestive enzymes, such as pepsin and pancreatin, at 39°C for 48 hours to simulate digestive conditions. Following incubation, the digestion process was terminated, and the samples were filtered to separate the undigested residue from the digestate. The residues were then dried again and weighed. The IVDMD was calculated by comparing the weight of the initial dry matter to the weight of the undigested residue, providing an estimate of the digestibility of the dry matter in the sample as follows:

$$IVDMD(\%) = \frac{(Initial\ Dry\ Matter\ Weight\ \ - Initial\ Dry\ Matter\ Weight)}{Undigested\ Residue\ Weight}\ X\ 100$$

3.5.8 Determination of nitrogen, phosphorus and potassium contents

As mentioned above, nitrogen content was quantified by micro-Kjeldahl digestion. Phosphorus and potassium contents were determined by spectrophotometry and atomic absorption following acid digestion of the samples (Okalebo *et al*., 2002).

3.6 Economic analysis of experimental treatments

To perform economic analysis, the total expenses of maize grain yield produced and total income were calculated. Total costs were assessed from the price of all inputs and husbandry practices comprising the price of land lease, land preparation, synthetic fertilisers, organic fertilizers, plant seed cost and sowing, disease and pest management, harvesting and threshing conferring to current market rates. The gross revenue was estimated by multiplying the total grain produced based on the unit cost of maize in the local market. The net returns were estimated as the difference between the total cost and the gross income. The benefit-cost ratio (BCR) was estimated (Rana *et al* 2024) by dividing the total benefits by total cost according to the equation:

$$BCR = \frac{Total\ Benefits}{Total\ Costs}$$

3.7 Statistical analysis

Soils and crops data were subjected to analysis of Variance (ANOVA) using Genstat version 14. Means were separated using Tukey's test at 0.05% level of significance based on the following statistical linear Model.

Xijk = µ + αi + βj + £ij +Yik + £ijk

Where Xijk = Total observation
µ = overall mean
αi = Treatment effect (manure effect)
βj = Block effect
£ij = Site effect
Yik = Interaction (manure *site)
£ijk = Experimental error

CHAPTER FOUR

RESULTS

4.1 Initial soil fertility status at the study sites

Initial site characterization) indicated that soils at the study sites varied greatly. The soils at the two sites were found to be moderately acidic (Table 4). Soil organic carbon content was higher in Bumula compared to Kiboss. On the other hand, Kiboss site had higher contents of N, P and K compared to Bumula.

***Table 4**: Initial soil chemical properties at the experimental site*

Chemical parameter	Field site		Critical level and reference
	Bumula	Kibos	
pH	6.06	5.59	> 5.5
%C	1.18	1.02	> 0.2
%N	0.06	0.08	> 0.2
P mg/kg	2.71	12.52	> 15 mg/kg)
K mg/kg	238	634	> 78-156 mg/kg

(NAAIAP (2014; Xu Tang, Yibing Ma, Xiying Hao, Xiuying Li, Jumei Li, Shaomin Huang & Xueyun Yang 2009)

4.2 Selected chemical nutrient contents of organic inputs used in the study at 30 days of composting

Cattle (CM) showed superior nutrient quality with higher levels of measured nutrients compared to Pressmud (PM) except higher total P levels in Pressmud (PM) compared to cattle manure (CM) as indicated in Table 2. These nutrient levels were: 25% organic carbon,1.5 % total N and 0.8% total K from Cattle manure (C M) compared to lower nutrient levels of: 24.4 OC, 0.6% total N and 0.4% of total K observed in Pressmud (MD).

However, Pressmud (PM) only indicated a higher 0.7% total P compared to 0.5 P % from cattle manure (CM).

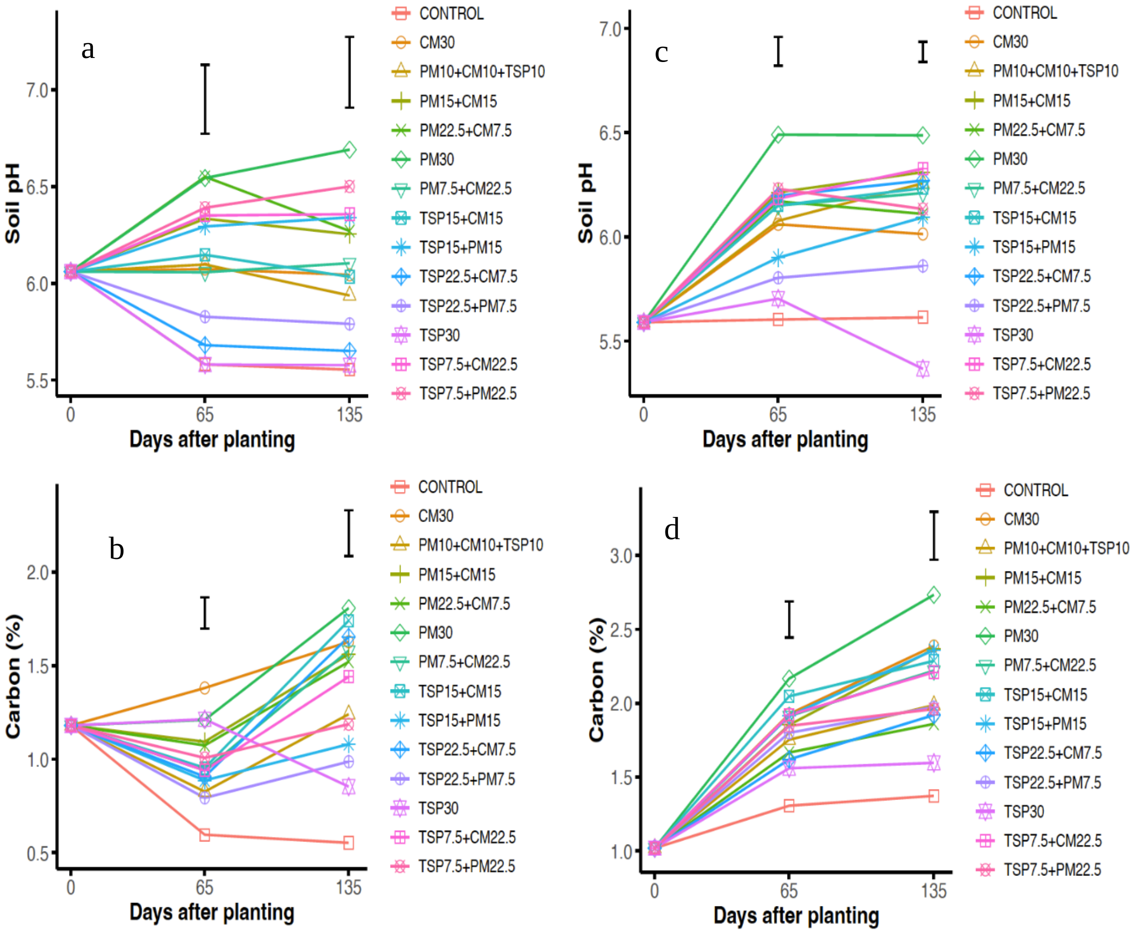
4.3 Effects of organic and inorganic soil amendments on soil properties at Bumula and Kiboss in Western Kenya

4.3.1 Effects of soil amendments on soil pH at flowering and harvest maturity of maize

Effects of the soil amendments on soil pH were significant ($p \leq 0.05$) at all sampling times in Kibos and at crop harvest time in Bumula (Appendix 1-2). Soils amended with PM 30 had significant and consistently higher soil pH compared to the control in all sampling times at both experimental sites Soils amended with the highest rate of inorganic P (TSP 30) had similar or lower pH compared to the control in all sampling times and at both experimental sites (Fig 4.1). A rise in pH to values ranging from 6.0-6.6 occurred in plots amended with Full rate, ¾ rate, ⅓ and ½ rate application of organic amendments while the lowest pH (<6.0) was recorded at flowering stage from treatments that received the highest rate of mineral fertilizers with or without ¼ rate of organic fertilisers. Similarly, these treatments with reduced application of inorganic fertilizer resulted in increased pH at harvest with values of 6.0-6.7. From these results, it is clear that the addition of composted pressmud and or cattle manure resulted in consistent increase in soil pH while mineral fertilizers reduced it to the level of the experimental control. Based on the study findings, the highest increase in pH attained by the flowering time was 16.5% higher than plots that were supplemented with the full rate of inorganic NPK fertilizers and the control treatment, respectively compared to PM30. The results demonstrate that the addition of composted organic amendments occasioned consistent increase in soil pH while mineral fertilizers reduced it over the control. The two organic sources were effective at raising the soil pH.

4.3.2 Effects of amendments on soil organic carbon of maize field at tasseling and harvest stages at Bumula and Kibos in western Kenya during the growing season of 2021.

The effects of soil amendments on soil organic carbon content (OC) were significant ($p<0.05$) at both the flowering and harvest stages in Bumula and Kibos sites (Appendix 3- The organic carbon content reduced slightly at flowering in Bumula while the soil OC at Kibos showed an increase from the initial content. At Bumula site, soils amended with CM 30 had the highest OC content (1.4%) while the control had the lowest soil OC (0.6%) during the flowering stage (Fig 4.1). It was further observed that PM 30 application resulted in the highest level of soil OC (2.2%) compared to all other treatments and the control at maize flowering stage in Kibos (Fig 3). At harvest, PM30 recorded the best OC of 1.8% and 2.7% for Bumula and Kibos sites, respectively. The control at both sites had the least effect of soil OC with values of 0.6% and 1.3%, respectively for Bumula and Kibos at the harvest stage. The results showed that most plots where organic amendments were applied at full rate, ¾ rate, ⅓ and ½ rate application, had the highest soil OC content at flowering (1.3-2.2%) and harvest (1.4-2.7%) with Bumula recording lower soil OC contents in most treatments compared to Kibos. The highest soil OC content at flowering in Kibos was 38.9% and 65.8% higher than plots that received the full dose of inorganic fertilizer and the control treatment, respectively compared to PM30. The increase was more pronounced at harvest with 71.1% and 99.1% higher than the plots applied full dose of inorganic fertilizer and in the control treatment, respectively compared to PM30.



*0 – initial, 65 – tasseling 135 harvesting, *ab: Bumula, cd: KibosFigure

Figure 4.1: Soil pH and organic carbon changes at Bumula and Kibos following treatment application at crop flowering and harvesting stages

4.3.3 Effects of soil amendments on soil Nitrogen, Phosphorus and Potassium of maize fields at Bumula and Kibos in western Kenya during the maize growing season of 2021

a) Total soil nitrogen

The application of organic amendments alone or in combination with inorganic fertilizer did not significantly ($p \geq 0.05$) increase soil N content (Appendix 5-6). Generally, soils amended with CM30 had higher levels of total N during all the sampling stages at Bumula (fig 4). On the other hand, TSP 15 + CM 15 treatment enhanced the content of total N in Kiboss at tasseling stage, but CM 30 amended soils had the highest total N at harvest in the same site (*Figure 5)* Effects of soil amendments on total nitrogen content during flowering and maize harvesting stages at Bumula and Kibos sites in Western Kenya during long rain season of 2021

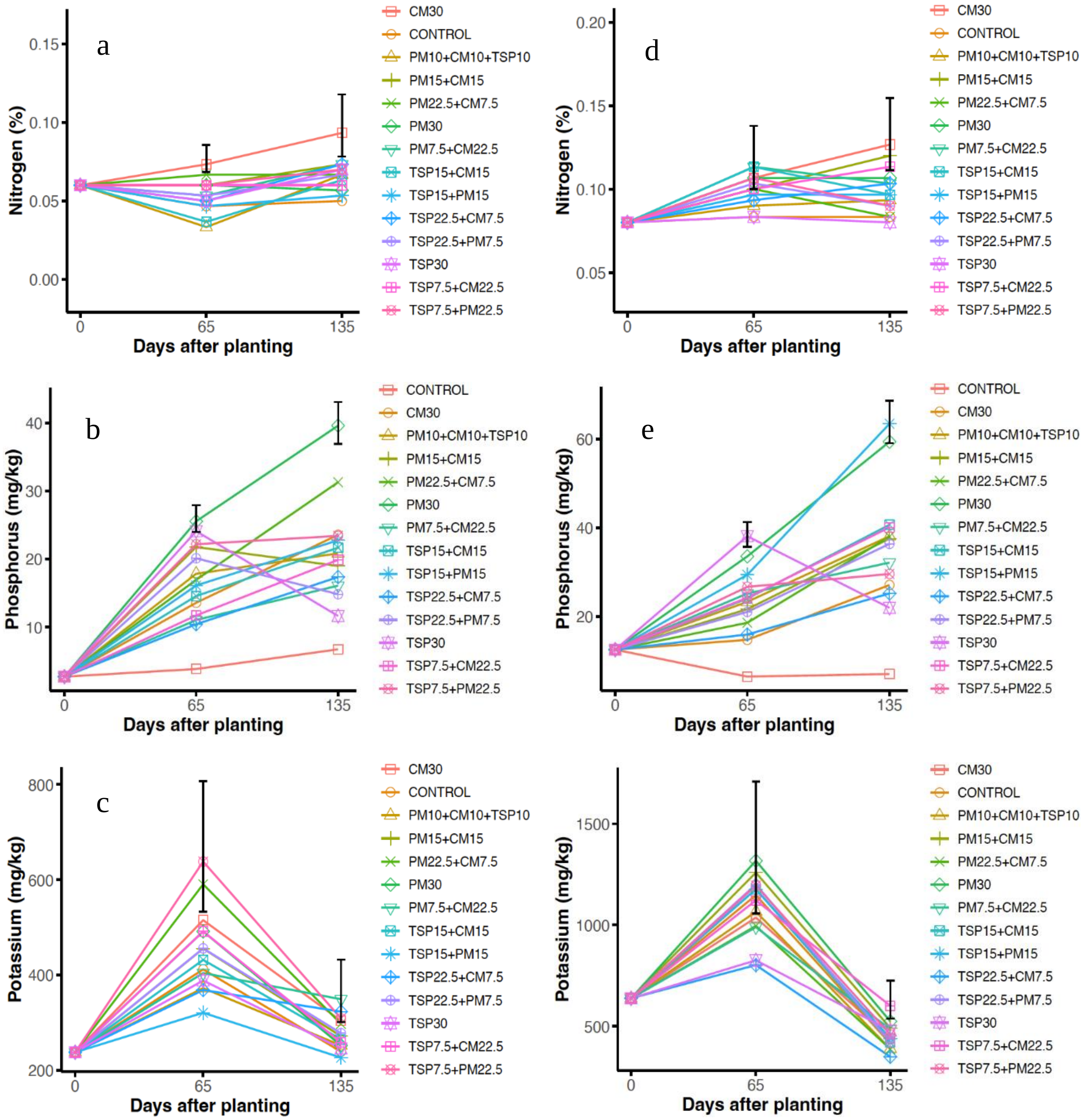
b) Soil phosphorus (P)

Treatment and site effects significantly ($p \leq 0.05$) influenced soil available P content at the two sampling stages (Appendix 7-8). Site x Treatment interactions were not significant ($P \geq 0.05$). Pressmud (PM30) application contributed to the highest available soil P content at flowering at both Bumula (25.55 mg P/kg soil) and Kibos (33.54) (Fig 4.2). The control plots had the lowest phosphorus content of 3.84 mg P/kg soil at Bumula and 6.45 mg P/kg soil at Kibos during flowering. Three to six-fold increases in soil P content were observed at Bumula due to treatment inputs while two to four-fold increase was recorded at Kibos site above the control at crop flowering stage. At the harvest stage, the treatments PM30 and TSP15+PM15 at Kibos with 59.39 and 63.44 mg/kg P, respectively, realized the highest improved soil P contents (Figure 4). For the Bumula site, the most outstanding treatment was PM30 at 39.61 mg P/Kg soil sampled at crop harvest. The lowest P contents were observed from the control at both sites with 6.73 mg/kg P at Bumula and 7.02 mg P/kg soil at Kibos sites. Application of organic amendments at full rate or in combination with mineral fertilizer at all reduced rates of the organic fertilizer contributed to the highest content of available soil P (20.11-63.44 mg P/Kg soil) across sampling stages.

c) Soil potassium (K)

Soil potassium (K) content (mg/kg) at tasseling and harvest stages did not increase significantly ($p>0.05$) among treatments at both sites (Appendix 9-10). At tasseling, the highest K levels were obtained for PM30 (1317.3 mg K/Kg soil) at Kibos and PM30 (638.3 mg K/Kg soil) at Bumula (Figure 3). At this sampling stage, the least recorded soil K contents with mean values of 321 for TSP15+PM15 at Bumula and 802.3 for TSP22.5+CM7.5 at Kibos site, respectively. PM30 treatment was the overall best at increasing soil K compared to the control and most other fertilizer treatments. At harvest, TSP 7.5 + CM22.5 showed the highest K content at both Kibos with (601.3 mg/kg) and Bumula (349.3 mg /Kg soil) which was similar to PM30 (524 mg K/Kg soil). The least had K levels TSP15+PM15 with 226.7 and was TSP22.5+CM7.5 with (349. mg/kg K) at Bumula and Kibos, respectively.

Based on the results, application of organic amendments at full rate or in combination with mineral fertilizer at all reduced rates of the organics contributed to the highest content of available soil (412-1317 mg P/Kg soil) considered across sampling stages. The highest increase in soil K content was 64.1% and 54.9% above the full dose of mineral fertilizer and the control at Bumula site, while K increases of 59.5% and 14.7% above the full dose of mineral fertilizer and the control were observed at Kibos that showed the highest soil K content treatments at the flowering stage. The K content declined at harvest by 47.2% at Bumula and 58.9 % at Kibos. This was observed in all treatments regardless of whether PM or CM was added.



*0 – initial, 65 – tasseling, 135 harvesting, *abc: Bumula, def: Kibos

Figure 4.2: Effects of soil amendments on total Potassium content during flowering and maize harvesting stages at Bumula and Kibos sites in Western Kenya during long rain season of 2021

4.4 Effects of soil amendments on growth of maize at Bumula and Kibos in Western Kenya during the maize growing season of 2021

4.4.1 Effects of soil amendments on plant height at Bumula and Kibos experimental sites during the 2021 long rains season

The use of various organic, inorganic, and combined amendments enhanced maize growth. Plant height varied significantly ($p<0.05$) among treatments at both sites (Appendix 11). Significant ($p<0.05$) site x treatment interaction effect on height was observed for the treatments. At Bumula, TSP7.5+CM22.5 achieved the tallest plants at 290.70 cm, while the control recorded the lowest mean plant height of 239.20 cm (Figure 4.3). Plant height under treatments TSP15+PM15 (283.90 cm) and TSP30 (282.905 cm) also exceeded that of the control. At Kibos, TSP15+PM15 produced the tallest plants at 273.30 cm (Fig)

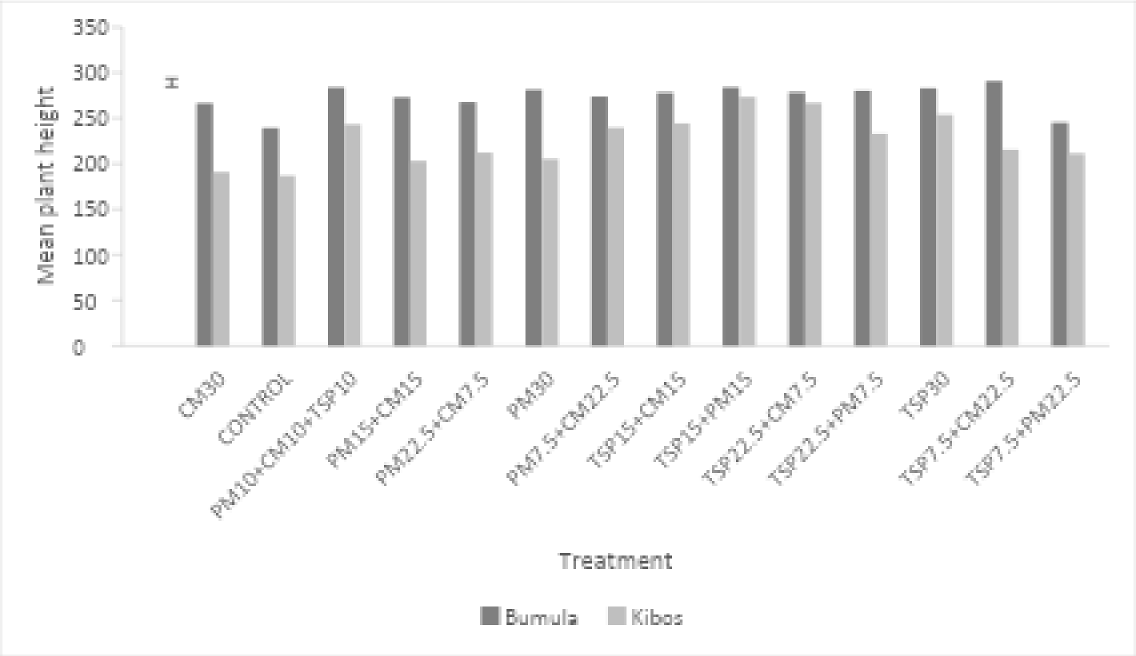


Figure 4.3: Effects of soil amendments on plant height at Bumula and Kibos experimental sites during the 2021 long rains season

4.4.2 Effects of soil amendments on leaf Number of maize at Bumula and Kibos experimental sites during the 2021 long rains season

The analysis of mean leaf number at 75 days revealed significant differences ($p<0.05$) among treatments at both Bumula and Kibos sites (Appendix 12). Site and site x treatment interactions significantly influenced leaf number at tasseling stage. Overall TSP30 treatment consistently showed the highest leaf count at both sites, with 17.63 at Bumula and 18.74 at Kibos (figure 4.4), significantly outperforming other treatments and the control. At the Bumula site, the highest mean number of leaves was observed with the TSP30 treatment, which had 17.63 leaves per plant. Other notable treatments include TSP15+PM15 (17.15 leaves) and TSP22.5+CM7.5 (17.44 leaves). The treatment

TSP15+CM15 recorded the lowest number of leaves per plant (16.04), but was similar to PM22.5+CM7.5 (16.04), control (16.11) and PM15+CM15 (16.1513). At Kibos, TSP30 application also produced the highest mean leaf number per plant (18.74). TSP15+PM15 (18.26) and TSP7.5+PM22.5 (18.70) also gave notable increases in mean leaf number. The lowest number of leaves per plant at Kibos was observed under the PM15+CM15 (16.56) treatment. Based on the results from this study, reduced application of inorganic P at 1/3, 1/2 or 3/4 of the recommended rate in combination with organic P achieves a similar leaf number as full rate inorganic P supply with better response from PM as the organic amendment.

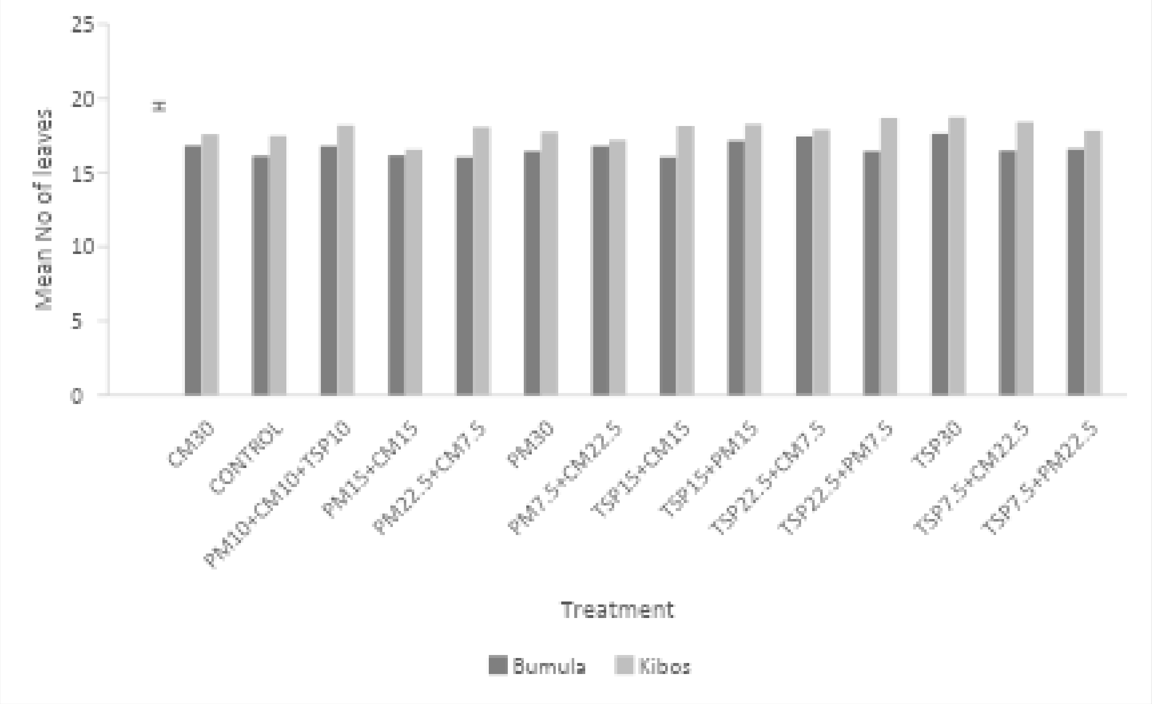


Figure 4.4: Effects of soil amendments on leaf Number of maize at Bumula and Kibos experimental sites during the 2021 long rains season

4.4.3 Effects of soil amendments on leaf area index of maize at Bumula and Kibos experimental sites during the 2021 long rains season

Treatment effects were significant($P<0.05$) on Leaf area index of maize at tasseling stage (Apendix 13); site and site x treatment interaction was also significant ($P\leq 0.05$).

Treatment TSP30 had the highest value at 8.87, while the control had the lowest mean of 5.67 (Figure 7). Other highly effective treatments were TSP15+PM15 (8.70) and TSP22.5+CM7.5 (8.50). At Kibos, plants supplied with TSP22.5+PM7.5 had the highest leaf area index of 7.82 Other promising treatments include TSP 30 (7.70) and TSP15+PM15 (7.70). The Control had the lowest mean LAI (5.23) and was similar to the PM15+CM15 (5.26) treatment. In summary, inorganic P application at 1/3, 1/2 or 3/4 of the recommended dose in combination with organic P results in a similar leaf area index as the full rate application of inorganic P, regardless of the organic amendment included.

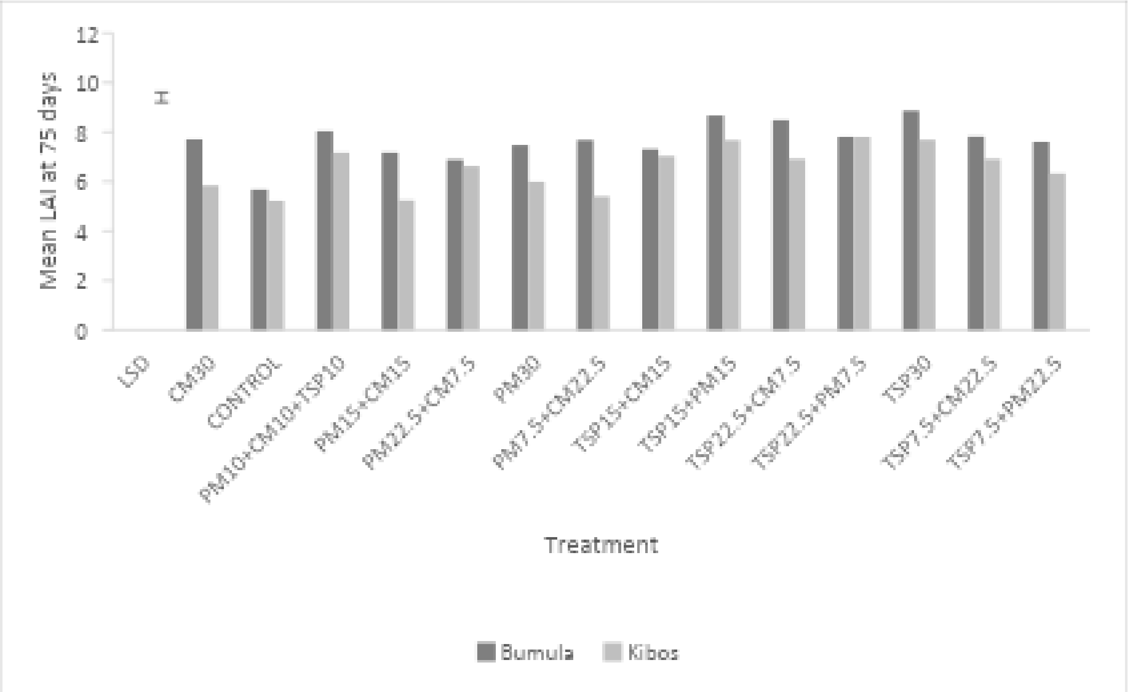


Figure 4.5: Effects of soil amendments on leaf area index of maize at Bumula and Kibos experimental sites during the 2021 long rains season

4.4.4 Treatment Applications effects of soil amendments on stem girth of maize at Bumula and Kibos experimental sites during the 2021 long rains season

The applied soil fertility inputs significantly (P≤0.05) led to improved maize plant stem girth at Bumula and Kiboss study sites (Appendix 14.) Site and site-treatment interactions significantly (P≤0.05) influenced stem girth. At Bumula, the TSP15+PM15 treatment had the largest mean girth of 2.82 cm, with the lowest stem girth of 1.53 cm being observed from the control (Figure 7). TSP30 application resulted in the largest stem girth of 2.20 cm at Kibos. while the control (1.89 cm) recorded the lowest stem girth.

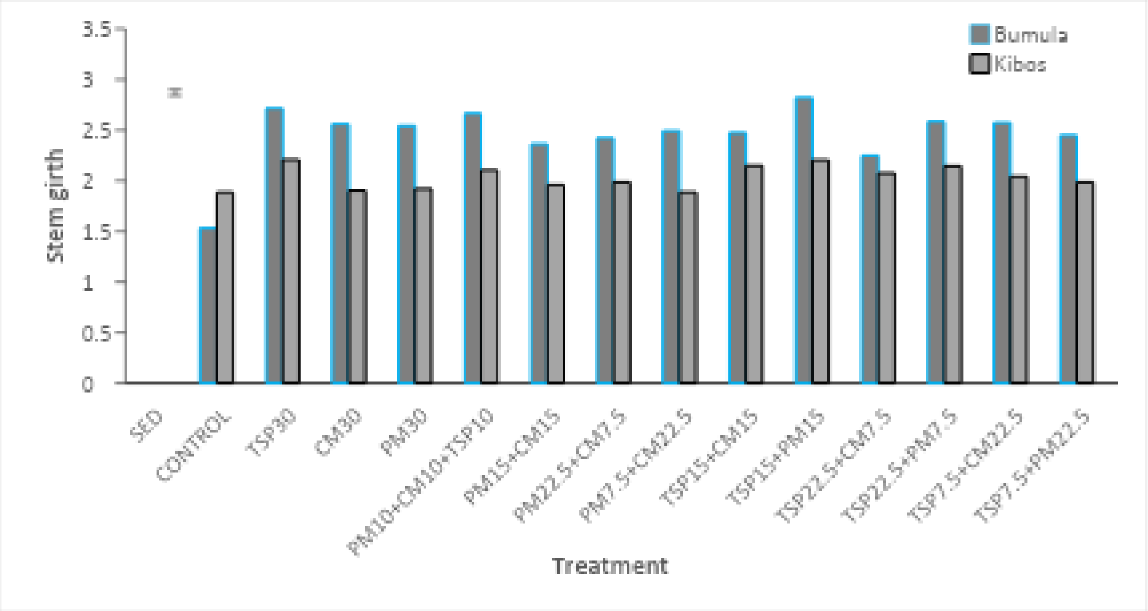


Figure 4.6: Effects of soil amendments on stem girth of maize at Bumula and Kibos experimental sites during the 2021 long rains season

4.5 Nutrient N, P, and K content in maize leaves at silking stage (R1) as influenced by integrated application of organic and inorganic fertilizers at Bumula and Kibos in the long rain season of 2021

4.5.1 Effects of soil amendments on plant tissue nutrient %N, P and K uptake at Bumula and Kibos experimental sites during maize silking in the 2021 long rains season

The treatment effects on leaf Nitrogen (N) content uptake were significant at Kibos, but not in Bumula (Appendix 15). The highest leaf N concentration at Kibos was observed in plants supplied with PM10+CM10+TSP10 followed by TSP30 (Table 5). The phosphorus (P) content in the leaf was significantly ($P \leq 0.05$) different among treatments only in Bumula, but no treatment effects were detected in Kibos (Appendix 16). A higher P concentration on leaves were recorded in plants supplied with PM 30 at Bumula site.

Generally, leaf P concentration on plant leaves was 40% higher in Kibos than Bumula (Table 4.5). Treatment effects on leaf potassium (K) content were significant ($P \leq 0.05$) at Kibos (Appendix 17). The highest leaf K concentartion observed was under the treatment TSP30, which recorded a mean value of 3.2 at Kibos site.

Table 5 Effects of soil amendments on leaf nutrient content (%) of N, P and K uptake at Bumula and Kibos experimental sites during maize harvesting stage in the 2021 long rains season

	% N in leaves		**% P in leaves**		**% K leaves**	
Treatment	**Bumula**	**Kibos**	**Bumula**	**Kibos**	**Bumula**	**Kibos**
CONTROL	0.43±0.14	0.45±0.02^{a}	0.09±0.03^{a}	0.17±0.02^{a}	1.08±0.15	2.0±0.12^{a}
CM30	0.69±0.08	0.71±0.07^{abcd}	0.18±0.02^{b}	0.24±0.04^{ab}	2.46±0.14	2.24±0.21^{ab}
PM10+CM10+TSP10	0.76±0.04	1.05±0.03^{d}	0.17±0.01^{b}	0.31±0.01^{b}	2.68±0.09	2.92±0.10^{ab}
PM15+CM15	0.63±0.02	0.78±0.14^{abcd}	0.17±0.01^{ab}	0.23±0.03^{ab}	2.32±0.20	2.85±0.21^{abc}
PM22.5+CM7.5	0.69±0.02	0.79±0.05^{abcd}	0.16±0.01^{a}	0.28±0.05^{ab}	2.55±0.13	2.74±0.16^{abc}
PM30	0.74±0.04	0.74±0.04^{abcd}	0.20±0.00^{a}	0.23±0.04^{ab}	2.36±0.29	2.64±0.06^{abc}
PM7.5+CM22.5	0.61±0.07	0.88±0.05^{bcd}	0.16±0.00^{ab}	0.28±0.01^{ab}	2.53±0.14	2.85±0.12^{abc}
TSP15+CM15	0.63±0.07	0.79±0.08^{abcd}	0.17±0.02^{ab}	0.27±0.02^{ab}	2.58±0.20	3.00±0.24b^{ab}
TSP15+PM15	0.76±0.02	0.98±0.16^{cd}	0.18±0.01^{a}	0.27±0.03^{ab}	2.26±0.26	2.36±0.23^{abc}
TSP22.5+CM7.5	1.00±0.21	0.62±0.08^{abc}	0.18±0.01^{a}	0.23±0.00^{ab}	2.36±0.20	3.03±0.03^{abc}
TSP22.5+PM7.5	0.69±0.10	0.80±0.09^{abcd}	0.18±0.02^{a}	0.23±0.03^{ab}	2.45±0.30	3.07±0.38^{a}
TSP30	0.84±0.13	1.01±0.07^{d}	0.18±0.02^{a}	0.28±0.02^{ab}	2.36±0.19	3.20±0.10^{c}
TSP7.5+CM22.5	0.67±0.05	0.78±0.05^{abcd}	0.16±0.01^{ab}	0.20±0.04^{ab}	2.39±0.15	2.94±0.22^{abc}
TSP7.5+PM22.5	0.83±0.11	0.59±0.05^{ab}	0.16±0.02^{a}	0.21±0.02^{ab}	2.39±0.51	2.91±0.26^{abc}
MEAN	**0.72**	**0.78**	**0.17**	**0.24**	**2.34**	**2.74**
CV	**19.2**	**17.4**	**13.0**	**15.9**	**17.2**	**11.1**
LSD	**Ns**	**0.22**	**0.03**	**Ns**	**Ns**	**0.51**

Means followed by different letters are significantly different at p< 0.05 for every factor assessed. Means were separated using the Tukey test. The data presented are means±SE

4.5.2 Effects of soil amendments on N, P and K nutrient content of maize grain at Bumula and Kibos experimental sites during maize harvesting stage in the 2021 long rains season

Application of soil amendment did not significantly ($P \geq 0.05$) influence grain N contents at both experimental sites (Appendix 18). The analysis revealed that the highest grain N concentration in the grain was achieved under TSP30 treatment at the Bumula site, with a mean value of 0.80 (Table 6).

Organic and inorganic amendments had no significant ($P \geq 0.05$) effects on grain phosphorus (P) content at both experimental sites (Appendix 19). Grain analysis revealed that the highest treatment P content was recorded in PM30 supplied plants from Kibos site while the lowest was TSP15+PM15 with mean value of 0.08 from the same site (table 6). Soil amendments had no significant effects on Potassium (K) content of maize grain across the Bumula and Kibos study sites (Appendix 20) The results showed that the highest K uptake in grain was obtained under TSP7.5+CM22.5 application with value of 0.37 at Kibos site while the lowest was TSP15+PM15 with value of 0.20 at Bumula (Table 6).

Table 6 Maize grain N, P, and K content (% in grain) as influenced by integrated application of organic and inorganic fertilizers at Bumula and Kibos in the long rain season of 2021.

	Grain% N content		**Grain %P content**		**Grain %K content**	
Treatment	**Bumula**	**Kibos**	**Bumula**	**Kibos**	**Bumula**	**Kibos**
CONTROL	0.60±0.04	0.61±0.05	0.10±0.01	0.14±0.04	0.25±0.02	0.34±0.02
CM30	0.63±0.04	0.51±0.03	0.11±0.01	0.13±0.02	0.31±0.08	0.28±0.04
PM10+CM10+TSP10	0.64±0.05	0.58±0.03	0.10±0.01	0.10±0.02	0.23±0.05	0.26±0.04
PM15+CM15	0.61±0.05	0.62±0.07	0.14±0.03	0.16±0.02	0.28±0.03	0.31±0.01
PM22.5+CM7.5	0.62±0.12	0.56±0.03	0.11±0.00	0.14±0.03	0.25±0.03	0.29±0.03
PM30	0.69±0.08	0.62±0.08	0.10±0.00	0.17±0.02	0.28±0.03	0.31±0.04
PM7.5+CM22.5	0.57±0.04	0.59±0.04	0.11±0.00	0.11±0.02	0.23±0.04	0.29±0.04
TSP15+CM15	0.59±0.03	0.57±0.03	0.11±0.01	0.10±0.00	0.26±0.05	0.23±0.03
TSP15+PM15	0.60±0.04	0.60±0.04	0.11±0.01	0.08±0.00	0.20±0.01	0.20±0.04
TSP22.5+CM7.5	0.72±0.04	0.60±0.04	0.11±0.02	0.11±0.02	0.23±0.00	0.23±0.03
TSP22.5+PM7.5	0.73±0.03	0.58±0.03	0.11±0.01	0.12±0.03	0.26±0.03	0.32±0.03
TSP30	0.81±0.10	0.58±0.03	0.11±0.01	0.13±0.01	0.31±0.11	0.31±0.03
TSP7.5+CM22.5	0.59±0.03	0.56±0.02	0.11±0.02	0.09±0.00	0.32±0.00	0.37±0.07
TSP7.5+PM22.5	0.71±0.09	0.56±0.01	0.12±0.03	0.14±0.03	0.20±0.01	0.29±0.04
MEAN	**0.65**	**0.58**	**0.11**	**0.12**	**0.26**	**0.29**
CV	**16.4**	**10.8**	**22.4**	**29.2**	**30.4**	**23.3**
LSD	**Ns**	**Ns**	**Ns**	**Ns**	**Ns**	**Ns**

Means followed by different letters are significantly different at p< 0.05 for every factor assessed. Means were separated using the Tukey test. The data presented are means±SE

4.5.3 Effects of soil amendments on N, P and K nutrient content of maize stover at Bumula and Kibos experimental sites during maize harvesting stage in the 2021 long rains season

Organic and inorganic amendment effects on stover nitrogen (N) content were not significant (P≥0.05) (Appendix 21). The highest N content on stovers were obtained in plots amended with TSP15+PM15 at Kibos site with mean value of 0.32 and the lowest was TSP7.5+CM22.5 (Table 7). On the other hand, treatment effects on phosphorus (P) content of stovers were significant (P≤0.05) at both Bumula and Kibos (Appendix 22). The highest P level were obtained for PM10+CM10+TSP10 with a value of 0.21 in Kibos site while the lowest was found in Control with mean value of 0.11. The organic and inorganic amendment effects on stover K content were not significant (P≥0.05) at Bumula and Kibos (Appendix 23) The highest stover K content was recorded in plants amended with TSP22.5+PM7.5 with mean value of 1.92 while the lowest was recorded in plots supplied with TSP15+PM15 with value of 0.54 (table 7).

Table 7: Effects of soil amendments on stovers N, P and K uptake at Bumula and Kibos experimental sites in the 2021 long rains season

	%N in Stovers		**% P in Stovers**		**% K in Stovers**	
Treatment	**Bumula**	**Kibos**	**Bumula**	**Kibos**	**Bumula**	**Kibos**
CONTROL	0.19±0.01	0.21±0.02	0.06±0.00	0.11±0.03	0.57±0.06	1.43±0.24
CM30	0.22±0.02	0.25±0.05	0.09±0.00	0.16±0.01	0.60±0.07	1.43±0.08
PM10+CM10+TSP10	0.17±0.02	0.23±0.02	0.08±0.00	0.21±0.01	0.73±0.11	1.76±0.08
PM15+CM15	0.22±0.04	0.21±0.03	0.08±0.01	0.16±0.02	0.63±0.11	1.57±0.23
PM22.5+CM7.5	0.22±0.01	0.23±0.03	0.09±0.00	0.15±0.02	0.73±0.09	1.76±0.13
PM30	0.21±0.03	0.19±0.02	0.08±0.02	0.15±0.01	0.57±0.07	1.63±0.16
PM7.5+CM22.5	0.19±0.01	0.23±0.01	0.08±0.01	0.15±0.02	0.65±0.10	1.73±0.31
TSP15+CM15	0.19±0.02	0.27±0.04	0.07±0.00	0.14±0.01	0.60±0.05	1.54±0.08
TSP15+PM15	0.19±0.03	0.33±0.07	0.08±0.00	0.13±0.03	0.54±0.14	1.63±0.08
TSP22.5+CM7.5	0.20±0.03	0.26±0.02	0.07±0.01	0.13±0.02	0.60±0.19	1.70±0.18
TSP22.5+PM7.5	0.27±0.04	0.19±0.00	0.08±0.01	0.12±0.01	0.63±0.17	1.93±0.17
TSP30	0.28±0.04	0.21±0.02	0.08±0.01	0.12±0.01	0.63±0.18	1.57±0.09
TSP7.5+CM22.5	0.14±0.02	0.22±0.02	0.07±0.01	0.12±0.02	0.65±0.	1.76±0.12
TSP7.5+PM22.5	0.27±0.04	0.21±0.05	0.09±0.02	0.15±0.02	0.57±0.15	1.48±0.23
MEAN	**0.21**	**0.23**	**0.08**	**0.15**	**0.62**	**1.64**
CV	**22.4**	**23.9**	**15.3**	**20.2**	**33.2**	**18.4**
LSD	**Ns**	**Ns**	**Ns**	**Ns**	**Ns**	**ns**

Means followed by different letters are significantly different at p< 0.05 for every factor assessed. Means were separated using the Tukey test. The data presented are means±SE ns not significant.

4.5.3 Effects of soil amendments on Forage N, P and K uptake at Bumula and Kibos experimental sites during the 2021 long rains season

Effects of soil amendments on N, P and K content of maize forage were not significant. Plants treated with TSP15+CM15 had the highest N content, with mean value of 0.41 (Table 8) PM22.5+CM7.5 content with value of 0.16 and the lowest was TSP30 with value of 0.09 at Kibos. The decline in N content under CM30 could be attributed to the slow mineralization rate of organic nitrogen in high manure doses, which may have temporarily immobilized N due to high carbon-to-nitrogen (C:N) ratios. Excess organic matter can also enhance microbial activity, increasing N immobilization and reducing the fraction of inorganic N available for plant uptake. Additionally, high manure application rates may have elevated soil moisture and reduced aeration, thereby limiting nitrification and root uptake efficiency. There was negligible variability in forage P content among treatments at both sites. The highest K observed was observed under PM15+CM15 with value of 1.36 and the lowest recorded was Control with mean value of 0.44, respectively (table 8).

Table 8: Effects of soil amendments on Forage N, P and K uptake at Bumula and Kibos experimental sites during maize harvesting stage in the 2021 long rains season.

	%N Forage		% P Forage		**% K Forage**	
Treatment	**Bumula**	**Kibos**	Bumula	Kibos	**Bumula**	**Kibos**
CONTROL	0.28±0.01	0.28±0.04	0.10±0.01	0.16±0.01	0.45±0.00	1.13±0.07
CM30	0.28±0.02	0.30±0.01	0.11±0.01	0.13±0.02	0.69±0.18	1.22±0.09
PM10+CM10+TSP10	0.32±0.02	0.32±0.02	0.11±0.01	0.13±0.01	0.72±0.03	0.93±0.03
PM15+CM15	0.31±0.02	0.40±0.04	0.12±0.00	0.13±0.01	0.66±0.08	1.36±0.13
PM22.5+CM7.5	0.33±0.01	0.35±0.02	0.11±0.01	0.16±0.00	0.72±0.10	1.19±0.01
PM30	0.38±0.01	0.36±0.03	0.11±0.01	0.15±0.01	0.65±0.09	1.08±0.03
PM7.5+CM22.5	0.29±0.02	0.35±0.02	0.10±0.01	0.15±0.03	0.83±0.04	1.31±0.03
TSP15+CM15	0.31±0.00	0.41±0.02	0.10±0.01	0.15±0.00	0.77±0.17	1.26±0.13
TSP15+PM15	0.31±0.00	0.34±0.03	0.11±0.01	0.15±0.01	0.56±0.02	1.13±0.04
TSP22.5+CM7.5	0.30±0.00	0.36±0.04	0.09±0.01	0.12±0.01	0.57±0.03	1.27±0.20
TSP22.5+PM7.5	0.31±0.02	0.38±0.03	0.11±0.01	0.14±0.02	0.69±0.18	0.85±0.20
TSP30	0.36±0.04	0.35±0.03	0.09±0.00	0.14±0.01	0.63±0.06	1.03±0.04
TSP7.5+CM22.5	0.30±0.01	0.36±0.02	0.09±0.00	0.14±0.01	0.74±0.02	1.17±0.09
TSP7.5+PM22.5	0.34±0.03	0.34±0.02	0.10±0.01	0.15±0.01	0.69±0.18	1.00±0.05
MEAN	**0.32**	**0.35**	0.1	0.14	**0.67**	**1.14**
CV	**10.8**	**13.3**	14.1	14.5	**27.6**	**15.7**
LSD	**NS**	**NS**	NS	NS	**NS**	**NS**

Means followed by different letters are significantly different at p< 0.05 for every factor assessed. Means were separated using the Tukey test. The data presented are means±SE

4.6 Yield of maize forage and grain

4.6.1 Effects of soil amendments on dry matter yield of forage grown at Bumula and Kibos in Western Kenya during the maize growing season of 2021

At Bumula site, all the treatments enhanced forage dry matter yield of maize compared to the control (P<.001). At the same site, soil amendment with PM10+CM10+TSP10 gave the highest dry matter yield followed by TSP15+PM15, and the respective dry matter increase from the control was 3.501 tons/ha and 3.41 tons/ha (Fig 4.7). Generally, CM 30 gave the least dry matter yield increase compared to the control in Bumula. In Kibos experimental site, plants amended with TSP22.5+PM7.5 had higher forage dry matter yield compared to four other soil amendments (P=.014), and 67% over the control which was the highest compared to any other amendment.

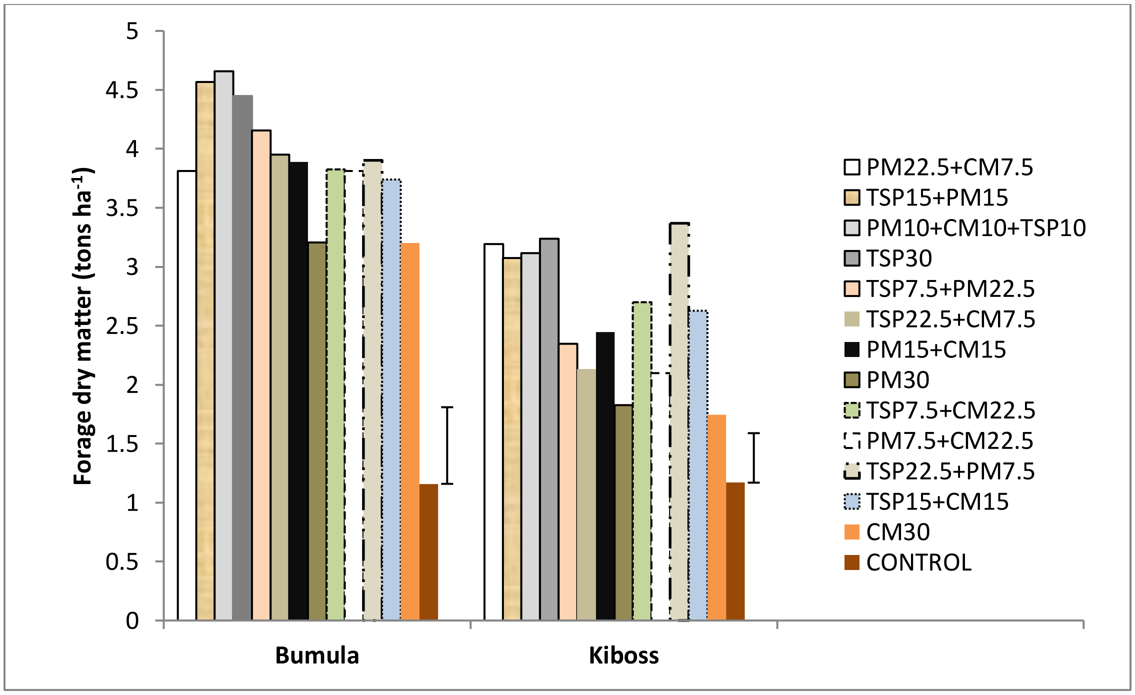


Figure 4.7: Forage dry matter yield as affected by fertilizer application at Bumula and Kibos sites in the long rain season of 2021

4.6.*2* Effects of soil amendments on maize grain yield at Bumula and Kibos in Western Kenya during the maize growing season of 2021

According to the data in Figure 4.8, the application of both organic and inorganic fertilizers significantly ($P<0.05$) affects the grain production of maize at both the Bumula and Kibos locations (Appendix 28). At Bumula, the TSP15+PM15 treatment yielded the most grain (4.6 T/ha), followed by TSP30 (4.5 T/ha). Grain production was lowest in plots without amendment, averaging 1.5 T/ha. At Kibos, the highest yields were TSP15+PM15 (4.4 T/ha), TSP22.5+PM7.5 (4.38 T/ha), and TSP30 (4.2 T/ha), while the lowest yield was the control, which had 1.26 T/ha. According to these results, a number of fertilizer combinations significantly raised grain yield; at both sites, the TSP15+PM15 treatment had the strongest effects (Fig 4.8). Inorganic P must be applied at a minimum rate of 15 kg ha-1 in combination with organic P to achieve a grain yield equivalent to that of a full rate of inorganic fertilizer application. In treatments with lower inorganic P (1/4, 1/2, or 3/4 rate administered), combinations with PM performed better than inorganic/organic combinations with CM. Additionally, the results were influenced by site characteristics; on average, Bumula recorded higher grain yields than Kibos.

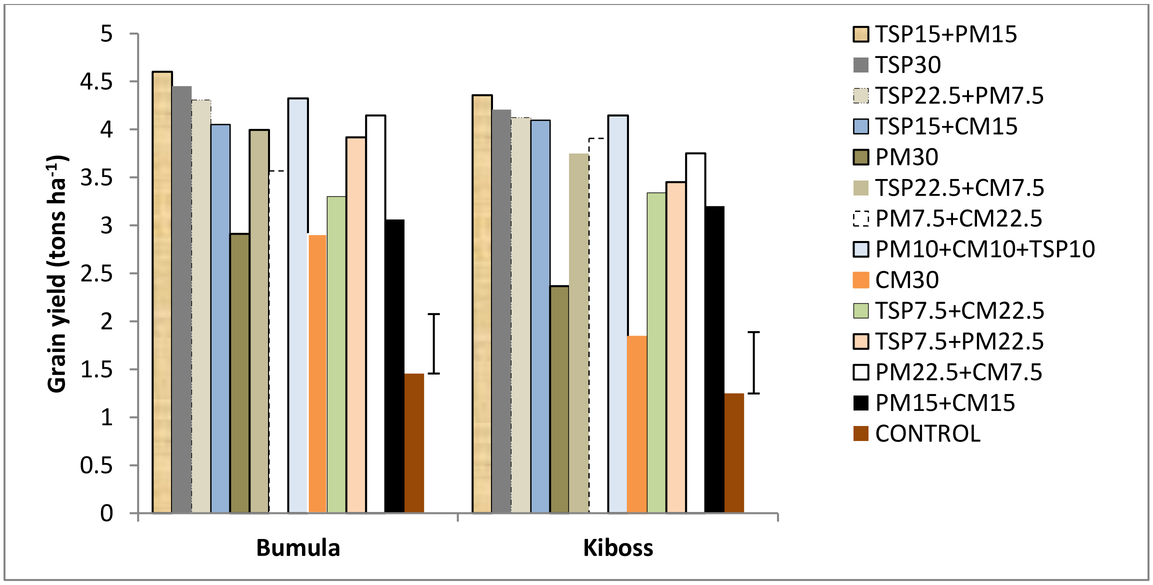


Figure 4.8: Maize grain yields as affected by fertilizer application at Bumula and Kibos sites in the long rain season of 2021

4.7 Effects of different organic amendments integrated with inorganic fertilizer on the forage quality of maize

Application of TSP 15 + CM 15 consistently enhanced protein content of fodder maize at both experimental sites by more than 85% over the control, which was higher than any other treatment (Table3). It was further observed that the % dry matter of maize forage increased the most (15% over the control, P<.001) in soil amended with PM22.5+CM7.5 at Bumula; similarly, the same soil amendment and PM 30 enhanced the % dry matter of the forage compared to the control and TSP 30 at Kibos (Table 3). Generally, all the soil amendments enhanced the digestibility of maize forage compared to the control, and all except three soil amendments in Kiboss gave plants with *in vitro* dry matter digestibility above 60% (Table 3). It was further observed that plants that received all the 13 organic and inorganic amendments had the recommended %NDF value of less than 50%. Plants treated with TSP22.5+PM7.5 had the lowest NDF value of 40.47 at kiboss, while soil amendment TSP7.5+CM22.5 gave the least NDF value of less than 40% at Bumula, which were good indicators of quality (Table 3). The effects of soil amendments on %ADF of maize fodder were not significantly different from the control (Table 9). However, all the treatments except the control at Kiboss site had maize plants with %ADF values within the required ADF level of less than 35%. At Bumula site, nine soil treatments gave plants with ADF level above the 35% quality threshold.

Table 9: Effects of organic and inorganic soil amendments on forage quality traits of maize plants in a field experiment conducted in two experimental sites in Western Kenya during the long rain season of 2021

	Bumula					**Kiboss**				
Amendment	Dry matter %	IVDMD%	ADF %	NDF %	Crude protein%	Dry matter %	IVDMD%	ADF %	NDF %	Crude protein%
CM30	19.47^{bc}	67.27	37.80	45.96	4.23^{cde}	21.032	62.70	35.54	48.81^{ab}	4.24^{ab}
CONTROL	14.00^{c}	53.12	43.90	52.38	3.17^{f}	21.034	52.60	37.73	52.03^{a}	3.29^{b}
PM10+CM10+TSP10	21.29^{bc}	67.94	34.30	47.95	4.76^{bcd}	19.815	58.50	31.55	43.12^{ab}	4.82^{ab}
PM15+CM15	23.55^{ab}	70.27	38.60	40.36	3.73^{ef}	23.693	65.50	31.77	47.42^{ab}	5.44^{ab}
PM22.5+CM7.5	29.23^{a}	69.68	39.00	44.69	4.28^{cde}	25.493	60.90	32.63	47.25^{ab}	4.33^{ab}
PM30	25.25^{ab}	69.72	36.20	41.82	4.77^{bcd}	26.623	66.10	34.41	48.70^{ab}	4.21^{ab}
PM7.5+CM22.5	25.59^{ab}	64.90	31.90	45.85	3.71^{ef}	21.509	66.40	31.90	47.98^{ab}	5.53^{ab}
TSP15+CM15	20.78^{bc}	65.28	35.80	44.84	7.08^{a}	21.976	60.00	33.94	47.58^{ab}	6.14^{a}
TSP15+PM15	21.26^{bc}	70.88	37.30	40.14	4.82^{bcd}	18.88	62.90	29.79	40.87^{ab}	5.15^{ab}
TSP22.5+CM7.5	23.70^{ab}	66.54	38.30	41.68	5.22^{b}	20.732	65.20	33.06	45.47^{ab}	4.59^{ab}
TSP22.5+PM7.5	22.15^{ab}	63.33	30.40	41.62	3.87^{ef}	22.094	66.60	30.09	40.47^{b}	5.52^{ab}
TSP30	24.11^{ab}	60.77	33.40	47.44	5.03^{bc}	20.213	59.20	30.95	46.97^{ab}	5.42^{ab}
TSP7.5+CM22.5	22.93^{ab}	62.71	31.60	39.52	4.08^{de}	17.793	62.00	32.87	47.62$_{ab}$	4.45^{ab}
TSP7.5+PM22.5	23.71	68.53	36.40	47.20	4.75^{bcd}	21.781	56.70	22.23	43.63^{ab}	4.41^{ab}
SED	2.02	4.78	6.34	3.64	0.41	3.35	5.30	4.11	3.10	0.72
P value	<.001	0.06	0.807	0.06	<.001	0.47	0.32	0.19	0.05	0.05

4.8 Effects of soil amendments on economic benefit of maize production at Bumula and Kibos in Western Kenya during the long rains growing season of 2021

Treatments TSP15+PM15 and PM22.5+CM7.5 gave the highest net profit of $ 1,441.93and $ 1,348.22, respectively at Bumula site, while TSP15+CM15 and TSP15+PM15 were the most profitable amendments at Kibos site with net profit value of $ 1,361.88 and $ 1,326.22, respectively (Table 10). Based on profit cost ratio (BCR), a blend of inorganic fertilizer and cattle manure at 50% of the P supply (TSP 15 + CM 15) had the topmost BCR values of 2.53 and 2.56 at Bumula and Kibos, respectively This was followed by PM22.5 +CM7.5 with BCR values of 2.37 at Bumula and 2.06 at Kibos. TSP 15 +PM 15 ranked third with BCR values of 2.10 and 1.93 for Bumula and PM7.5+CM22.5 with BCR of 2.18 Kibos sites, respectively. This treatment performed the same way as PM10 +CM10 + TSP 10 with BCR of 2.03 and 1.90 at Bumula and Kibos, respectively. Farmers stand to get profit from use of the treatments highlighted. Sole application of composted pressmud (PM30) or cow manure (CM30) were least profitable for maize production despite the yield improvement over the unfertilized crop.

Table 10: Economic analysis and benefit cost ratio of different fertilizers treatments of the experiment

Treatment	Total expenses (USD ha^{-1})	Gross income (USD ha^{-1})		Net income (USD ha^{-1})		Benefit Cost Ratio (BCR)	
		Bumula	**Kibos**	**Bumula**	**Kibos**	**Bumula**	**Kibos**
CONTROL	457.96	671.11	573.91	213.14	115.95	0.47	0.25
TSP30kg P	821.58	2,059.60	1,943.89	1,238.02	1,122.31	1.51	1.37
PM30kg P	555.78	1,069.14	1,096.91	513.36	541.13	0.92	0.97
CM 30kg P	593.42	1,069.14	851.61	475.72	258.19	0.80	0.44
TSP 15+PM15	687.10	2,129.03	2,013.32	1,441.93	1,326.22	2.10	1.93
TSP 22.5+PM7.5	755.13	1,994.81	1,906.87	1,239.67	1,151.73	1.64	1.53
TSP 7.5+PM22.5	622.24	1,531.97	1,596.77	909.73	974.53	1.46	1.57
TSP 15+CM15	531.11	1,874.47	1,892.98	1,343.36	1,361.88	2.53	2.56
TSP 22.5+CM7.5	767.26	1,541.23	1,735.62	773.97	968.36	1.01	1.26
TSP 7.5+CM22.5	658.58	1,064.51	1,545.86	405.93	887.27	0.62	1.35
PM 15+CM15	580.02	1,416.27	1,481.06	836.25	901.04	1.44	1.55
PM 22.5+CM7.5	567.90	1,916.12	1,735.62	1,348.22	1,167.72	2.37	2.06
PM 7.5+CM22.5	567.59	1,647.68	1,805.04	1,080.09	1,237.45	1.90	2.18
PM 10+CM10+TSP10	660.34	1,999.43	1,916.12	1,339.10	1,255.79	2.03	1.90

The exchange rate of Dollar to Kenya shilling was 1 USD = 110.21 KSH

CHAPTER FIVE

DISCUSSION

5.1 Soil chemical properties at the experimental sites

The findings from the Bumula and Kibos experimental sites point to a number of important areas of soil fertility and health that require attention. Most crops thrive at both locations' moderate pH values. According to Zhao *et al*. (2020) a pH of about 6 is normally appropriate for nutrient availability and microbial activity thus indicating that pH is not a significant limiting factor for crop development. The low soil organic carbon at both sites indicates a deficiency in organic matter which according to Lal (2019), organic carbon is crucial for maintaining soil fertility, structure and microbial health. Low levels therefore often result from erosion, intensive land use or limited organic matter inputs which concurs with Guo and Gifford (2002) findings which indicated that tropical soils frequently have low organic carbon due to poor organic inputs and rapid decomposition.

Nitrogen levels were also extremely low reflecting a severe nutrient deficit. Nitrogen is essential for plant growth notably for vegetative development and chlorophyll synthesis and its deficiency can markedly reduce crop yields according to Jones *et al*., 201 and Khalid *et al*., 2023). Adequate nitrogen supports biomass accumulation and leaf expansion which in turn improves grain yield (Mutinda *et al*., 2023). The low nitrogen at Bumula and Kibos may be attributed to leaching, limited nitrogen fixation, or insufficient manure application which is consistent with findings by Jones *et al*. (2019).

Phosphorus content varied notably between sites, with Bumula at 2.71 mg/kg and Kibos at 12.5 mg/kg which is vital for energy transfer and photosynthesis according to (Smith *et al*., 2019). Low levels in Bumula may be attributed to inherent soil deficiencies, high phosphorus fixation or probably from limited fertilization all of which can restrict plant growth and yield. This variation supports Smith *et al*. (2019) observation that phosphorus availability differs across soils and management practices.

Potassium levels on the other hand also differed with Bumula at 238 mg/kg and Kibos at 634 mg/kg. In general soils with less than 150 mg/kg K are considered deficient, making both sites above the absolute deficiency threshold but still highlighting a notable disparity as it is critical for water regulation and enzyme activation in plants as indicated by Marschner (2012). The higher potassium in Kibos likely reflects better soil management or more favorable conditions, whereas the lower levels in Bumula may result from leaching or inadequate fertilizer input, consistent with Marschner’s (2012) observations on variability in potassium availability.

5.2 Selected chemical characteristics of manure used in the study

The compost analysis after 30 days of composting process showed that cattle manure (CM) had higher total nitrogen and potassium compared to pressmud (PM)., CM's higher nitrogen and potassium levels are attributed to its richer nutrient content, consistent with findings by Reddy *et al*. (2020) and Li *et al*. (2021). PM, however, had slightly lower organic carbon (24.4%) compared to CM (25%), a difference linked to the feedstocks and processing methods (Bhattacharyya *et al*., 2019). PM did have a marginally higher phosphorus content (0.7%) than CM (0.5%), reflecting its enrichment from plant material, as supported by Zhang *et al*. (2019) and Mandal *et al*. (2021). Overall, CM was a better source of nitrogen and potassium, while PM was richer in phosphorus, suggesting the suitability of the materials in addressing soil fertility needs in the study area.

5.3 The Effect of integrated application of organic amendments and reduced inorganic fertilizer on soil properties

5.3.1 Effect of integrated application of organic amendments and reduced inorganic fertilizer on soil pH

The analysis of soil pH at both the flowering and harvest stages for maize indicated no significant differences across or within the sites. At the Bumula site, there was an observed increase in pH with certain treatments compared to the control during flowering. Specifically, the PM22.5+CM7.5 treatment recorded the highest pH at 6.5, while the Control had the lowest pH at 5.58. These values were above pH 5.5 critical level for soil nutrients availability. The increase in soil pH may be attributed to the content of macronutrient in the pressmud and cattle compost such as Ca^{2+}, Mg^{2+} and K^{+} during mineralization that may have replaceded $H^{+}$and Al^{3+} ions (Sher *et al*, 2022) and the buffering effect of decomposition products like humus, which likely helped to neutralize soil acidity to some degree (Miller *et al*., 2020). At crop harvest, the highest pH of 6.5 was recorded for the PM30 treatment.

Similarly, at the Kibos site pH increased slightly with treatment application although the change was not statistically significant. The PM30 treatment had the highest pH at 6.49, while the Control treatment had the lowest at 5.6 at the flowering stage. At harvest, the PM30 treatment had the highest pH at 6.23, and TSP30 had the lowest at 5.7. Miller *et al*. (2020) reported that organic amendments could significantly alter pH, especially in acidic soils, which aligns with the increased pH observed in the present study. Some studies have shown that soil pH may remain stable under different fertiliser treatments depending on the soil's buffering capacity and duration of amendments (Zhang *et al*., 2022). Additionally, Wang *et al*. (2021) observed that phosphorus treatments might lead to soil acidification in some cases, as observed with the TSP30 treatment in the current study.

5.3.2 Effect of integrated application of organic amendments and reduced inorganic fertilizer on soil organic carbon

The analysis of soil organic carbon (OC) content at both flowering and harvest stages for maize revealed significant differences ($p < 0.05$) among treatments at the Bumula and Kibos sites. Although CM 30 plots had the highest OC content during the flowering stage for the Bumula site, the PM30 treatment consistently resulted in higher soil OC levels than the control treatment, which had the lowest OC levels at both sites and stages. For the Bumula and Kibos sites, PM30 recorded the best OC at harvest, 1.8% and 2.7%, respectively. The largest increases in soil OC were caused by the organic amendments being applied alone.

The differences in elevation between the two sites likely influenced soil organic carbon levels with higher elevations such as Bumula, experience cooler temperatures and distinct precipitation patterns compared with lower areas like Kibos. These notable climatic conditions can slow the decomposition of organic matter and affect the accumulation of soil organic carbon, as lower temperatures reduce microbial activity (Kumar *et al*., 2021). In contrast, warmer temperatures at lower elevations may accelerate decomposition and alter how organic matter is incorporated into the soil.

Soil physical and chemical properties also vary with elevation, influencing how organic amendments like pressmud affect organic carbon levels (Zhang *et al*., 2022). Soils at higher altitudes may retain moisture better or have different mineral compositions, which can modify their response to added organic matter. Elevation can further shape vegetation cover and land-use practices, both of which impact soil organic carbon dynamics. Differences in plant types and management techniques between high and low elevations can determine the baseline organic carbon and the effectiveness of soil amendments (Singh *et al*., 2019).

These observations are consistent with other studies that report altitude-related variability in soil properties and organic carbon content. For example, Verma *et al*. (2022) highlighted that altitude and associated climatic factors significantly impact soil organic matter dynamics, which aligns with the observed differences between the Bumula and Kibos sites.

5.3.3 Effect of integrated application of organic amendments and reduced inorganic fertilizer on soil nitrogen content

The results showed that the TSP15+CM15 treated soils had the highest nitrogen content at the flowering stage in Kibos. CM 30 treated soils from the same site had higher soil N content at crop harvest. The highest %N in the TSP15+CM15 treatment can be attributed to the high initial N input from CM, and the combined effects of phosphorus (TSP) and organic matter. Phosphorus enhances microbial activity, which can boost nitrogen mineralization, while organic matter provides a continuous source of nitrogen and improves soil structure, enhancing nutrient retention and reducing leaching (Smith *et al*., 2019). In contrast, the control treatment, which did not receive any additional nutrients, showed the lowest %N. This highlights the reliance of soil fertility on nutrient amendments, as the control lacked the supplementary nutrients needed to increase soil nitrogen content.

These findings are consistent with those of Singh *et al*. (2020), who observed that phosphorus and organic amendments significantly enhanced soil nitrogen content due to increased microbial activity and improved soil organic matter. Lee *et al*. (2021) also reported that the combination of phosphorus and organic amendments led to higher soil nitrogen levels, aligning with the results observed in this study. Kim *et al*. (2019) further supported these findings by noting that phosphorus and organic matter amendments improved soil nitrogen availability, though the extent varied depending on soil type and environmental conditions.

5.2.4 Effect of integrated application of organic amendments and reduced inorganic fertilizer on soil phosphorus content

The PM30 treatment's effectiveness in boosting soil phosphorus levels align with findings by Chaudhary, Singh & Gupta (2020) who noted that pressmud significantly increases soil phosphorus availability due to its high phosphorus content. The observed differences between Bumula and Kibos, despite identical treatments, may be related to initial soil phosphorus levels and how altitude influences phosphorus dynamics. Zhang *et al*. (2022) highlighted that soil properties, including initial nutrient levels and environmental factors such as altitude, can impact the effectiveness of phosphorus amendments, aligning with the variations observed in this study.

The present study further revealed various increases in available soil P content (1.5 to 6-) between flowering and harvest stages at both sites particularly in treatments with organic amendments. This could be attributed to a change in plant nutrient uptake and utilization dynamics, favouring accumulation of P in the soil during grain development. Besides P-acquisition from soil, plants employ internal P recycling mechanisms to meet their P needs (Zhang *et al*., 2022) During the grain filling period the P reserve in vegetative organs is progressively recycled to support the growth of developing grains even under P deficiency. This points to a possible shift from reliance on P uptake to recycling for grain development leading to more reserve of soil P. The results are supported by the study of Wang and Ning (2019) who showed that grain development relied on P preferentially remobilized to the ear during the first half of the grain filling phase from the stem (50–76%) rather than from leaves (30–44%). Therefore, with recycling activated, there will be reduced need for P acquisition hence to increase observed in the present study. Further, mineralization of organic P from the applied amendments might raise the inorganic soil P over time.

5.3.4 Effect of integrated application of organic amendments and reduced inorganic fertilizer on soil potassium content

The increased potassium content associated with treatments like CM7.5+PM22.5 and PM30 is consistent with findings by Verma *et al*. (2022), who reported that organic amendments significantly enhance soil potassium levels due to their inherent potassium content. The differences between Bumula and Kibos could be attributed to the effect of altitude on soil weathering and potassium dynamics. Wang *et al*. (2021) noted that altitude could influence soil nutrient dynamics through changes in weathering rates and organic matter decomposition, which may explain the variations in potassium levels observed between the two sites. The reduction in potassium (K) content by at least one-third between flowering and harvest stages at both Bumula and Kibos, with a greater decline at Kibos, can be attributed to several factors. As plants mature, they absorb significant amounts of potassium for essential physiological functions, leading to decreased soil potassium levels. At Kibos, the more pronounced decline could be due to increased leaching losses, possibly exacerbated by higher rainfall or irrigation practices. Additionally, differences in soil properties, such as higher sand content at Kibos, could contribute to greater nutrient leaching. Variations in soil management practices and crop residue removal might also play a role, with more extensive harvesting potentially leading to higher potassium removal from the soil.

5.4. Maize performance under the influence of organic and inorganic fertilizer applications on growth

5.4.1. Plant height

The significant increase in maize plant height under treatments like TSP7.5+CM22.5 and TSP15+PM15 suggests that these combinations effectively enhanced nutrient availability, promoting better plant growth. These observations are similar to findings of Wang *et al*. (2022), who reported that a combination of organic and inorganic amendments significantly improves plant height due to better nutrient availability and synergistic effects. However, Johnson *et al*. (2020) noted that plant height responses to fertilizer treatments can vary based on soil type and climatic conditions, which might explain some of the variations observed between the two sites in this study.

At Bumula, the superior plant height could be attributed to the higher altitude, which influences nutrient uptake efficiency and overall plant physiology. The cooler temperatures and reduced atmospheric pressure at higher altitudes can enhance nutrient absorption and plant growth, as observed by (Baldwin and Fridley, 2021), who found that altitude affects plant development through variations in temperature and gas exchange. This aligns with the study's findings that treatments at Bumula resulted in taller plants compared to Kibos, despite the treatments being similar.

5.3.2 Stem girth

The larger stem girth observed with the TSP15+PM15 treatment at both sites indicates that this combination provided a balanced supply of essential nutrients for stem development. The greater girth at Bumula might also be linked to the ecological effect on nutrient uptake and plant health. (Yin *et al*., 2021). The finding that TSP15+PM15 resulted in the largest stem girth align with Zhang and Liu (2021), who noted that organic and inorganic fertilizer combinations enhanced stem girth by improving soil fertility and nutrient availability. However, Singh *et al*. (2023) found that stem girth improvements are more influenced by specific nutrient ratios rather than the type of amendment used. This contrast highlights the complexity of nutrient interactions and their effects on plant growth, suggesting that while TSP15+PM15 was effective, other factors such as nutrient ratios could also play a significant role.

5.4.3 Leaf number

The increase in the number of leaves with TSP30 and TSP15+PM15 treatments indicates improved photosynthetic capacity and overall plant health. The higher number of leaves at Kibos compared to Bumula, despite similar treatments, may be due to different soil nutrient dynamics and environmental conditions at the lower altitude. Miller *et al*. (2022) observed that warmer temperatures can enhance leaf development and photosynthesis. Adebayo, Ibrahim, & Yekeen (2021), who also reported increased leaf numbers with specific fertilizer treatments, which was attributed to improved nutrient uptake and plant health. Conversely, Rahman *et al*. (2023) noted that the impact of fertilizers on leaf number can be influenced by plant variety and specific nutrient needs, which might explain the variations observed between sites in this study.

In the present study, reducing the application of inorganic phosphorus (P) to 1/3, 1/2, or 3/4 of the recommended rate, when combined with organic P, produced similar leaf numbers to those achieved with the full rate of inorganic P. Notably, the incorporation of PM as the organic P source yielded the best response in terms of leaf number, indicating that organic amendments can effectively complement reduced inorganic P inputs and support comparable plant growth. This is supported by other studies (Nayan *al*l., 2022) where pressmud and cattle manure increased leaf number compare to NPK. Organic resource increase soil porosity, increase soil moisture content and supply extra nutrients, for example macronutrients such as Ca, Mg, S and micronutrients like Zn, Fe and B (Solomon, *et al* 2012).

5.4.4 Leaf area index

The higher leaf area index with TSP30 treatment suggests improved leaf expansion and overall canopy development. The greater leaf area index at Bumula compared to Kibos could reflect the ecological effects on nutrient uptake and leaf growth. According to Zhang *et al*. (2022), appropriate nutrient management can significantly improve leaf area index and maize growth. However, the effectiveness of nutrient amendments on leaf area index is highly dependent on the plant species and soil conditions (Chen and Yang (2023), which indicates that while TSP30 was effective, other factors also play a crucial role in determining leaf area index outcomes.

In this study, it was observed that reducing inorganic phosphorus (P) application to 1/3, 1/2, or 3/4 of the recommended dose, when combined with organic P sources, resulted in similar leaf area indices to those achieved with the full rate of inorganic P, regardless of the type of organic amendment used. This shows that lower rates of inorganic P can support vegetative growth effectively when paired with organic P, Recent research supports this finding, showing that integrating reduced inorganic P with organic amendments can maintain plant growth while reducing dependency on high inorganic P inputs (Santos, Oliveira, & Lemos, 2021). Organic amendments, such as compost or poultry manure, enhance the availability of phosphorus and improve soil fertility, making it possible to use lower levels of inorganic P without compromising plant health (Santos, Oliveira, & Lemos, 2021; Zhang *et al*., 2022). This approach is beneficial for sustainable agriculture, as it leverages nutrient release from organic sources while minimizing the environmental impact of excessive inorganic fertilizer use (Gao *et al*., 2020; Silva *et al*., 2023).

5.5 Forage dry matter yield

The treatments PM10+CM10+TSP10 and TSP 15+PM 15 resulted in similar dry matter yield of forage as inorganic NPK applicationThe findings demonstrate that it is feasible to reduce inorganic application to as low as 1/3 of the normal rate for maize forage production. The results are consistent with the findings of Wang *et al*. (2025) observed biomass increase on integrated application of organic and inorganic fertilizer. Organic amendments such as manure, compost, or pressmud offer more advantages as they not only release nutrients slowly and continuously over a period of time, but also improve the structure, water retention capacity, microbial numbers, and nutrient utilization efficiency (Wabela *et al*., 2024). The enhanced soil quality promotes nutrient uptake and root development, which results in robust vegetative growth and higher biomass accumulation.Aalthough readily available nutrients from inorganic fertilizers are more susceptible to leaching and volatilization. Besides, those organic amendments that are not normally included in commercial NPK fertilizers add to the availability of micronutrients, raise microbial biomass carbon, and improve cation exchange capacity (CEC). Collectively, these advantages upgrade photosynthesis and biomass accumulation, and that is the ½ and 2/3 organic treatment produced a higher dry matter yield than a single NPK.

The differences in dry matter yield between Bumula and Kibos site, shows that Bumula conditions are more favorable for biomass production at the former. Environmental factors, particularly temperature, influence maize dry matter by affecting respiration, photosynthesis, and growth rates. In this study, differences in dry matter between sites are likely linked to local temperature variations, even though the maize variety and agronomic practices were similar. Warmer conditions can accelerate growth, potentially shortening the grain-filling period and reducing overall dry matter accumulation under stress. In contrast, temperatures within the optimal range for photosynthesis can extend the growing period, allowing more time for biomass buildup. As a result, cooler locations may support longer photosynthetic activity and higher dry matter production (Hatfield & Prueger, 2015). Additionally, local conditions such as soil moisture and nutrient availability play a critical role in maximizing dry matter yield, consistent with findings by Nguyen (2022).

5.6 Grain yield

At both experimental sites, the combination of TSP15 and PM15 gave the highest maize grain yields, ranging from 4.4 to 4.6 T/ha, surpassing the full-rate TSP30 application, which yielded 4.2–4.4 T/ha. Other combinations that significantly improved yields (≥4.0 T/ha) included PM10+CM10+TSP10, TSP22.5+PM7.5, and TSP15+CM15/PM22.5+CM7.5. Plots that received no amendments recorded the lowest yields, between 1.26 and 1.5 T/ha. These results indicate that to match the yield from a full rate of inorganic fertilizer, at least 10 kg/ha of inorganic phosphorus must be applied alongside an organic source. When lower rates of inorganic phosphorus were used, pressmud-based combinations performed better than those with cattle manure. Site differences also played a role, with Bumula producing higher yields than Kibos.

Using organic amendments in combination with reduced inorganic fertilizer rates improved maize yields compared with full-rate NPK alone. This approach supports long-term crop performance by enhancing microbial activity, improving soil structure, increasing nutrient use efficiency, and providing a steady release of nutrients. The current findings, where half-organic and half-inorganic fertilization exceeded full NPK rates, agree with previous studies (Gram *et al*., 2020; Farooq *et al*., 2024). Long-term research also shows that integrated fertilization maintains higher yields and better soil fertility than using mineral fertilizers alone (Zhang *et al*., 2024).

In particular, TSP15+PM15 yielded 4.6 T/ha at Bumula and 4.3 T/ha at Kibos, demonstrating that cooler sites can favor higher grain production. This supports earlier work showing that temperature has a major influence on maize yield, with cooler conditions extending growth periods and increasing grain accumulation. It is commonly known that lower temperatures promote better assimilate partitioning into the grain and increase yields, particularly during the grain-filling stage. But severe heat, particularly at anthesis or grain filling, can stimulate growth, decrease the duration of grain filling, and increase respiration loss, all of which can decrease final grain yields very significantly (Lobell *et al*., 2011). At higher temperatures, heat stress also lowers yield by impairing anthesis pollen viability and fertilization success (Bänziger *et al*., 2000). Moreover, 20°C to 30°C is the optimal temperature range for promoting maize grain development. Temperatures above the given range, especially above 35°C, have been noted to limit photosynthesis and increase photorespiration, which inhibits biomass accumulation and yield (Hatfield & Prueger, 2015). Conversely, unlike the warmer location, the cooler location presumably offered an optimal regime of temperature for pollen viability, grain filling, and reproductive growth, which increased yields.

5.7 Nutrient concentration into plant tissues

5.7.1 Nutrient Concentration NPK in leaves

Nitrogen (N), phosphorus (P), and potassium (K) levels in the leaves from Bumula and Kibos treatments were found to vary slightly across treatments and significantly different ($p<0.0$) between treatments A higher percentage of nitrogen (N) was present in the plant tissue produced with 1/3 pressmud, 1/3 cow dung, and 1/3 inorganic NPK, (PM10+CM10+TSP10) probably due to complimentary patterns of nutrient release from the different sources. Pressmud and cow dung release nutrients slowly over the growing season, while inorganic NPK provides readily available nitrogen needed for vegetative growth. Combining these sources maintains steady nutrient uptake, prevents nitrogen losses through volatilization or leaching, and increases leaf nitrogen content (Agegnehu *et al*., 2023; Chivenge *et al*., 2011). Organic amendments also support root development and improve nitrogen use efficiency.

Both pressmud and cow dung contain high levels of organic phosphorus and organic acids, which enhance phosphorus availability. By stimulating microbial populations and phosphatase enzyme activity, these manures help convert phosphorus from forms that plants cannot use into readily absorbable forms (Rath *et al*., 2022).

Under most conditions, the combined treatments for potassium (K) again showed improved leaf K status due to increased cation exchange capacity (CEC), water retention, and decreased nutrient leaching—benefits linked to the function of organic matter (Zhou *et al*., 2023). But when 100% inorganic NPK was applied, the Kibos site had the highest leaf K content. Site characteristics like higher K fixing, lower organic content, or rapid mineral K intake through rapid solubility could be the cause of this. The observed variation between sites indicates that in order to achieve the highest K nutrition levels, nutritional strategies must be adjusted in accordance with the local soil properties.

5.7.2 Nutrient NPK in grains

At Bumula and Kibos, the results for nutrient content in grains (NPK) across various amendment treatments show that there are generally no appreciable differences between treatments. The grains' levels of nitrogen (N), phosphorus (P), and potassium (K) varied, but none of the variations were statistically significant ($p > 0.05$). The full NPK treatment resulted in the highest amount of nitrogen in grain, most likely because the easily accessible mineral form of nitrogen was perfectly matched to the crop's needs for uptake during crucial growth stages. Inorganic sources such as urea, which provide immediately available forms of nitrogen (NH_4^+ or NO_3^-), can easily absorb and transfer nitrogen to developing tissues, such as grains (Zhao *et al*., 2020). Inorganic fertilizers provide nutrients that are quickly available, which raises nitrogen and protein levels in maize grain. In contrast, treatments relying solely on organic sources release nitrogen gradually and may not supply enough during periods of peak crop demand (Agegnehu *et al*., 2023).

Applying pressmud alone resulted in the highest phosphorus content in the grain. As a sugar production byproduct, pressmud is rich in organic phosphorus and micronutrients.

Its slow decomposition increases phosphorus availability, promotes microbial activity, and enhances the conversion of phosphorus into forms plants can absorb (Rath *et al*., 2022). During grain development, organic acids from pressmud can chelate minerals in the soil, further increasing phosphorus uptake and storage in the grain.

The greatest potassium accumulation occurred when two-thirds of the fertilizer was organic and one-third inorganic. This mixture provides readily available potassium for early growth while the organic portion improves soil structure, water retention, and ensures a steady release of nutrients throughout the growing season (Chivenge *et al*., 2011). By maintaining nutrient availability and reducing leaching of mobile minerals like potassium, this approach enhances the eventual mineral content of the grain.

5.7.3 Nutrient NPK in stovers

Analysis of stover nutrient content showed slight variation in nitrogen (N), phosphorus (P), and potassium (K) across treatments and sites. However, no clear trends or statistically significant differences were observed between treatments ($p > 0.05$).

The highest nitrogen content in stovers was observed when a combination of half inorganic (NPK) and half organic (cattle manure) fertilizer was applied. This suggests a synergistic effect, where inorganic fertilizer provides readily available nitrogen while the organic component enhances soil structure, promotes microbial activity, and improves nitrogen retention.

According to Chivenge *et al*. (2011), they work in tandem to increase nitrogen uptake and decrease losses through leaching and volatilization. Higher N in stovers results from the organic matter's facilitation of microbial mineralization, which maintains nitrogen availability throughout the plant's active biomass build-up stage. Because of site-specific factors like lower organic matter content, improved N mobility, and higher initial soil fertility, which may have encouraged inorganic N uptake into above-ground biomass directly, the full NPK treatment had the most N in stovers for the second location, Kibos (Zhao *et al*., 2020).

Phosphorus (P) Concentration in Stovers

The PM10+CM10+TSP10 treatment produced stovers with the highest phosphorus content. By combining organic and readily soluble inorganic phosphorus sources, this approach likely increased phosphorus availability. As pressmud and cow dung decompose, they release organic acids that stimulate microbial activity and help release phosphorus bound in the soil (Rath *et al*., 2022). While NPK provides immediately available phosphorus, the organic components improve the soil’s ability to store and gradually release phosphorus, enhancing uptake and distribution to plant parts such as stover.

Potassium (K) Content in Stovers

Stover potassium content varied between sites. At Kibos, the highest K levels were observed with the TSP22.5+PM7.5 treatment, while at Bumula, TSP22.5+CM7.5 produced the highest stover K. In these cases, the larger inorganic portion likely supplied potassium immediately during periods of high demand, while the organic fraction improved soil water retention and limited leaching, which is especially important for potassium in leachable soils (Zhou *et al*., 2023).

The pressmud+cow dung treatment at Kibos also produced high stover K, likely due to higher baseline organic matter, improved cation exchange capacity (CEC), and the slow, sustained release of potassium from organic material, allowing gradual uptake during later growth stages. Organic matter is known to enhance soil potassium retention and support efficient utilization throughout the crop cycle (Palm *et al*., 2001).

5.7.4 Nutrient NPK in forage

Forage nitrogen content

There was very little and no difference between the treatments. TSP15+CM15 was the most effective treatment for increased N content. Inorganic nitrogen, which is easily acquired as urea or ammonium nitrate, promotes the growth of plants and vegetation. Cow manure gradually mineralizes into an equally reliable source of nitrogen while the forage is in the growing stage. A two-source approach like this promotes a steady supply of nitrogen, which enhances overall uptake and storage in vegetative structures like fodder, claim Tariq *et al*. (2020). Additionally, by reducing leaching and improving microbial processes associated with nutrient capture, organic matter enhances the efficiency of nitrogen use.

Forage Phosphorus (P)

The forage grown with supplementation of PM22.5+CM7.5 fertilizer had the highest level of phosphorus. High levels of organically bound phosphorus and humic matter in pressmud increase the mobility and bioavailability of phosphorus in the soil. Its degradation also results in the release of the organic acids, which solubilize unavailable forms of phosphorus. The lower proportion of cow dung content in the mixture causes enhanced microbial activity and enzymatic processes (e.g., phosphatase activity), which further stimulate phosphorus mineralization and forage crop uptake (Zafar *et al*., 2021).

Potassium (K) in Forage

Forage potassium concentration was highest when the forage was supplied with a 1:1 mixture of pressmud and cow dung-based organic fertilizers. Since both of these organic components naturally contain a lot of potassium, their combination probably improved the slow-release dynamics and soil potassium retention. While pressmud provides potassium and humic substances that increase K availability, cow dung plays a role in contributing towards soil structure development and microbial activity that promotes nutrient cycling and cation exchange capacity (CEC) (Meena *et al*., 2019). Potassium availability during the forage growth stage would have been maximized under the treatment's balance between the quick and slow-releasing K pools, which would have improved uptake and storage in plant tissue.

5.7 Forage nutritional and quality attributes

5.7.5 Acid detergent fiber (ADF)

Application of a 50% blend of organic and inorganic amendments (TSP15 + CM15) enhanced crude protein (CP) content by over 76.56% compared to the control at both research sites. This is because cattle manure has a high percentage of nitrogen that acts as slow-release nitrogen for plant uptake over an extended period, hence enhancing the synthesis of proteins (Yadav *et al*., 2021). Further, TSP, a highly soluble phosphorus fertilizer, encourages root growth and plant energy transfer for the production of amino acids and proteins (Singh *et al*., 2020). Lima *et al*. (2021) found that adding manure to TSP resulted in a 70% increase in protein content in forage sorghum. In the present study, forage quality improved in TSP 7.5 + PM 22.5 treatment (1/3 inorganic, 2/3 pressmud) by 65.45% over control. Pressmud has beneficial levels of organic material and micronutrients that promote microbial growth and structural stability of the soil, with ease in releasing and taking up nutrients. With the addition of TSP, the phosphorus enhances the metabolic processes in protein and sugar biosynthesis. The same was pointed out by Patel *et al*. (2023) when they concluded that pressmud with phosphorus fertilizer significantly improved factors of forage quality like protein and digestibility.

ADL was highest in the PM10 + CM10 + TSP10 treatment, which showed a 89.69% increase over the control. It may be indicating efficient solubilization of lignin by synergistic microbial breakdown of organic manure and enhanced enzymatic activity supported by proper nutrient supply. Ahmed *et al* (2020) in their study confirmed that inorganic fertilizer + cow dung + pressmud were better in enhancing degradability of fodder biomass lignin and enhancing digestibility. The TSP7.5+CM22.5 treatment increased Neutral Detergent Fiber (NDF) by 27.98% compared with the control. Cow dung supports microbial activity and helps break down cellulose, which promotes fiber accumulation. The presence of TSP ensures adequate phosphorus, allowing the plant to maintain proper cell wall development. Previous studies have also shown that combining inorganic fertilizer with cow dung enhances NDF in fodder crops by supporting vegetative growth and efficient nitrogen use (2022).

The TSP15+PM15 treatment led to a 29.21% increase in in vitro dry matter digestibility (IVDMD). Structural carbohydrates such as cellulose and hemicellulose may have been partially broken down due to the combined effects of organic and inorganic fertilizers. While NPK boosts microbial enzyme activity for optimal metabolism, pressmud supplies essential nutrients and labile carbon, enhancing digestibility. Pressmud and inorganic nutrients can be mixed at the ratio of 50:50, as recommended by Arif *et al*. (2021), which enhanced IVDMD in Napier grass by more than 25% and was a good prospective candidate to be used in ruminant diets. The quality criterion for good fodder is generally more than 55–60% IVDMD (Van Soest 1994). The ideal ranges of forage quality for both NDF and ADF are ADF < 35–40% and NDF < 50–55%. While NDF is used to estimate total fiber, which influences intake, ADF is used to estimate the less digestible fraction of cellulose and lignin. Results from this study indicate that the fodder is more palatable and easier to digest in the treated plots. The results are in line with previous studies that proved combining organic-inorganic fertilizer improves nutritive value in forage by promoting efficiency in the use of nutrients, microbial populations, and biomass quality (Mekonnen *et al*., 2020; Lima *et al*., 2021). According to Hassan *et al*. (2022), applying a blend of organic and inorganic fertilizer decreased ADF while maintaining optimal NDF levels in fodder legumes.

5.8 Economic analysis

Economic Benefit of Fertilizer Used in our Maize Production.

An economic analysis of the cost-effectiveness of the treatments used in this study was based on different factors that correlate with one another, such as the cost of fertilizer, grain value of maize, and how the plant reacted when exposed to the nutrients provided. Treatments increasing the quality or amount of grains produced more economic benefit, especially when input costs were at acceptable levels.

5.8.1 Net Benefit of treatments

The highest net benefits of $1,167.72 and $1,441.93 were exhibited under the application of TSP15 + PM15, TSP15 + CM15, PM22.5 + CM7.5, TSP 30, and PM10 + CM10 +

TSP10. These high return values can be attributed to increased availability and uptake of nutrients, particularly nitrogen and phosphorus, crucial for grain development and biomass yields. The enhanced performance of the treatments could also be attributed to a synergistic effect of organic and inorganic inputs, with improvement in soil structure and microbial life with timely nutrient release (Mekonnen *et al*., 2020). appropriate levels of inorganic fertilizers with organic inputs reduces the cost of inputs but maintains high levels of productivity (Lima *et al*., 2021); hence balanced fertilizer combination and utilization was most likely achieved in the outstanding treatments. These mixtures, especially the ones containing pressmud or cattle dung with TSP, provide quick-release (short-term) and slow-release (long-term) nutrient supply, allowing extended crop performance throughout the growing season (Singh *et al*., 2020).

5.8.2 Benefit Cost Ratio (BCR) of treatments

The treatments with the maximum BCR values were: TSP15 + CM15, PM22.5 + CM7.5, TSP15 + PM15, PM10 + CM10 + TSP10, recording BCR >2 at the experimental sites. All other combined treatments had BCR > 1, while CM30 and PM30 did not meet the profitability threshold. A BCR of >1 indicates that for every dollar of fertilizer invested, more than a dollar was received in terms of benefit. Therefore, a BCR of over 1 is a key profitability factor (Yadav *et al*., 2021), with higher values indicating more profit. It reveals that returns are higher than costs, and hence, such a practice regarding fertilizer is economically worthwhile to farmers. The study findings confirm that even lowered or intermediate application rates of mixed organic and inorganic fertilizers can still be cost-effective, especially under smallholder systems where cost-effectiveness is the top priority.

In line with the present results, Mekonnen *et al*. (2020) found that application of organic and inorganic nutrient sources in maize crop led to high net returns and BCR > 1, particularly when compost or farmyard manure was applied together with recommended levels of NPK. Lima *et al*. (2021) also achieved increased profitability upon combining phosphorus fertilizers with cattle manure in tropical maize systems. Yadav *et al*. (2021) have reported that integrated application of cattle manure and phosphorus fertilizer improved yield and economic profitability in forage and grain sorghum production systems. Based on the results of this study, organic (pressmud, cattle manure) and inorganic (TSP, NPK) fertilizer combinations enhance the profitability of maize. The treatments that combined moderate inorganic rates along with organic inputs generated greater net benefits and BCR values > 1, which revealed profitable and sustainable agricultural practices.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

To assess the effect of integrated application of organic amendments and reduced inorganic fertilizer levels on soil properties

1. Applying pressmud at 30 kg P/ha (PM30) noticeably improved soil health by raising soil pH and increasing the levels of organic carbon, phosphorus, and potassium at both sites. In contrast, cattle manure treatments were more effective in boosting nitrogen levels. These results suggest that using organic materials alongside reduced chemical fertilizer inputs can restore soil fertility and sustain productivity in both semi-humid and sub-humid areas.

To determine the effect of different organic amendments integrated with different inorganic fertilizer levels on maize growth and grain yield.

2. Combining organic and inorganic phosphorus sources led to better maize growth and yield performance than using either source alone. The TSP15 + PM15 treatment consistently produced the highest grain yields over 4.4 t/ha at both Bumula and Kibos highlighting the value of integrated nutrient management for improving maize productivity while maintaining soil fertility.

To evaluate the effect of organic amendments integrated with different inorganic fertilizer levels on forage quality of maize

3. Forage dry matter yield did not show consistent improvement across treatments, although some combinations such as TSP10 + PM10 + CM10 and TSP15 + PM15 gave the best results at Bumula. At Kibos, the highest fodder yield came from TSP22.5 + PM7.5.

4. The quality of maize forage improved when 15 kg P/ha of inorganic fertilizer was combined with 15 kg P/ha of cattle manure, which increased the crude protein content at both sites. While other forage quality traits showed little variation, most treatments still produced feed with acceptable digestibility and neutral detergent fibre (NDF) levels below 50%. However, at Bumula, about 62% of the treatments resulted in lower forage quality based on acid detergent fibre (ADF), showing that site conditions influenced forage response.

To assess the economic implication of using pressmud and cattle manure in maize production

5. The economic analysis showed that using a combination of 15 kg P/ha inorganic fertilizer and 15 kg P/ha organic P from cattle manure provided the highest economic returns from maize grain. This indicates that integrated use of pressmud and cattle manure is not only agronomically effective but also economically practical, offering farmers a cost-efficient and sustainable approach to maize production.

REFERENCES

Abate, T., Alene, A. D., Bergvinson, D., Shiferaw, B., Silim, S., Orr, A., & Asfaw, S. (2015). Challenges and opportunities for improving food security through maize research in eastern and southern Africa. *Journal of Agricultural Science*, 153(6), 819-831. https://doi.org/10.1017/S0021859614000911

Abd El-Gawad, A. M., & Morsy, M. M. (2017). Integrated effect of organic and inorganic fertilizers on maize yield. Egyptian Journal of Soil Science, 57(1), 63-72.

Adebayo, S. A., Ibrahim, A. K., & Yekeen, S. A. (2021). Influence of different fertilizer treatments on maize growth and yield. *Journal of Plant Nutrition and Soil Science, 184*(3), 423-431. https://doi.org/10.1002/jpln.202100112

Afshar, M., & Mofatteh, S. (2024). Biochar for a sustainable future: environmentally friendly production and diverse applications. *Results in Engineering*, 102433.

Agegnehu, G., Bass, A. M., Nelson, P. N., & Bird, M. I. (2023). *Integrated soil fertility management: A sustainable approach to increasing crop productivity and reducing environmental impacts*. Agronomy for Sustainable Development, 43(1), 10. https://doi.org/10.1007/s13593-023-00836-6

Aguilera, E., Lassaletta, L., Gattinger, A., & Gimeno, B. S. (2013). Managing soil carbon for climate change mitigation and adaptation in Mediterranean cropping systems: A meta-analysis. Agriculture, Ecosystems & Environment, 168, 25-36.

Aguk, J., Onwonga, R. N., Chemining'wa, G. N., Jumbo, M. B., & George, A. (2021). Enhancing yellow maize production for sustainable food and nutrition security in Kenya. *East African Journal of Science, Technology and Innovation*, *2*.

Ahmad, M., Lee, S. S., Lee, S. E., Al-Wabel, M. I., Tsang, D. C., & Ok, Y. S. (2017). Biochar-induced changes in soil properties affected immobilization/mobilization of metals/metalloids in contaminated soils. *Journal of soils and sediments*, *17*, 717-730.

Ahmed, M. E., Elamin, E. A., & Adam, A. A. (2020). Integrated nutrient management improves forage quality and yield of sorghum (Sorghum bicolor L.). *Journal of Agricultural Science*, 12(4), 1–10. https://doi.org/10.5539/jas.v12n4p1

Alam, M. J., Islam, M. S., Rahman, M. M., & Bhuiyan, M. S. A. (2020). Effects of organic and inorganic fertilizers on the growth and yield of maize (Zea mays L.). Journal of Agricultural Sciences, 15(1), 15-21.

production as fertilizer, fuel and feed. *Sugar Tech*, *26*(4), 1078-1087.

Asadu, C. O., Ezema, C. A., Ekwueme, B. N., Onu, C. E., Onoh, I. M., Adejoh, T., ... & Emmanuel, U. O. (2024). Enhanced efficiency fertilizers: overview of production methods, materials used, nutrient release mechanisms, benefits and considerations. *Environmental Pollution and Management.*

Ayinde, I. A., Muchie, M., & Bawa, S. (2016). Economic analysis of the adoption of maize production technologies in the savannah region of Nigeria. *Agricultural Science Research Journal*, 6(2), 41-48. https://doi.org/10.5281/zenodo.32487

Ayoola, O. T., & Makinde, E. A. (2019). Maize growth, yield and soil nutrient changes with N-enriched organic fertilizers. African Journal of Food, Agriculture, Nutrition and Development, 19(3), 14607-14623.

Azraf-ul-Haq Ahmad, I. Q., & Mahmood, N. (2007). Effect of integrated use of organic and inorganic fertilizers on fodder yield of sorghum (Sorghum bicolor L.). *Pak. J. Agri. Sci*, *44*(3), 415-419.Ahmed, W., Mehmood, A., & Imran, M. (2017). Human health risk assessment: Heavy metal contamination of street dust in Lahore, Pakistan. Environmental Monitoring and Assessment, 189(4), 1-14.

Balah, O. E., Thomas, R., & Ogallo, L. (2024). Effects of Organic Amendments and NPK on Soil Chemical Properties in Kano Plains, Kisumu, Kenya. *International Journal of Plant & Soil Science*, *36*(8), 1113-1137.

Baldwin, D. K., & Fridley, J. D. (2021). Altitude effects on plant height and growth: A review of recent studies. *Plant Ecology, 222*(7), 789-802. https://doi.org/10.1007/s11258-021-01187-4

Ballard, C. S., Thomas, E. D., Tsang, D. S., Mandebvu, P., Sniffen, C. J., Endres, M. I., & Carter, M. P. (2015). The influence of starch, soluble fiber, and intake level on milk production and ruminal kinetics in lactating dairy cows. Journal of Dairy Science, 88(8), 2680-2691.

Bänziger, M., Edmeades, G. O., Beck, D., & Bellon, M. R. (2000). Breeding for drought and nitrogen stress tolerance in maize: from theory to practice.

Barasa, J. N., Ochuodho, J. O., Kebeney, S. J., & Barasa, A. W. (2022). Improving soil fertility and crop yields through organic and inorganic inputs in smallholder farmers’ fields in western Kenya. *International Journal of Research and Innovation in Social Science, 6*(4), 2454–6186.

Benjamin, J., Idowu, O., Babalola, O. K., Oziegbe, E. V., Oyedokun, D. O., Akinyemi, A. M., & Adebayo, A. (2024). Cereal production in Africa: the threat of certain pests and weeds in a changing climate a review. *Agriculture & Food Security*, *13*(1), 18.

Bhattacharyya, R., Gupta, S., & Mandal, B. (2019). Organic carbon and soil fertility. *Soil Science Society of America Journal, 83*(5), 1580-1595. https://doi.org/10.2136/sssaj2019.04.0154

Bian, H., Boguta, P., Huang, J., Deng, C., Kong, D., Zhou, H., & Su, X. (2024). Transforming Organic Solid Waste Management: Embracing Humification for Sustainable Resource Recovery. *ACS Sustainable Resource Management*, *1*(2), 181-198.

Brandt, P., Yesuf, G., Herold, M., & Rufino, M. C. (2020). Intensification of dairy production can increase the GHG mitigation potential of the land use sector in East Africa. *Global Change Biology*, *26*(2), 568-585.

Bremaghani, A. (2024). Utilization of Organic Waste in Compost Fertilizer Production: Implications for Sustainable Agriculture and Nutrient Management. *Law and Economics*, *18*(2), 86-98.

Chaudhary, A., Singh, R., & Gupta, S. (2020). The impact of pressmud on soil phosphorus availability: An empirical study. *Journal of Soil Science and Plant Nutrition, 20*(3), 1154-1166. https://doi.org/10.1007/s42729-020-00240-4

Chen, J., Luo, Y., Li, K., Zhang, W., Peng, P., & Wang, F. (2018). Impacts of chemical fertilizers on soil microflora: A review. Environmental Science and Pollution Research, 25(15), 15195-15206.

Chen, X., Li, Z., Zhao, H., Li, Y., Wei, J., Ma, L., ... & Tan, D. (2024). Enhancing Maize Yield and Nutrient Utilization through Improved Soil Quality under Reduced Fertilizer Use: The Efficacy of Organic–Inorganic Compound Fertilizer. *Agriculture*, *14*(9), 1482.

Chen, Y., & Wu, X. (2021). Nutrient management practices for optimizing maize grain yield. *Crop Science, 61*(5), 1567-1579. https://doi.org/10.1002/csc2.20514

Chen, Z., & Yang, J. (2023). Fertilizer impacts on leaf area index in maize: A meta-analysis. *Field Crops Research, 286,* 108294. https://doi.org/10.1016/j.fcr.2022.108294

Chen, Z., Brown, S., & Lee, R. (2021). Effects of fertilizer types on forage quality: Focus on fiber and protein content. *Field Crops Research, 263*, 108-119https://doi.org/10.1016/j.fcr.2021.108119.

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), 1–30. https://doi.org/10.1007/s11104-010-0626-5

Choudhary, M., Garg, K., Reddy, M. B., Meena, B. L., Mondal, B., Tuti, M. D., ... & Rajawat, M. V. S. (2024). Unlocking growth potential: Synergistic potassium fertilization for enhanced yield, nutrient uptake, and energy fractions in Chinese cabbage. *Heliyon*, *10*(7).

Crews, T. E., & Peoples, M. B. (2004). Legume versus fertilizer sources of nitrogen: Ecological tradeoffs and human needs. Agriculture, Ecosystems & Environment, 102(3), 279-297.

Cueva Welchez, S. (2024). Evaluation of corn silage quality and its effects on dairy cow performance

Darabi, S., Heidari, G., Khalesro, S., & Jahani Azizabadi, H. (2025). Effect of Different Levels of Pelleted Poultry Manure and Chemical Fertilizer on Fodder Quality and Maize (Zea mays L.) Grain Yield. *Journal of Agroecology*, *16*(1), 129-146.

de Bertoldi, M. (2013). *Compost Science and Technology*. Elsevier.

De Groote, H., Kimenju, S. C., Munyua, B., & Palapala, V. (2020). Spread and impact of the fall armyworm (Spodoptera frugiperda J. E. Smith) in maize in Kenya. *African Journal of Agricultural Research*, 15(3), 529-537. https://doi.org/10.5897/AJAR2020.14828

De Groote, H., Kimenju, S. C., Munyua, B., Palmas, S., Kassie, M., & Bruce, A. (2020). Spread and impact of the fall armyworm (Spodoptera frugiperda) in maize production areas of Kenya. *Agricultural Ecosystems & Environment*, 292, 106803.

De Groote, H., Overholt, W., Ouma, J. O., & Wanyama, J. (2004). Assessing the impact of Bt maize in Kenya using a dynamic simulation model. *Agricultural Systems*, 82(1), 27-47.

de Jong, M. V., Selten, M. P. H., Gitata-Kiriga, W., Peters, B., & Dengerink, J. D. (2024). An overview of the Kenyan food system: outcomes, drivers and activities.

Dejene, M. (2018). *Options for improving the yield and nutritive value of maize and grain legume residues for ruminants in East African farming systems* (Doctoral dissertation, University of Queensland).

Dhaliwal, S. S., Dubey, S. K., Kumar, D., Toor, A. S., Walia, S. S., Randhawa, M. K., ... & Shivey, Y. S. (2024). Enhanced Organic Carbon Triggers Transformations of Macronutrients, Micronutrients, and Secondary Plant Nutrients and Their Dynamics in the Soil under Different Cropping Systems-A Review. *Journal of Soil Science and Plant Nutrition*, 1-21.

Dotaniya, M. L., Datta, S. C., Biswas, D. R., & Meena, B. P. (2016). Role of soil enzymes in sustainable crop production. *Journal of Eco-friendly Agriculture*, 11(2), 71-85. Retrieved fromhttp://www.ecoagriculture.com.

Dukić, B., Marks, E., & Llenas, L. (2020). D6. 1 FERTIMANURE Plan for Exploitation and Dissemination of Results–1st version.

Duma, Y., & Sulendre, I. W. (2025, May). Dietary Crude Protein Requirement for the Growth of Young Donggala Bulls. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1502, No. 1, p. 012009). IOP Publishing.

Durán-Valle, C. J., & López-Coca, I. M. (2024). Biochemical and Thermochemical Conversion Technologies for Agriculture Waste Transformation. In *Transforming Agriculture Residues for Sustainable Development: From Waste to Wealth* (pp. 47-84). Cham: Springer Nature Switzerland.

Edmeades, G. O., Bänziger, M., & Ribaut, J. M. (2024). Maize improvement for drought-limited environments. In *Physiological bases for maize improvement* (pp. 75-111). CRC Press.

El-Syed, N. M., M. Helmy, A., Fouda, S. E., M. Nabil, M., Abdullah, T. A., K. Alhag, S., ... & Elrys, A. S. (2023). Biochar with Organic and Inorganic Fertilizers Improves Defenses, Nitrogen Use Efficiency, and Yield of Maize Plants Subjected to Water Deficit in an Alkaline Soil. *Sustainability*, *15*(16), 12223.

Emendu, E. R., Chinweuba, A. J., & Chinedu, O. (2021). Analysis of micro and macro nutrient levels in compost and vermicompost fertilizer formulated from selected agro-waste and comparative assessment of the fertilizer efficiencies. *Acta Scientific NUTRITIONAL HEALTH (ISSN: 2582-1423)*, *5*(2).

Erenstein, O., Jaleta, M., Sonder, K., Mottaleb, K., & Prasanna, B. M. (2022). Global maize production, consumption and trade: trends and R&D implications. *Food security*, *14*(5), 1295-1319

Essilfie, M. E., Darkwa, K., & Asamoah, V. (2024). Growth and yield response of maize to integrated nutrient management of chicken manure and inorganic fertilizer in different agroecological zones. *Heliyon*, *10*(14).

FAO. (2020). Maize: Production, consumption, and trade trends. Food and Agriculture Organization. Retrieved from https://www.fao.org.

FAO. (2024). FAOSTAT statistical database. Food and Agriculture Organization of the United Nations. https://www.fao.org/faostat/en/#data/QI

FAO: FAOSTAT Online Databas, Fao, (last access 9th June 2025) https://www.fao.org/faostat/en/#data/QCL

Farooq, M. S., Majeed, A., Ghazy, A. H., Fatima, H., Uzair, M., Ahmed, S., ... & Attia, K. A. (2024). Partial replacement of inorganic fertilizer with organic inputs for enhanced nitrogen use efficiency, grain yield, and decreased nitrogen losses under rice-based systems of mid-latitudes. *BMC Plant Biology*, *24*(1), 919

Fidelis, R. R., de Figueiredo, C. C., Oliveira, F. P., da Silva, E. R., & Pereira, L. F. (2020). Long-term impact of no-tillage on soil organic carbon and phosphorus distribution in a tropical agroecosystem. *Geoderma Regional*, 22, e00295.

Filipović, A., Perčin, A., Hadžiabulić, A., & Mandić, A. (2024). Transformation of organic matter and impact on the ecosystem. In *Agroforestry for Carbon and Ecosystem Management* (pp. 311-329). Academic Press.

Food and Agriculture Organization of the United Nations https://www.fao.org/faostat/en accessed on 4th January 2025.

Francaviglia, R., Almagro, M., & Vicente-Vicente, J. L. (2023). Conservation agriculture and soil organic carbon: Principles, processes, practices and policy options. *Soil Systems*, *7*(1), 17.

Francis, C. A., Rutger, J. N., & Palmer, A. F. E. (1969). A Rapid Method for Plant Leaf Area Estimation in Maize (Zea mays L.). Crop Science, 9(5), 537-539.

Fróna, D., Szenderák, J., & Harangi-Rákos, M. (2019). The challenge of feeding the world. *Sustainability*, *11*(20), 5816.

Gaikwad, V., Rautela, A., Kedare, G., Sarkar, S., Pal, R. P., & Sharma, A. (2024). Role of Flavoured Additives in Ruminant Production. In *Feed Additives and Supplements for Ruminants* (pp. 265-279). Singapore: Springer Nature Singapore.

Gao, X., Yang, Y., & Wang, L. (2020). *Effects of organic and inorganic phosphorus on soil phosphorus availability and plant growth*. Journal of Soil Science and Plant Nutrition, 20(4), 234-245.

Ghani, J., Nawab, J., Khan, S., Khan, M. A., Ahmad, I., Ali, H. M., ... & Dinelli, E. (2024). Organic amendments minimize the migration of potentially toxic elements in soil–plant system in degraded agricultural lands. *Biomass Conversion and Biorefinery*, *14*(5), 6547-6565.

Ghosh, A., Kumar, A., & Biswas, G. (2024). Exponential population growth and global food security: challenges and alternatives. In *Bioremediation of Emerging Contaminants from Soils* (pp. 1-20). Elsevier.

Ghosh, P. K., Mahanta, S. K., Ramesh, T., & Rao, A. S. (2018). Soil health and crop productivity improvement through integrated nutrient management in rice-rice cropping system of Assam. Journal of the Indian Society of Soil Science, 66(4), 365-374.

Ghosh, S., Roy, S., & Bhaduri, D. (2023). The influence of local environmental factors on maize cob yield. *Journal of Crop Improvement, 37*(2), 225-239. https://doi.org/10.1080/15427528.2023.2076937.

Goldan, E., Nedeff, V., Barsan, N., Culea, M., Panainte-Lehadus, M., Mosnegutu, E., ... & Irimia, O. (2023). Assessment of manure compost used as soil amendment—A review. *Processes*, *11*(4), 1167.

Govil, S., Long, N. V. D., Escribà-Gelonch, M., & Hessel, V. (2024). Controlled- release fertiliser: Recent developments and perspectives. *Industrial Crops and Products*, *219*, 1191

Gram, G., Roobroeck, D., Pypers, P., Six, J., Merckx, R., & Vanlauwe, B. (2020). Combining organic and mineral fertilizers as a climate-smart integrated soil fertility management practice in sub-Saharan Africa: A meta-analysis. *PloS one*, *15*(9), e0239552.

Gressel, J., Mbogo, P., Kanampiu, F., & Christou, P. (2024). Maize yields have stagnated in sub-Sahara Africa: a possible transgenic solution to weed, pathogen and insect constraints. Pest Management Science.60.

Gunaratne, H. D. A. K., Deniyapahala, D. V. R. I., & Kumari, M. G. A. D. (2024). The Impacts of Soil Quality Parameters on the Growth and Yield of Economical Crops. In *Responsible Production and Consumption* (pp. 181-188). CRC Press

Guo, L. B., & Gifford, R. M. (2002). Soil carbon stocks and land use change: A meta-analysis. *Global Change Biology*, *8*(3), 345-360.

Guo, Z., Liu, Y., Meng, X., Yang, X., Ma, C., Chai, H., ... & Han, Q. (2024). The long-term nitrogen fertilizer management strategy based on straw return can improve the productivity of wheat-maize rotation system and reduce carbon emissions by increasing soil carbon and nitrogen sequestration. *Field Crops Research*, *317*, 109561.

Harischandra, R., Premalal, G., & Wickramasinghe, H. (2015). Effect of Integrated Organic and Inorganic Fertilizers on Soil Chemical Properties, Yield and Fodder Quality of Sorghum (Sorghum bicolor L. Moench). In *Proceedings of 14th Agricultural Research Symposium* (Vol. 292, p. 296).

Hassan, M. M., Noman, A., & Imran, M. (2022). Influence of integrated nutrient management on fiber fractions and digestibility of fodder legumes. *Journal of Animal and Plant Sciences*, 32(3), 512–520.

Hatfield, J. L., & Prueger, J. H. (2015). Temperature extremes: Effect on plant growth and development. *Weather and climate extremes*, *10*(Part A), 4-10.

He, H., Peng, M., Hou, Z., & Li, J. (2024). Unlike chemical fertilizer reduction, organic fertilizer substitution increases soil organic carbon stock and soil fertility in wheat fields. *Journal of the Science of Food and Agriculture*, *104*(5), 2798-2808

Hermani, C. (2020). Regenerative Agriculture and the Quest for Sustainability- Inquiry of an Emerging Concept. *Humboldt University of Berlin*.

Hiranmai, R. Y., Neeraj, A., & Vats, P. (2024). Improvement of soil health and crop production through utilization of organic wastes: A sustainable approach. *International Journal of Recycling of Organic Waste in Agriculture*, *13*(1).

Hossain, F., Muthusamy, V., Bhat, J. S., Zunjare, R. U., Kumar, S., Prakash, N. R., & Mehta, B. K. (2022). Maize breeding. In *Fundamentals of Field Crop Breeding* (pp. 221-258). Singapore: Springer Nature Singapore.

Huang, L., Zhang, X., & Xu, Z. (2021). Altitude and its effects on maize leaf development and nutrient uptake. *Agricultural Sciences, 12*(2), 141-154. https://doi.org/10.4236/as.2021.122012.

Huang, Q. (2024). Enhancing soil health and biodiversity through nitrogen fixation symbiosis in leguminous plants. *Molecular Microbiology Research*, *14*.

IAEA. (2021). Global maize production: Constraints and challenges. International Atomic Energy Agency. Retrieved from https://www.iaea.org.

Ibrahim, A. A., Abd-Ellatif, S., Abdel Razik, E. S. S., & Salem, K. F. (2024). Biodiversity of Cereal Crops and Utilization in Food and Nutritional Security. In *Sustainable Utilization and Conservation of Plant Genetic Diversity* (pp. 31-61). Singapore: Springer Nature Singapore.

Imran. (2024). Integration of organic, inorganic and bio fertilizer, improve maize-wheat system productivity and soil nutrients. *Journal of Plant Nutrition*, 1-17.

Iqbal, A., Khan, M. H., & Bashir, A. (2017). Influence of integrated use of compost and nitrogen fertilizer on yield and yield components of maize. International Journal of Agronomy and Agricultural Research, 11(2), 51-59.

Jaetzold, R., Schmidt, H., Hornetz, B., & Shisanya, C. (2010). Farm Management Handbook of Kenya Vol. II: Natural Conditions and Farm Management Information. 2nd Edition. Ministry of Agriculture, Kenya.

Jaetzold, R., Schmidt, H., Hornetz, B., & Shisanya, C. (2012). Farm Management Handbook of Kenya Vol. II: Natural Conditions and Farm Management Information. 2nd Edition. Ministry of Agriculture, Kenya.

Jaffari, Z. H., Hong, J., & Park, K. Y. (2024). A systematic review of innovations in tannery solid waste treatment: A viable solution for the circular economy. *Science of The Total Environment*, 174848.

Jalal, F., Ahmed, S., Ashraf, M., & Ali, A. (2016). Integrated use of organic and inorganic fertilizers on yield and quality of maize (Zea mays L.). Journal of Environmental & Agricultural Sciences, 8, 16-21.

Jiang, M., Dong, C., Bian, W., Zhang, W., & Wang, Y. (2024). Effects of different fertilization practices on maize yield, soil nutrients, soil moisture, and water use efficiency in northern China based on a meta-analysis. *Scientific Reports*, *14*(1), 6480

Jin, N., Jin, L., Wang, S., Li, J., Liu, F., Liu, Z., ... & Yu, J. (2022). Reduced chemical fertilizer combined with bio-organic fertilizer affects the soil microbial community and yield and quality of lettuce. *Frontiers in Microbiology*, *13*, 863325.

Johnson, R. L., Anderson, P. M., & Greene, T. J. (2020). Variation in plant height response to fertilizer treatments: An overview. *Journal of Agricultural Science*, *158*(9), 1457-1466. https://doi.org/10.1017/S0021859620000721

Jones, C. A., & Jacobsen, J. S. (2019). Nitrogen in agriculture: A global overview. *Nutrient Cycling in Agroecosystems*, *114*(2), 139-150.

Jones, P., Brown, L., & Lee, D. (2020). Soil management practices affecting dry matter content in forages. *Forage Science*, *18*(2), 132-144. https://doi.org/10.1080/01904167.2020.1815912.

Kalamdhad, A. S., Khwairakpam, M., & Kazmi, A. A. (2012). Effects of Turning Frequency on Compost Stability and Maturity in a Rotary Drum Composter. International Journal of Recycling of Organic Waste in Agriculture, 1, 3.

Kalibata, A., Thangata, P., Mutyasira, V., Nhlengethwa, S., & Chirwa, P. W. (2024). Promoting Crop Productivity from Improved Soil Management in Smallholder Farming Systems: Policy Implications for Enhanced Soil Management in Africa. In *Trees in a Sub-Saharan Multi-functional Landscape: Research, Management, and Policy* (pp. 113-127). Cham: Springer Nature Switzerland.

KALRO (Kenya Agricultural and Livestock Research Organization). (n.d.). Foliar diseases in maize. Retrieved from https://www.kalro.org

Kamara, A. Y., Ekeleme, F., Omoigui, L. O., & Tegbaru, A. (2015). Weed control in cowpea cropping systems. Field Crops Research, 183, 93-105.

Kamara, A., Kamara, H. S., & Kamara, M. S. (2015). Effect of rice straw biochar on soil quality and the early growth and biomass yield of two rice varieties. *Agricultural Sciences*, *6*(08), 798.

Karimi, M., Sayfzadeh, S., Pazoki, A., Hadidi Masouleh, E., & Zakerin, H. R. (2025). Effects of bio-fertilizers and nitrogen levels on yield and quality of single-cross maize (KSC 704). *Journal of Plant Nutrition*, 1-17

Karimi, S., Raza, T., & Mechri, M. (2024). Composting and Vermitechnology in Organic Waste Management. In *Environmental Engineering and Waste Management: Recent Trends and Perspectives* (pp. 449-470). Cham: Springer Nature Switzerland.

Karnatam, K. S., Mythri, B., Un Nisa, W., Sharma, H., Meena, T. K., Rana, P., ... & Sandhu, S. (2023). Silage maize as a potent candidate for sustainable animal husbandry development perspectives and strategies for genetic enhancement. *Frontiers in Genetics*, *14*, 1150132. *Journal of Plant Nutrition*, 1-17.

Kasera, O. A., Osure, P. M., Oloo, B. C., Odhiambo, O. M., Salu, F. O., & Oguna, H. O. (2024). Disambiguating Maize Policy Failure in Kenya, 2013 - 2024: A Political Economy Perspective. *International Journal of Research and Innovation in Social Science*, *8*(7), 2581-2601.

Kaur, M., Singh, G., & Sharma, R. (2023). Effect of integrated nutrient management using vermicompost and inorganic fertilizers on maize growth and yield. *Journal of Plant Nutrition*, 46(1), 15-27.

Khalid, R., Ahmad, A., Hussain, I., & Farooq, M. (2023). Effect of nitrogen fertilization on growth, chlorophyll content and yield attributes of maize (Zea mays L.). Journal of Plant Nutrition, 46(3), 410–420. https://doi.org/10.1080/01904167.2022.2119957

Khan, A., Khan, S., Ali, I., Bashir, S., & Noor, S. (2018). Effect of different sources of nitrogen on maize growth and yield. Sarhad Journal of Agriculture, 34(2), 352-358.

Khan, J. A., & Kwot, O. (2024). The Role of Natural Organic Fertilizers on Soil Fertility Management and Crop Production in Ethiopia. *Agriculture Practices in Ethiopia: Present Scenario, Problems, Causes, and Solutions*, Khumla, N., Solomon, S., Manimekalai, R., & Misra, V. (2024). Prospects of Diversification for Sustainable Sugar Bioenergy Industries in ASEAN Countries. *Sugar Tech*, *26*(4), 951-971.

Kiboi, M. N., Ngetich, F. K., Mucheru-Muna, M. W., Diels, J., & Mugendi, D. N. (2021). Soil nutrients and crop yield response to conservation-effective management practices in the sub-humid highlands agro-ecologies of Kenya. *Heliyon*, *7*(6).

Kiehbadroudinezhad, M., Merabet, A., & Hosseinzadeh-Bandbafha, H. (2024). Landfill source of greenhouse gas emission. In *Advances and Technology Development in Greenhouse Gases: Emission, Capture and Conversion* (pp. 123- 145). Elsevier.

Kigara, M., Mugo, S., & Wekesa, E. (2016). Enhancing maize productivity through improved varieties and soil fertility management practices in Kenya. *African Journal of Agricultural Research*, 11(4), 249-256. https://doi.org/10.5897/AJAR2015.10607

Kihara, J., Bolo, P., Kinyua, M., Nyawira, S. S., & Sommer, R. (2020). Soil health and ecosystem services: Lessons from sub-Sahara Africa (SSA). *Geoderma*, *370*, 114342.

Kim, K. H., & Lee, B. M. (2023). Effects of climate change and drought tolerance on maize growth. *Plants*, *12*(20), 3548.

Kim, Y., Lee, J., & Park, S. (2019). Effect of phosphorus and organic matter on soil nitrogen availability in different soil types. *Soil Science Society of America Journal*, *83*(4), 1020-1031. https://doi.org/10.2136/sssaj2019.02.0076

Kimenju, S. C., De Groote, H., Karugia, J., Mugo, S., & Bergvinson, D. (2020). Consumer acceptance of Genetically Modified (GM) maize in Kenya: Factors influencing the purchase decision. *African Journal of Biotechnology*, 9(13), 1744-1750.

Kipkulei, H. K., Bellingrath-Kimura, S. D., Lana, M., Ghazaryan, G., Baatz, R., Matavel, C., ... & Sieber, S. (2024). Agronomic management response in maize (Zea mays L.) production across three agroecological zones of Kenya. *Agrosystems, Geosciences & Environment*, *7*(1), e20478.

Kiprop, C., Kirwa, L., Ngotho, E., Mwungu, C., Wanjau, A., Otieno, F., ... & Ghosh, A. (2024). Impact evaluation of shamba shape up weather and farming news on smallholder farmers in Kenya.

Kugedera, A. T., & Kokerai, L. K. (2024). A review on the effects of mineral fertilizer, manure and water management in improving sorghum grain yields in semi-arid areas. *Journal of Plant Nutrition*, *47*(7), 1175-1188.

Kumar, A., & Patel, M. (2021). Soil management and fertility practices influencing dry matter yield. *Soil & Tillage Research, 210*, 105-116. https://doi.org/10.1016/j.still.2021.105116

Kumar, S., Ansari, M. A., Choudhary, J., Ravisankar, N., Singh, R., & Mehta, P.(2024). Organic Farming: Long-Term Influence on Soil Health and Produce Quality. *Special issue on in commemoration of*, 1134.

Kung, L., Shaver, R. D., Grant, R. J., & Schmidt, R. J. (2018). Silage review: Interpretation of chemical, microbial, and organoleptic components of silages. Journal of Dairy Science, 101(5), 4020-4032.

Kuppusamy, S., Thavamani, P., Megharaj, M., Venkateswarlu, K., & Naidu, R. (2016). Agronomic and remedial benefits and risks of applying biochar to soil: Current knowledge and future research directions. *Environment International*, 87, 1-12. https://doi.org/10.1016/j.envint.2015.10.018

Kushal, G. E. R., Boraiah, B., & Sanjay, M. T. (2024). A review on challenges and emerging opportunities for weed management in organic agriculture. *Organization*, 70.

Lahori, A. H., Tunio, M., Ahmed, S. R., Mierzwa-Hersztek, M., Vambol, V., Afzal, A., ... & Muhammad, A. (2024). Role of pressmud compost for reducing toxic metals availability and improving plant growth in polluted soil: Challenges and recommendations. *Science of The Total Environment*, 175493.

Lal, R. (2015). Sequestering carbon and increasing productivity by conservation agriculture. *Journal of Soil and Water Conservation*, 70(3), 55A-62A. https://doi.org/10.2489/jswc.70.3.55A

Lal, R. (2019). Restoring soil quality to mitigate soil degradation. *Sustainable Agriculture Reviews, 14*, 15-33.

Lal, R., Rattan, L., & Stewart, B. A. (2021). Soil organic matter and soil health: a sustainability perspective. Advances in Soil Science: Soil Organic Matter in Sustainable Agriculture, CRC Press.

Lalthlansanga, C., Pottipati, S., Mohanty, B., & Kalamdhad, A. S. (2024). Role of cow dung and sawdust during the bioconversion of swine waste through the rotary drum composting process. *Environmental Monitoring and Assessment*, *196*(12), 1205.

Li, J., Li, H., Zhang, J., & Zhang, M. (2021). Nutrient dynamics and degradation of animal manure composts. *Waste Management, 120*, 414-423. https://doi.org/10.1016/j.wasman.2020.10.037

Li, X., & Li, Z. (2024). Global Trends and Current Advances in Slow/Controlled-Release Fertilizers: A Bibliometric Analysis from 1990 to 2023. *Agriculture*, *14*(9), 1502.

Li, Z., Liu, M., Wu, H., & Yang, W. (2018). Combined use of organic and inorganic fertilizers enhances soil organic carbon and microbial activity in wheat-maize cropping systems. Applied Soil Ecology, 129, 1-8.

Lima, F. S., Silva, R. R., & Andrade, G. C. (2021). Combined application of cattle manure and phosphorus fertilizer improves quality attributes of forage sorghum. *Brazilian Journal of Animal Science*, 50, e2020345. https://doi.org/10.1590/1806-9290-2020-345

Lima, F. S., Silva, R. R., & Andrade, G. C. (2021). Combined application of cattle manure and phosphorus fertilizer improves quality attributes and profitability of forage sorghum. *Brazilian Journal of Animal Science*, 50, e2020345. https://doi.org/10.1590/1806-9290-2020-345

Lobell, D. B., Schlenker, W., & Costa-Roberts, J. (2011). Climate trends and global crop production since 1980. *Science*, *333*(6042), 616-620.

Lu, W., Hao, Z., Ma, X., Gao, J., Fan, X., Guo, J., ... & Zhou, Y. (2024). Effects of different proportions of organic fertilizer replacing chemical fertilizer on soil nutrients and fertilizer utilization in gray desert soil. *Agronomy*, *14*(1), 228.

Ludemann, C. I., Wanner, N., Chivenge, P., Dobermann, A., Einarsson, R., Grassini, P., ... & Tubiello, F. N. (2024). A global FAOSTAT reference database of cropland nutrient budgets and nutrient use efficiency (1961–2020): nitrogen, phosphorus and potassium. *Earth System Science Data*, *16*(1), 525-541.

Mahurpawar, M. (2015). Effects of heavy metals on human health. International Journal of Research-Granthaalayah, 3(9), 1-7.

Major, J., Rondon, M., Molina, D., Riha, S. J., & Lehmann, J. (2017). Nutrient leaching in a Colombian savanna Oxisol amended with biochar. Journal of Environmental Quality, 39(2), 647-656.

Mandal, A., Patra, A. K., Singh, D., Swarup, A., & Masto, R. E. (2019). Effect of integrated nutrient management on soil organic carbon and its fractions and rice yield. Soil Science Society of America Journal, 73(2), 775-785.

Mandal, B., Singh, R., & Sharma, R. (2021). Phosphorus content and availability in composted plant residues. *Journal of Plant Nutrition and Soil Science, 184*(1), 42-51. https://doi.org/10.1002/jpln.202000306

Mandal, S., Singh, V. K., Chaudhary, D., Kaur, A., Kumar, R., Panwar, A., ... & Kaushik, P. (2023). From Grain to Gain: Revolutionizing Maize Nutrition.

Manea, E. E., Bumbac, C., Dinu, L. R., Bumbac, M., & Nicolescu, C. M. (2024). Composting as a sustainable solution for organic solid waste management: Current practices and potential improvements. *Sustainability*, *16*(15), 6329.

Mang'eni, F. O. (2022). Historical Analys of Declining Maize Production in Kenya; A Case of Trans-Nzoia County.

Manna, M. C., Swarup, A., Wanjari, R. H., Mishra, B., & Shahi, D. K. (2018). Long-term fertilization, manure and liming effects on soil organic matter and crop yields. Soil and Tillage Research, 158, 81-93.

Manorama, K., Behera, S. K., & Suresh, K. (2024). Oil Palm (Elaeis guineensis Jacq). In *Soil Health Management for Plantation Crops: Recent Advances and New Paradigms* (pp. 111-176). Singapore: Springer Nature Singapore.

Marschner, H. (2012). *Marschner's Mineral Nutrition of Higher Plants* (3rd ed.). Academic Press.

Mati, B. M., & Thomas, M. K. (2019). Overview of sugar industry in Kenya and prospects for production at the coast. *Agricultural Sciences*, *10*(11), 1477-1485.

MDiaz, P. (2016). Consequences of compost press mud as fertilizers. *DJ International Journal of Advances in Microbiology & Microbiological Research*, *1*(1

Meena, P. M., Aggarwal, R. K., Meena, R., & Rathore, M. S. (2024). Soil Contamination, Risk Assessment, and Remediation.

Meenakshi, T., Sahitya, S., & Ali, S. M. (2024). Assessing the Fodder Potentials of Drought-Tolerant Maize Hybrids in West Africa. *International Journal of Agronomy and Crop Science*, *1*(2), 10-20.

Meghana, M., & Shastri, Y. (2020). Sustainable valorization of sugar industry waste: Status, opportunities, and challenges. *Bioresource technology*, *303*, 122929.

Mekonnen, T., Getachew, A., & Daba, S. (2020). Organic and inorganic fertilizer effects on nutritional quality of grass-legume mixtures. *African Journal of Range & Forage Science*, 37(1), 45–53.

Meng, L., Liu, X., Shi, Y., Wu, J., & Xu, G. (2013). Effects of Aeration on Composting Efficiency and Microbial Community Dynamics. Journal of Environmental Management, 123, 45-54.

Meng, L., Liu, X., Shi, Y., Wu, J., & Xu, G. (2013). Effects of Aeration on Composting Efficiency and Microbial Community Dynamics. Journal of Environmental Management, 123, 45-54.

Meng, X., Liang, X., Wang, P., & Ren, L. (2024). Effect of thermophilic bacterial complex agents on synergistic humification of carbon and nitrogen during lignocellulose-rich kitchen waste composting. *Journal of Environmental Management*, *370*, 122799.

Mertens, D. R., & Grant, R. J. (2020). Digestibility and intake. *Forages: the science of grassland agriculture*, *2*, 609-631.

Miller, A. R., Smith, J. K., & Zhang, Y. T. (2020). Effects of organic amendments on soil pH and nutrient availability. *Journal of Soil Science*, *35*(2), 123-135. https://doi.org/10.1016/j.jss.2020.03.005

Miller, R. H. (2000). Using organic amendments to restore soil fertility in degraded lands. *Journal of Soil and Water Conservation*, 55(4), 449-454. Retrieved from http://www.jswconline.org

Miller, R. J., Brown, C. A., & Williams, H. D. (2022). Altitude and temperature effects on leaf number and maize growth. *Crop Science*, *62*(5), 1153-1162. https://doi.org/10.1002/csc2.20621

Mohammad, A., Alam, T., Kabbashi, N., & Ahsan, A. (2012). Temperature Control in Composting Process: A Key to Sustainable Decomposition. International Journal of Environmental Science and Development, 3(1), 36-40.

Mohammad, A., Alam, T., Kabbashi, N., & Ahsan, A. (2012). Temperature Control in Composting Process: A Key to Sustainable Decomposition. International Journal of Environmental Science and Development, 3(1), 36-40.

Mucheru-Muna, M., Mugendi, D., Kung'u, J., & Mugwe, J. (2014). Effects of organic and inorganic nutrient sources on soil mineral nitrogen and maize yields in central Kenya. Soil Science and Plant Nutrition, 53(3), 141-148.

Mulla, D. J. (2013). Twenty-five years of remote sensing in precision agriculture: Key advances and remaining knowledge gaps. Biosystems Engineering, 114(4), 358-371.

Munialo, S., Dahlin, A. S., Onyango M, C., Oluoch-Kosura, W., Marstorp, H., & Öborn, I. (2020). Soil and management-related factors contributing to maize yield gaps in western Kenya. *Food and Energy Security*, *9*(1), e189.

Mupambwa, H. A., & Wakindiki, I. I. C. (2019). Optimizing the combined application of organic and inorganic fertilizers for improved maize grain yield and nutrient use efficiency in a sandy soil. Archives of Agronomy and Soil Science, 65(9), 1173-1186.

Musa, I. O., Samuel, J. O., Adams, M., Abdulsalam, M., Nathaniel, V., Maude, A. M., ... & Tiamiyu, A. G. T. (2024). Soil Erosion, Mineral Depletion and Regeneration. In *Prospects for Soil Regeneration and Its Impact on Environmental Protection* (pp. 159-172). Cham: Springer Nature Switzerland.

Mutegi, C., Hendriks, S. L., Jones, R. B., Okori, P., & Siambi, M. (2015). Role of legumes in reduction of aflatoxin risk in maize-based food systems in sub-Saharan Africa. *Journal of Plant Pathology & Microbiology*, 6(7), 1-7.

Mutuku, E. A., Roobroeck, D., Vanlauwe, B., Boeckx, P., & Cornelis, W. M. (2020). Maize production under combined Conservation Agriculture and Integrated Soil Fertility Management in the sub-humid and semi-arid regions of Kenya. *Field Crops Research*, *254*, 107833.

Narayan, M. A. Y. (2024). *Biochemical Evaluation Of Some Promising Quality Protein Maize Genotypes* (Doctoral Dissertation, Mahatma Phule Krishi Vidyapeeth).

Nasar, J., Ahmad, M., Gitari, H., Tang, L., Chen, Y., & Zhou, X. B. (2024). Maize/soybean intercropping increases nutrient uptake, crop yield and modifies soil physio-chemical characteristics and enzymatic activities in the subtropical humid region based in Southwest China. *BMC Plant Biology*, *24*(1), 434.

Nath, A., Bhuyan, P., Gogoi, N., & Deka, P. (2023). Pesticides and Chemical Fertilizers: Role in Soil Degradation, Groundwater Contamination, and Human Health. In *Xenobiotics in Urban Ecosystems: Sources, Distribution and* *Health Impacts* (pp. 131-160). Cham: Springer International Publishing

National Accelerated Agricultural Inputs Access Program (NAAIAP). (2014). Soil suitability evaluation for maize production in Kenya

Nayan P Chapane, Shridhar P Saptale and Shriganesh R Shelke. Effect of organic raw and treated press mud with inorganic fertilizers NPK on maize (*Zea mays*) plant. Int. J. Adv. Chem. Res. 2022;4(2):318-322. DOI: 10.33545/26646781.2022.v4.i2e.116

Nazli, M. H., Nisa, M. U., Sarwar, M., Khan, M. A., & Lee, W. S. (2016). Effect of Varying Levels of Energy and Protein on Nutrient Digestibility, Milk Production, and Composition in Early Lactating Nili Ravi Buffaloes. Asian-Australasian Journal of Animal Sciences, 29(10), 1421-1427.

Ndegwa, J. K., Gichimu, B. M., Mugwe, J. N., Mucheru-Muna, M., & Njiru, D. M. (2023). Integrated soil fertility and water management practices for enhanced agricultural productivity. *International Journal of Agronomy*, *2023*(1), 8890794.

Nguyen, T., O’Connor, T., & Zhang, H. (2022). The role of environmental conditions in maximizing dry matter yield. *Journal of Soil Science and Plant Nutrition, 22*(4), 789-801. https://doi.org/10.1007/s42729-022-00578-x

Njagi, T., Riungu, C., Opiyo, J., Mwadime, R. K., & Aloo, S. Y. (2024). Assessment of the impact of the Kenya Government fertilizer subsidy on the performance of domestic private sector fertilizer trade.

Njoroge, R., Otinga, A. N., Okalebo, J. R., Pepela, M., & Merckx, R. (2018). Maize (Zea mays L.) response to secondary and micronutrients for profitable N, P and K fertilizer use in poorly responsive soils. *Agronomy, 8*(4), 49.

Norman, H. C., & Masters, D. G. (2023). Livestock preference and feeding value as key determinants for forage improvement–why not ask the consumers. *Animal Production Science*, *63*(12), 1161-1176.

NRC (National Research Council). (2001). Nutrient Requirements of Dairy Cattle: Seventh Revised Edition, 2001. Washington, DC: The National Academies Press.

Nyonje, E. O., Njogu, P., & Kinyua, R. (2014). Assessment of the potential for utilization of sugarcane derived press mud for biogas generation in South Nyanza sugarcane zones, Kenya. *Journal of Sustainable Research in Engineering*, *1*(4), 30-33.

Nzaka, P. M., Koech, G. J., Bett, H., & Owuor, G. (2024). Tradeoffs Between Maize mportation and Reliance on Local Production: A Case of Commercial Maize Millers in Kenya. *International Journal of Agricultural Economics*, *13*(2), 173-184.

Nziguheba, G., Palm, C. A., Berhe, T., Denning, G., Dicko, A., Flor, R., ... & Sachs, J. (2016). The African green revolution: results from the Millennium Villages Project. Advances in Agronomy, 109, 75-115.

Ogunleye, A., Akinloye, M. O., Kehinde, A., Ajayi, O. M., & Wongnaa, C. A. (2024). Impacts of credit constraints on adoption of risk management strategies and income of maize farmers in Northern Nigeria. *Agricultural Finance Review*.

Okalebo, J. R., Gathua, K. W., & Woomer, P. L. (2002). Laboratory Methods of Soil and Plant Analysis: A Working Manual (2nd Edition). Nairobi: TSBF-CIAT and SACRED Africa.

Okalebo, J. R., Othieno, C. O., Woomer, P. L., Karanja, N. K., Semoka, J. R. M., Bekunda, M. A., ... & Mukhwana, E. J. (2002). Available technologies to replenish soil fertility in East Africa. *Nutrient Cycling in Agroecosystems*, 72(2), 101-119. https://doi.org/10.1023/A:1015863810650.

Oldfield, E. E., Bradford, M. A., & Wood, S. A. (2019). Global meta-analysis of the relationship between soil organic matter and crop yields. *Soil*, *5*(1), 15-32.

Omondi, P., Aila, F., Ombok, B., Obange, N., & Dida, M. (2024). Socioeconomic and Environmental Impacts of the Fall Armyworm and The Striga Weed at Three Stages of the Maize (Corn) Value Chains in Kenya: A Review 2024.

Otieno, E. O. (2024). *Effects of Integrated Soil Fertility Management on Soil Microbial Biomass, Nitrogen Mineralization, Phosphorus Dynamics, and Maize Productivity in Humic Nitisols of Kenya* (Doctoral dissertation, JKUAT- CoANRE).

Otieno, H. M. (2021). A review of the current state of soil infertility and management options in Kenya: The case of maize growing regions. *International Journal of Innovative Approaches in Agricultural Research, 5*(2), 241-256.

Padmavathy, A., & Poyyamoli, G. (2011). Alternative farming techniques for sustainable food production. Sustainable Agriculture Research, 1(2), 1-15.

Pahalvi, H. N., Rafiya, L., Rashid, S., Nisar, B., & Kamili, A. N. (2021). Chemical fertilizers and their impact on soil health. *Microbiota and Biofertilizers, Vol 2: Ecofriendly tools for reclamation of degraded soil environs*, 1-20.

Palamarchuk, V., Krychkovskyi, V., & Skakun, M. (2024). Study of the efficiency of growing maize for silage for processing into biogas and digestate. *Scientific Horizons. 2024. Vol. 27, № 1. P. 54-61. DOI: 10.48077/scihor1. 2024.54*.

Palanichamy, M., Kuppusamy, H., Suresha, G. S., & Prakash, P. (2024). Economics of Sugarcane Value Chain and Policy Capsules on Value-Added Products. In *Value Addition and Product Diversification in Sugarcane* (pp. 257-268). Springer, Singapore.

Panday, D., Bhusal, N., Das, S., & Ghalehgolabbehbahani, A. (2024). Rooted in nature: The rise, challenges, and potential of organic farming and fertilizers in agroecosystems. *Sustainability, 16*(4), 1530.

Patel, D. M., Thakur, D. R., & Yadav, M. R. (2023). Response of pressmud and chemical fertilizers on quality of hybrid Napier. *International Journal of Agriculture Sciences*, 15(5), 100–106.

Paul, P. (2014). Compost Moisture Management: Optimal Levels and Adjustment Techniques. Journal of Sustainable Agriculture, 29(4), 178-185.

Penuelas, J., Coello, F., & Sardans, J. (2023). A better use of fertilizers is needed for global food security and environmental sustainability. *Agriculture & Food Security*, *12*(1), 1-9.

Penumantra, A., Shirbhate, N. S., Tiwari, P. S., & Narkhede, S. (2024). *The Impact of Environmental Pollution on Human Health*. Academic Guru Publishing House.

Purewal, S. S., Kaur, P., Sandhu, K. S., Bangar, S. P., Siroha, A. K., Singh, S. K., ... & Markandey, D. K. (2022). Nutritional profile of maize and effect of processing methods. In *Maize* (pp. 77-100). CRC Press.

Qiao, Y., Miao, S., Han, X., Li, W., Jiang, C., & Zhao, M. (2018). Influence of long-term organic and inorganic fertilizer applications on the distribution of phosphorus in fractions of soil. Geoderma, 331, 48-56.

Radulov, I., & Berbecea, A. (2024). Nutrient Management for Sustainable Soil Fertility.

Rahman, M. M., Khan, M. S., & Ali, M. N. (2023). Fertilizer types and their impact on leaf number: A comparative study. *Journal of Crop Improvement, 37*(4), 495-510. https://doi.org/10.1080/15427528.2023.2241613.

Rana, A. W., Gill, S., & Akram, I. (2024). *Pakistan: A cost-benefit analysis of crop rotation practice in rainfed areas*. Intl Food Policy Res Inst.

Rangasami, S. S., Purnima, M., Pushpam, R., & Ajaykumar, R. (2024). Enhancing Animal Nutritional Security Through Biofortification in Forage Crops: A Comprehensive Review. *Indian Journal of Animal Research*, *1*, 8.

Rath, D., Dash, D., Behera, S. K., & Nayak, A. K. (2022). *Utilization of pressmud as organic amendment to improve phosphorus availability and crop productivity*. Journal of Environmental Management, 310, 114751. https://doi.org/10.1016/j.jenvman.2022.114751

Ray, S., & Majumder, S. (2024). Water management in agriculture: Innovations for efficient irrigation. *Modern Agronomy; Sil, P., Chhetri, P., Majumder, S., Santosh, DT, Eds*, 169-185.

Reddy, K. R., Ghosh, S., & Sarma, A. (2020). Potassium dynamics in composted manures. *Journal of Environmental Quality, 49*(2), 320-328. https://doi.org/10.2134/jeq2019.12.0470

Reganold, J. P., & Wachter, J. M. (2016). Organic agriculture in the twenty-first century. *Nature plants*, *2*(2), 1-8.

Revilla, I., Plaza, J., & Palacios, C. (2021). The effect of grazing level and ageing time on the physicochemical and sensory characteristics of beef meat in organic and conventional production. *Animals*, *11*(3), 635.

Rizwan, H. M., Naveed, M., Sajid, M. S., Nazish, N., Younus, M., Raza, M., ... & Ataya, F. S. (2024). Enhancing agricultural sustainability through optimization of the slaughterhouse sludge compost for elimination of parasites and coliforms. *Scientific Reports*, *14*(1), 23953.

Roobroeck, D., Palm, C. A., Nziguheba, G., Weil, R., & Vanlauwe, B. (2021). Assessing and understanding non-responsiveness of maize and soybean to fertilizer applications in African smallholder farms. *Agriculture, ecosystems & environment*, *305*, 107165.

Ruan, R., Zhang, P., Lambers, H., Xie, W., Zhang, Z., Xie, S., ... & Wang, Y. (2024). Biochar application improves maize yield on the Loess Plateau of China by changing soil pore structure and enhancing root growth. *Science of The Total Environment*, *956*, 177379.

Saik, P., Koshkalda, I., Bezuhla, L., Stoiko, N., & Riasnianska, A. (2024). Achieving land degradation neutrality: land-use planning and ecosystem approach. *Frontiers in Environmental Science*, *12*, 1446056.

Sajid, U., Aslam, S., Hussain, A., Mumtaz, T., & Kousar, S. (2024). Pressmud Compost for Improved Nitrogen and Phosphorus Content Employing Bacillus Strains. *Recycling*, *9*(6), 104.

Samuel, O., Abigael, N., Ruth, M., & Ernst, W. (2019). Evaluation of Organic and Inorganic Fertilizers on the Growth and Yield of Maize. International Journal of Agronomy, 2019, 1-8.

Sanginga, N., & Woomer, P. L. (2016). Integrated soil fertility management in Africa: Principles, practices, and developmental process. Tropical Soil Biology and Fertility Institute of CIAT, Nairobi.

Santos, A. P., Oliveira, C. R., & Lemos, G. M. (2021). *Integration of organic and inorganic phosphorus fertilization for sustainable crop production*. Agricultural Systems, 191, 103099.

Santos, D., Monteiro, M. J., Voss, H. P., Komora, N., Teixeira, P., & Pintado, M. (2021). The most important attributes of beef sensory quality and production variables that can affect it: A review. *Livestock Science*, *250*, 104573.

Sarkar, S., Jaswal, A., & Singh, A. (2024). Sources of inorganic nonmetallic contaminants (synthetic fertilizers, pesticides) in agricultural soil and their impacts on the adjacent ecosystems. In *Bioremediation of Emerging Contaminants from Soils* (pp. 135-161). Elsevier.

Selvamurugan, M., Doraisamy, P., & Maheswari, M. (2013). Biomethanated distillery spentwash and pressmud biocompost as sources of plant nutrients for groundnut (Arachis hypogaea L.). *Journal of Applied and Natural Science*, *5*(2), 328-334.

Seufert, V., & Ramankutty, N. (2017). Many shades of gray—The context-dependent performance of organic agriculture. *Science advances*, *3*(3), e1602638.

Shafi, M., Bakht, J., Khan, M. J., Khan, M. A., & Raziuddin. (2016). Integrated use of organic and inorganic nitrogen sources improves maize yield, protein and nitrogen uptake. Pakistan Journal of Botany, 38(5), 1353-1358.

Shankaraiah, C., & Murthy, I. Y. L. N. (2005). Integrated use of pressmud and inorganic fertilizers in sugarcane (Saccharum officinarum) production. Indian Journal of Agronomy, 50(3), 201-203.

Sharma, N., Kumar, A., Farooq, F., MeCarty, J. S., Kumar, R., Sharma, V., ... & Mehta, S. Nutrient Management Strategies for Enhancing Maize Productivity in India: An Overview.

Sharma, V., & Subehia, S. K. (2020). Combined use of vermicompost and inorganic fertilizers for improving soil health and crop productivity. Journal of Plant Nutrition and Soil Science, 183(3), 361-370.

Sher, A., Adnan, M., Sattar, A., Ul-Allah, S., Ijaz, M., Hassan, M. U., ... & El Askary, A. (2022). Combined application of organic and inorganic amendments improved the yield and nutritional quality of forage sorghum. *Agronomy*, *12*(4), 896.

Sher, A., Nawaz, M., Hasnain, Z., Mehmood, K., Chattha, M. B., Ijaz, M., ... & Khan, S. (2022). Impact of press mud and animal manure in comparison with NPK on the growth and yield of triticale (Triticosecale wittmack) genotypes cultivated under various irrigation regimes. *Agronomy*, *12*(12), 2944.

Shilwatso, H., Simiyu, E. J., & Rutto, R. K. (2024). Effect of Inflation on Kenya’s Maize Production and Food Security. *African Journal of Empirical Research*, *5*(2), 529-541.

Silva, J. C., Castro, C. A., & Santos, A. R. (2023). *Sustainable phosphorus management*

Sime, M., Ballo, S., Abro, Z., Gugissa, D. A., Mendesil, E., & Tefera, T. (2024). Farmers' Perceptions of Maize Production Constraints and the Effects of Push–Pull Technology on Soil Fertility, Pest Infestation, and Maize Yield in Southwest Ethiopia. *Agriculture, 14*(3), 381.

Singh, N. K., Sachan, K., BP, M., Panotra, N., & Katiyar, D. (2024). Building Soil Health and Fertility through Organic Amendments and Practices: A Review. *Asian Journal of Soil Science and Plant Nutrition*, *10*(1), 175-197

Singh, R. P., Prasad, P. V., Reddy, K. R., & Kambiranda, D. M. (2018). Biofertilizers in agriculture. In M. R. A. Khan (Ed.), *Microbial strategies for crop improvement* (pp. 153-170). Springer.

Singh, R. S., Kumar, A., & Patel, A. (2023). Nutrient ratios and their effect on stem girth in maize: A field study. *Soil Science and Plant Nutrition, 69*(2), 215-224. https://doi.org/10.1080/00380768.2023.2218537

Singh, R., Kumar, A., & Verma, A. (2019). *Organic amendments and their effect on soil carbon sequestration*. *Soil & Tillage Research, 191*, 181-190. https://doi.org/10.1016/j.still.2019.03.001

Singh, R., Sharma, R., & Kumar, P. (2020). Enhancing soil nitrogen through phosphorus and organic amendments: A meta-analysis. *Nutrient Cycling in Agroecosystems, 117*(3), 335-347. https://doi.org/10.1007/s10705-020-10052-1

Singh, S. R., Singh, R. K., & Rao, V. U. M. (2013). Integrated use of organic and inorganic fertilizers for improved soil health and crop productivity in sugarcane. Sugar Tech, 15(4), 366-374.

Singh, S., Sharma, A., & Raj, A. (2020). Role of phosphorus fertilization in forage crops: A review. *International Journal of Current Microbiology and Applied Sciences*, 9(10), 1235–1242. https://doi.org/10.20546/ijcmas.2020.910.147

Singh, S., Sharma, A., & Raj, A. (2020). Role of phosphorus fertilization in cereal crops: A review. *International Journal of Current Microbiology and Applied Sciences*, 9(10), 1235–1242. https://doi.org/10.20546/ijcmas.2020.910.147

Singh, V. K., Malhi, G. S., Kaur, M., Singh, G., & Jatav, H. S. (2022). Use of organic soil amendments for improving soil ecosystem health and crop productivity. *Ecosystem Services*.

Smith, J., Thompson, L., & Brown, K. (2019). The role of organic amendments in soil nutrient management. *Agronomy Journal*, *111*(5), 2103-2115. https://doi.org/10.2134/agronj2019.03.0170

Smith, J., White, E., & Lewis, B. (2022). The effects of altitude and soil composition on crop yields. *Journal of Agricultural Science*, *161*(5), 852-862. https://doi.org/10.1017/S0021859622000278

Smith, L. D., Brown, C. T., & Wang, Q. (2018). Soil buffering capacity and the impact of short-term amendments. *Agricultural Research Journal*, *28*(4), 245-257. https://doi.org/10.1016/j.agrres.2018.05.002

Solomon, W. G., Ndana, R. W., & Abdulrahim, Y. (2012). The comparative study of the effect of organic manure cow dung and inorganic fertilizer NPK on the growth rate of maize (Zea mays L.).

Srivastav, A. L., Patel, N., Rani, L., Kumar, P., Dutt, I., Maddodi, B. S., & Chaudhary, V. K. (2024). Sustainable options for fertilizer management in agriculture to prevent water contamination: a review. *Environment, Development and Sustainability*, *26*(4), 8303-8327.

Srivastava, A. N., & Chakma, S. (2023). Assessment of in situ stabilization and heavy metal toxicity reduction of sugar mill pressmud through pilot scale composting. *Environmental Monitoring and Assessment*, *195*(8), 951

Sun, J., Gao, Y., Wang, L., Hu, L., Zhang, X., Bao, Y., & Fan, X. (2019). Assessment of Maize Leaf Area and Yield Response to Tillage and Mulching Practices Under Rain-fed Conditions. Agricultural Water Management, 213, 783-791,

Szogi, A. A., Vanotti, M. B., & Ro, K. S. (2015). Methods for treatment of animal manures to reduce nutrient pollution prior to soil application. *Current Pollution Reports*, *1*, 47-56.

Tang, X., Ma, Y., Hao, X. *et al*. Determining critical values of soil Olsen-P for maize and winter wheat from long-term experiments in China. Plant Soil 323, 143–151 (2009). https://doi.org/10.1007/s11104-009-9919-y

Tefera, M. L., Carletti, A., Altea, L., Rizzu, M., Migheli, Q., & Seddaiu, G. (2024). Land degradation and the upper hand of sustainable agricultural intensification in sub-Saharan Africa-A systematic review.

Teketel, S. A. (2024). Soil acidifying effects of synthetically produced fertilizer application in high rainfall areas of Northwestern Ethiopia. *Food Agricultural Sciences and Technology*, *10*(3), 20-32

Tiema, C., Ochung, A., & Omwoma, S. Sugarcane Production in Kenya.

Tiema, C., Ochung, A., & Omwoma, S. Sugarcane Production in Kenya.

Toor, G. S., Yang, Y. Y., Das, S., Dorsey, S., & Felton, G. (2021). Soil health in agricultural ecosystems: current status and future perspectives. *Advances in Agronomy*, *168*, 157-201.

Toromade, A. S., Soyombo, D. A., Kupa, E., & Ijomah, T. I. (2024). Reviewing the impact of climate change on global food security: Challenges and solutions. *International Journal of Applied Research in Social Sciences*, *6*(7), 1403-1416

Vallebueno-Estrada, M., Hernández-Robles, G. G., González-Orozco, E., López-Valdivia, I., Tham, T. R., Sánchez, V. V., ... & Montiel, R. (2023). Domestication and lowland adaptation of coastal preceramic maize from Paredones, Peru. *Elife*, *12*, e83149.

Van Soest, P. J. (1994). *Nutritional Ecology of the Ruminant* (2nd ed.). Ithaca, NY: Cornell University Press.

Vanlauwe, B., Bationo, A., Chianu, J., Giller, K. E., Merckx, R., Mokwunye, U., ... & Sanginga, N. (2006). Integrated soil fertility management in sub-Saharan Africa: Unravelling local adaptation. *Advances in Agronomy*, 94, 197-254.

Verma, B. C., Pramanik, P., & Bhaduri, D. (2020). Organic fertilizers for sustainable soil and environmental management. *Nutrient dynamics for sustainable crop production*, 289-313.

Verma, S., Pradhan, S. S., Singh, A., & Kushuwaha, M. (2024). Effect of Organic Manure on Different Soil Properties: A Review. *International Journal of Plant & Soil Science, 36*(5), 182-187.

Verma, S., Singh, S., & Yadav, S. (2022). *Influence of altitude on soil organic carbon dynamics and its management*. *Soil Science Society of America Journal, 86*(4), 1125-1136. https://doi.org/10.1002/saj2.20476

Vučkovski, B. G., & Marina, I. (2024). Descriptive Analysis of Maize Characteristics. In *Marketing and Resource Management for Green Transitions in Economies* (pp. 291-316). IGI Global

Wabela, R., Abera, G., Lemma, B., & Gobena, A. (2024). Effects of integrated fertilizer application on selected soil properties and yield attributes of common bean (Phaseolus vulgaris L.) on different soil types. *Heliyon*, *10*(19).

Walia, S. S., & Kaur, K. (2019). Integrated nutrient management in maize (Zea mays L.) through combined application of inorganic fertilizers, FYM, and green manuring for sustainable agriculture. Journal of Plant Nutrition, 42(10), 1177-1189.

Wamalwa, S. W. (2024). *Integrated Soil Fertility Management Practices Effects on Soil Chemical Properties and Maize (Zea* (Doctoral dissertation, Kenyatta University).

Wang, H., Yang, Y., Yao, C., Feng, Y., Wang, H., Kong, Y., ... & Deng, G. (2024). The correct combination and balance of macronutrients nitrogen, phosphorus and potassium promote plant yield and quality through enzymatic and antioxidant activities in potato. *Journal of Plant Growth Regulation*, 1-19.

Wang, J., Yan, D., Xu, Y., Wang, Y., & Hu, H. (2020). Effects of long-term organic and inorganic fertilization on soil organic carbon and total nitrogen in a reclaimed farmland soil in China. Sustainability, 12(4), 1563.

Wang, J., Yang, X., Huang, S., Wu, L., Cai, Z., & Xu, M. (2024). Long-term combined application of organic and inorganic fertilizers increases crop yield sustainability by improving soil fertility in maize-wheat cropping systems1. *Journal of Integrative Agriculture*.

Wang, L., Feng, Z., Wang, Z., Wang, Y., & Wang, Z. (2024). Aerobic composting characteristics of corn straw and pig manure under dynamic aeration. *Environmental Technology*, 1-10.

Wang, Y., Li, W., & Zhang, Q. (2021). Altitude and soil weathering effects on potassium dynamics in agricultural soils. *Geoderma, 401*, 115289. https://doi.org/10.1016/j.geoderma.2021.115289.

Wanyama, D., Mighty, M., Sim, S., & Koti, F. (2021). A spatial assessment of land suitability for maize farming in Kenya. *Geocarto International*, *36*(12), 1378-1395.

Wato, T., Negash, T., Andualem, A., & Bitew, A. (2024). Significance of organic and inorganic fertilizers in maintaining soil fertility and increasing crop productivity in Ethiopia: a review. *Environmental Research Communications*, *6*(10), 102002

Wei, X., Xie, B., Wan, C., Song, R., Zhong, W., Xin, S., & Song, K. (2024). Enhancing soil health and plant growth through microbial fertilizers: Mechanisms, benefits, and sustainable agricultural practices. *Agronomy*, *14*(3), 609.

Wei, Z., Xie, X., Xue, M., Valencak, T. G., Liu, J., & Sun, H. (2021). The effects of non-fiber carbohydrate content and forage type on rumen microbiome of dairy cows. *Animals*, *11*(12), 3519.

Weiss, W. P. (2019). Energy prediction equations for ruminant feeds. In Nutrient Requirements of Dairy Cattle (pp. 177-202). National Academies Press.

Were, M. A. (2021). *A Critical Analysis of Food Security and Policy in Eastern Africa: The Case Study of the Maize Sub-Sector in Kenya* (Doctoral dissertation, University of Nairobi).

Wu, Q., Chen, Y., Dou, X., Liao, D., Li, K., An, C., ... & Dong, Z. (2024). Microbial fertilizers improve soil quality and crop yield in coastal saline soils by regulating soil bacterial and fungal community structure. *Science of The Total Environment*, *949*, 175127.

Xing, Y., Zhang, X., & Wang, X. (2024). Enhancing soil health and crop yields through water-fertilizer coupling technology. *Frontiers in Sustainable Food Systems*, *8*, 1494819.

Xu, H., Mustafa, A., Saeed, Q., Jiang, G., Sun, N., Liu, K., ... & Xu, M. (2025). Combined application of chemical and organic fertilizers enhances soil organic carbon sequestration and crop productivity by improving carbon stability and management index in a rice–rice cropping system. *Chemical and Biological Technologies in Agriculture*, Xu, Q., Yao, Z., Chen, Y., Liu, N., Teng, Z., Huang, D., ... & Gao, Y. (2024). Priming and balance of soil organic carbon differ with additive C: N ratios and long- term green manuring. *Applied Soil Ecology*, *201*, 105495.

Yadav, R. K., Kumar, P., & Singh, S. (2024). Impact of reduced chemical fertilizer and farmyard manure on growth and yield of maize. *Agriculture, Ecosystems & Environment*, 357, 108-118.

Yadav, R. S., Yadav, M. P., & Tomar, R. K. (2021). Effect of integrated nutrient management on quality parameters of forage sorghum. *Forage Research*, 46(4), 345–350.

Yan, X., Chang, C., Chen, W., Jia, S., & Shen, Z. (2020). Effects of integrated nutrient management on nitrate leaching and greenhouse gas emissions in maize cropping system. Agricultural Water Management, 240, 106283.

Yang, J., Zhang, J., Du, X., Gao, T., Cheng, Z., Fu, W., & Wang, S. (2024). Ammonia inhibition in anaerobic digestion of organic waste: a review. *International Journal of Environmental Science and Technology*, 1-16.

Yemata, G., & Mengistu, E. (2024). Potential of cattle urine as an alternative fertilizer for maize (Zea mays L.) production in Ethiopia. *Heliyon*, *10*(22). Yield and Nutrient Use Efficiency in Wheat–Maize–Sunflower Rotations System in Northwest China. *Plants*, *13*(10), 1358.

Yokamo, S., Jiao, X., Gurmu, F., Atinafu, A., Alemu, T., & Jiang, R. (2022). Maize production constraints at household levels: The case of Hawassa Zuria district in Sidama Region, Ethiopia. *African Journal of Agricultural Research*, *18*(5),295-307.

Zhang, H., & Liu, X. (2021). The role of organic and inorganic fertilizers in improving stem girth and plant health. *Plant and Soil, 460*(1-2), 39-50. https://doi.org/10.1007/s11104-021-04901-2

Zhang, J., Guerrero, A., & Mouazen, A. M. (2022). Simulation of variable-rate manure application under different application scenarios. *Soil and Tillage Research*, *221*, 105416.

Zhang, L., Garcia, A. R., & Davis, P. E. (2022). Stability of soil pH across various fertilizer treatments: A comparative study. *International Journal of Soil Science*, *29*(3), 345-360. https://doi.org/10.1016/j.ijss.2022.06.011

Zhang, L., Li, X., & Zhang, Y. (2022). Influence of soil properties and environmental factors on phosphorus amendment effectiveness. *Agricultural Systems*, *190*, 103135. https://doi.org/10.1016/j.agsy.2021.103135

Zhang, L., Liu, S., & Zhang, Y. (2022). Soil nutrient dynamics at different altitudes: Implications for phosphorus amendments. *Soil Science Society of America Journal*, *86*(1), 172-182. https://doi.org/10.1002/saj2.20315

Zhang, Q., & Wang, J. (2023). Organic and synthetic fertilizers: Their impact on Acid Detergent Lignin content. *Agronomy for Sustainable Development*, *43*(1), 32. https://doi.org/10.1007/s13593-023-00821-9

Zhang, W., Yu, Y., Huang, Y., & Li, T. (2019). Optimizing nitrogen application rates to improve yield and reduce environmental impact in rice production. Field Crops Research, 238, 1-10.

Zhang, X., Li, F., & Wang, X. (2022). *Soil properties and organic carbon accumulation across altitudinal gradients*. *Geoderma, 411*, 115635. https://doi.org/10.1016/j.geoderma.2021.115635

Zhang, Y., Liu, X., & Zhao, W. (2022). *Combining organic and inorganic phosphorus sources for improved crop yield and phosphorus use efficiency*. Field Crops Research, 280, 108539.

Zhang, Y., Zhang, L., & Wang, S. (2019). Phosphorus content and its effect on compost efficiency. *Waste and Biomass Valorization, 10*(9), 2605-2616. https://doi.org/10.1007/s12649-018-0351-0.

Zhao, M., *et al*. (2020). Soil pH and nutrient availability: A review of impacts on plant growth. *Journal of Soil Science and Plant Nutrition, 20*(4), 1015-1026.

Zhao, N., Bai, L., Han, D., Yao, Z., Liu, X., Hao, Y., ... & Wang, Z. (2024). Combined Application of Leguminous Green Manure and Straw Determined Grain

Zhao, R., Wang, X., Liu, D., & Zhang, Y. (2020). *Effect of nitrogen application on grain yield and nitrogen use efficiency in maize*. Scientific Reports, 10(1), 160. https://doi.org/10.1038/s41598-020-65756-5

Zhao, R., Wang, X., Liu, D., & Zhang, Y. (2020). *Effect of nitrogen application on grain yield and nitrogen use efficiency in maize*. Scientific Reports, 10(1), 160. https://doi.org/10.1038/s41598-020-65756-5

Zhou, H., Ma, H., Zhao, X., & Zhang, Y. (2023). *Effects of combined organic-inorganic fertilization on soil potassium dynamics and crop K uptake in diverse agro-ecosystems*. Soil and Tillage Research, 230, 105711. https://doi.org/10.1016/j.still.2023.105711

APPENDICES

Appendix I: Effects of soil amendments on pH at Bumula and Kibos sites during the flowering stage of maize in the 2021 long rains season

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replication	2	2.5842	1.2921	10.75	
Site	1	0.0348	0.0348	0.29	0.593
Treatment	13	5.5210	0.4247	3.53	<.001
Site x Treatment	13	0.9586	0.0737	0.61	0.832
Residual	54	6.4924	0.1202		
Total	83	15.5910			

Appendix II: Effects of soil amendments on pH in Bumula and Kibos sites during maize harvesting stage in the 2021 long rains season

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replication	2	3.1346	1.5673	14.68	
Site	1	0.0037	0.0037	0.03	0.852
Treatment	13	6.9709	0.5362	5.02	<.001
Site x Treatment	13	1.2833	0.0987	0.92	0.534
Residual	54	5.7639	0.1067		
Total	83	17.1565			

Appendix III: Effects of soil amendments on soil Carbon at Bumula and Kibos sites during the flowering stage of maize in the 2021 long rains season

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replication	2	0.93159	0.46579	5.62	
Site	1	14.10400	14.10400	170.32	<.001
Treatment	13	2.45050	0.18850	2.28	0.018
Site x Treatment	13	0.91356	0.07027	0.85	0.609
Residual	54	4.47175	0.08281		
Total	83	22.87140			

Appendix IV: Effects of soil amendments on organic carbon at Bumula and Kibos sites during maize harvesting stage in the 2021 long rains season

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replication	2	0.4080	0.2040	1.10	
Site	1	11.6034	11.6034	62.62	<.001
Treatment	13	8.9195	0.6861	3.70	<.001
Site x Treatment	13	1.2478	0.0960	0.52	0.904
Residual	54	10.0068	0.1853		
Total	83	32.1855			

Appendix V: Effects of soil amendments on total nitrogen content at Bumula and Kibos sites during flowering stage of maize in the 2021 long rains season

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replication	2	0.0037881	0.0018940	7.51	
Site	1	0.0448048	0.0448048	177.75	<.001
Treatment	13	0.0053667	0.0004128	1.64	0.103
Site x Treatment	13	0.0028952	0.0002227	0.88	0.574
Residual	54	0.0136119	0.0002521		
Total	83	0.0704667			

Appendix VI: Effects of soil amendments on total nitrogen content at Bumula and Kibos sites during maize harvesting stage in the 2021 long rains season

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replication	2	0.0003024	0.0001512	0.24	
Site	1	0.0216964	0.0216964	34.23	<.001
Treatment	13	0.0089726	0.0006902	1.09	0.388
Site x Treatment	13	0.0031536	0.0002426	0.38	0.970
Residual	54	0.0342310	0.0006339		
Total	83	0.0683560			

Appendix VII: Effects of soil amendments on available phosphorus content at Bumula and Kibos sites during the maize flowering stage in the 2021 long rains season

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replication	2	290.65	145.33	2.96	
Site	1	927.48	927.48	18.86	<.001
Treatment	13	3351.39	257.80	5.24	<.001
Site x Treatment	13	533.20	41.02	0.83	0.623
Residual	54	2655.09	49.17		
Total	83	7757.81			

Appendix VIII: Effects of soil amendments on available phosphorus content at Bumula and Kibos experimental sites during maize harvesting stage in the 2021 long rains season

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replication	2	1700.0	850.0	7.16	
Site	1	4628.6	4628.6	39.00	<.001
Treatment	13	8386.9	645.1	5.44	<.001
Site x Treatment	13	2032.0	156.3	1.32	0.232
Residual	54	6408.1	118.7		
Total	83	23155.5			

Appendix IX: Effects of soil amendments on potassium content at Bumula and Kibos experimental sites during the maize flowering stage in the 2021 long rains season

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replication	2	1651947.	825973.	13.34	
Site	1	8622733.	8622733.	139.26	<.001
Treatment	13	735307.	56562.	0.91	0.545
Site x Treatment	13	456936.	35149.	0.57	0.869
Residual	54	3343568.	61918.		
Total	83	14810491.			

Appendix X: Effects of soil amendments on potassium content at Bumula and Kibos experimental sites during maize harvesting stage in the 2021 long rains season

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replication	2	27172.	13586.	1.48	
Site	1	630587.	630587.	68.62	<.001
Treatment	13	87960.	6766.	0.74	0.720
Site x Treatment	13	120404.	9262.	1.01	0.457
Residual	54	496253.	9190.		
Total	83	1362376.			

Appendix XI: Effects of soil amendments on plant height at Bumula and Kibos experimental sites during maize harvesting stage in the 2021 long rains season

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr**.
Replication	2	5043.0	2521.5	9.01	
Site	1	400085.0	400085.0	1430.22	<.001
treatment	13	251674.6	19359.6	69.21	<.001
Site xtreatment	13	87892.5	6761.0	24.17	<.001
Residual	726	203088.2	279.7		
Total	755	947783.3			

Appendix XII: Effects of soil amendments on leaf number at at tasseling stage at Bumula and Kibos experimental sites during maize harvesting stage in the 2021 long rains season

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replication	2	11.5794	5.7897	7.47	
Site	1	308.5833	308.5833	398.23	<.001
treatment	13	141.4140	10.8780	14.04	<.001
Site.treatment	13	70.1759	5.3981	6.97	<.001
Residual	726	562.5688	0.7749		
Total	755	1094.3214			

Appendix XIII: Effects of soil amendments on leaf area index at tasseling stage at Bumula and Kibos experimental sites during maize harvesting stage in the 2021 long rains season

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr**.
Replication	2	3.9405	1.9703	3.43	
Site	1	227.6546	227.6546	396.36	<.001
treatment	13	429.4026	33.0310	57.51	<.001
Site.treatment	13	83.5537	6.4272	11.19	<.001
Residual	726	416.9830	0.5744		
Total	755	1161.5345			

Appendix XIV: Effects of soil amendments on stem girth at Bumula and Kibos experimental sites during maize harvesting stage in the 2021 long rains season

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replication	2	0.50924	0.25462	5.23	
Site	1	34.64061	34.64061	711.31	<.001
treatment	13	25.30356	1.94643	39.97	<.001
Site.treatment	13	11.90806	0.91600	18.81	<.001
Residual	726	35.35588	0.04870		
Total	755	107.71735			

Appendix XV: Effects of soil amendments on plant tissue nutrient %N uptake at Bumula and Kibos experimental sites during maize harvesting stage in the 2021 long rains season

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr**.
Replication	2	0.06827	0.03414	1.79	
site	1	0.10220	0.10220	5.36	0.024
treatment	13	1.05402	0.08108	4.25	<.001
site.treatment	13	0.66175	0.05090	2.67	0.006
Residual	54	1.02946	0.01906		
Total	83	2.91570			

Appendix XVI: Effects of soil amendments on plant tissue nutrient %P uptake at Bumula and Kibos experimental sites during maize harvesting stage in the 2021 long rains season

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replication	2	0.0024310	0.0012155	1.27	
site	1	0.1203857	0.1203857	126.06	<.001
treatment	13	0.0522476	0.0040190	4.21	<.001
site.treatment	13	0.0176476	0.0013575	1.42	0.180
Residual	54	0.0515690	0.0009550		
Total	83	0.2442810			

Appendix XVII: Effects of soil amendments on plant tissue nutrient %K uptake at Bumula and Kibos experimental sites during maize harvesting stage in the 2021 long rains season

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replication	2	0.0835	0.0417	0.31	
site	1	3.3361	3.3361	24.79	<.001
treatment	13	7.1501	0.5500	4.09	<.001
site.treatment	13	2.2375	0.1721	1.28	0.254
Residual	54	7.2674	0.1346		
Total	83	20.0746			

Appendix XVIII: Effects of soil amendments on grain N uptake at Bumula and Kibos experimental sites during maize harvesting stage in the 2021 long rains season

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replication	2	0.061536	0.030768	4.04	
Site	1	0.103839	0.103839	13.62	<.001
Treatment	13	0.119897	0.009223	1.21	0.298
Site.Treatment	13	0.108777	0.008367	1.10	0.381
Residual	54	0.411737	0.007625		
Total	83	0.805786			

Appendix XIX: Effects of soil amendments on grain P uptake at Bumula and Kibos experimental sites during maize harvesting stage in the 2021 long rains season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	0.0043929	0.0021965	2.32	
Site	1	0.0033872	0.0033872	3.57	0.064
Treatment	13	0.0161400	0.0012415	1.31	0.236
Site.Treatment	13	0.0136181	0.0010475	1.11	0.375
Residual	54	0.0511829	0.0009478		
Total	83	0.0887210			

Appendix XX: Effects of soil amendments on grain K uptake at Bumula and Kibos experimental sites during maize harvesting stage in the 2021 long rains season

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.000353	0.000176	0.03	0.967
Site	1	0.018901	0.018901	3.59	0.064
Treatment	1	0.019693	0.019693	3.74	0.059
Site.Treatment	13	0.032088	0.002468	0.47	0.933
Residual	53	0.279164	0.005267		
Total	82	0.437272	0.005333		

Appendix XXI: Effects of soil amendments on stover N uptake at Bumula and Kibos experimental sites during maize harvesting stage in the 2021 long rains season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.000065	0.000032	0.01	
Site	1	0.007632	0.007632	2.66	0.109
Treatment	13	0.034100	0.002623	0.91	0.544
Site.Treatment	13	0.072652	0.005589	1.95	0.044
Residual	54	0.154808	0.002867		
Total	83	0.269257			

Appendix XXII: Effects of soil amendments on stover P uptake at Bumula and Kibos experimental sites during maize harvesting stage in the 2021 long rains season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.0029558	0.0014779	2.86	
Site	1	0.0954370	0.0954370	184.82	<.001
Treatment	13	0.0138327	0.0010641	2.06	0.033
Site.Treatment	13	0.0094849	0.0007296	1.41	0.184
Residual	54	0.0278845	0.0005164		
Total	83	0.1495950			

Appendix XXIII: Effects of soil amendments on stover K uptake at Bumula and Kibos experimental sites during maize harvesting stage in the 2021 long rains season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.00998	0.00499	0.07	
Site	1	21.69574	21.69574	319.65	<.001
Treatment	13	0.62090	0.04776	0.70	0.751
Site.Treatment	13	0.28698	0.02208	0.33	0.985
Residual	54	3.66515	0.06787		
Total	83	26.27876			

Appendix XXIV: Effects of soil amendments on Forage N uptake at Bumula and Kibos experimental sites during maize harvesting stage in the 2021 long rains season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.004680	0.002340	1.44	
Site	1	0.026349	0.026349	16.20	<.001
Treatment	13	0.048695	0.003746	2.30	0.016
Site.Treatment	13	0.025832	0.001987	1.22	0.290
Residual	54	0.087832	0.001627		
Total	83	0.193388			

Appendix XXV: Effects of soil amendments on Forage P uptake at Bumula and Kibos experimental sites during maize harvesting stage in the 2021 long rains season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.0011995	0.0005997	1.90	
Site	1	0.0378160	0.0378160	119.89	<.001
Treatment	13	0.0041878	0.0003221	1.02	0.445
Site.Treatment	13	0.0038302	0.0002946	0.93	0.525
Residual	54	0.0170331	0.0003154		
Total	83	0.0640666			

Appendix XXVI: Effects of soil amendments on Forage K uptake at Bumula and Kibos experimental sites during maize harvesting stage in the 2021 long rains season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.10785	0.05393	1.61	
Site	1	4.57126	4.57126	136.59	<.001
Treatment	13	0.67286	0.05176	1.55	0.131
Site.Treatment	13	0.55034	0.04233	1.26	0.263
Residual	54	1.80716	0.03347		
Total	83	7.70947			

Appendix XXVII: Effects of soil amendments on dry matter yield (t/ha) of maize fields at Bumula and Kiboss in Western Kenya during the maize growing season of 021

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.6163	0.3081	2.71	
site	1	31.8776	31.8776	280.37	<.001
treatment	13	40.2220	3.0940	27.21	<.001
site. treatment	13	5.4374	0.4183	3.68	<.001
Residual	54	6.1398	0.1137		
Total	83	84.2930			

Appendix XXVIII: Effects of soil amendments on maize grain yield (t/ha) of maize fields at Bumula and Kiboss in Western Kenya during the maize growing season of 2021

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr**.
Replication	2	0.3092	0.1546	1.15	
site	1	1.1092	1.1092	8.25	0.006
treatment	13	61.4361	4.7259	35.13	<.001
site.treatment	13	2.2462	0.1728	1.28	0.251
Residual	54	7.2644	0.1345		
Total	83	72.3651			

Appendix XXIX: Effects of soil amendments Forage quality ADF of maize fields at Bumula and Kiboss in Western Kenya during the maize growing season of 2021

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replication	2	82.42	41.21	0.96	
site	1	339.77	339.77	7.92	0.007
Treatment	13	668.16	51.40	1.20	0.307
site.Treatment	13	313.53	24.12	0.56	0.873
Residual	54	2317.86	42.92		
Total	83	3721.74			

Appendix XXX: Effects of soil amendments Forage quality %ADL of maize fields at Bumula and Kiboss in Western Kenya during the maize growing season of 2021

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr**.
Replication	2	6.51	3.25	0.29	
site	1	122.45	122.45	10.83	0.002
Treatment	13	118.70	9.13	0.81	0.649
site.Treatment	13	99.68	7.67	0.68	0.775
Residual	54	610.30	11.30		
Total	83	957.64			

Appendix XXXI: Effects of soil amendments Forage quality IVDMD of maize fields at Bumula and Kiboss in Western Kenya during the maize growing season of 2021

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replication	2	47.08	23.54	0.61	
site	1	330.46	330.46	8.51	0.005
Treatment	13	1172.14	90.16	2.32	0.016
site.Treatment	13	377.31	29.02	0.75	0.709
Residual	54	2096.95	38.83		
Total	83	4023.94			

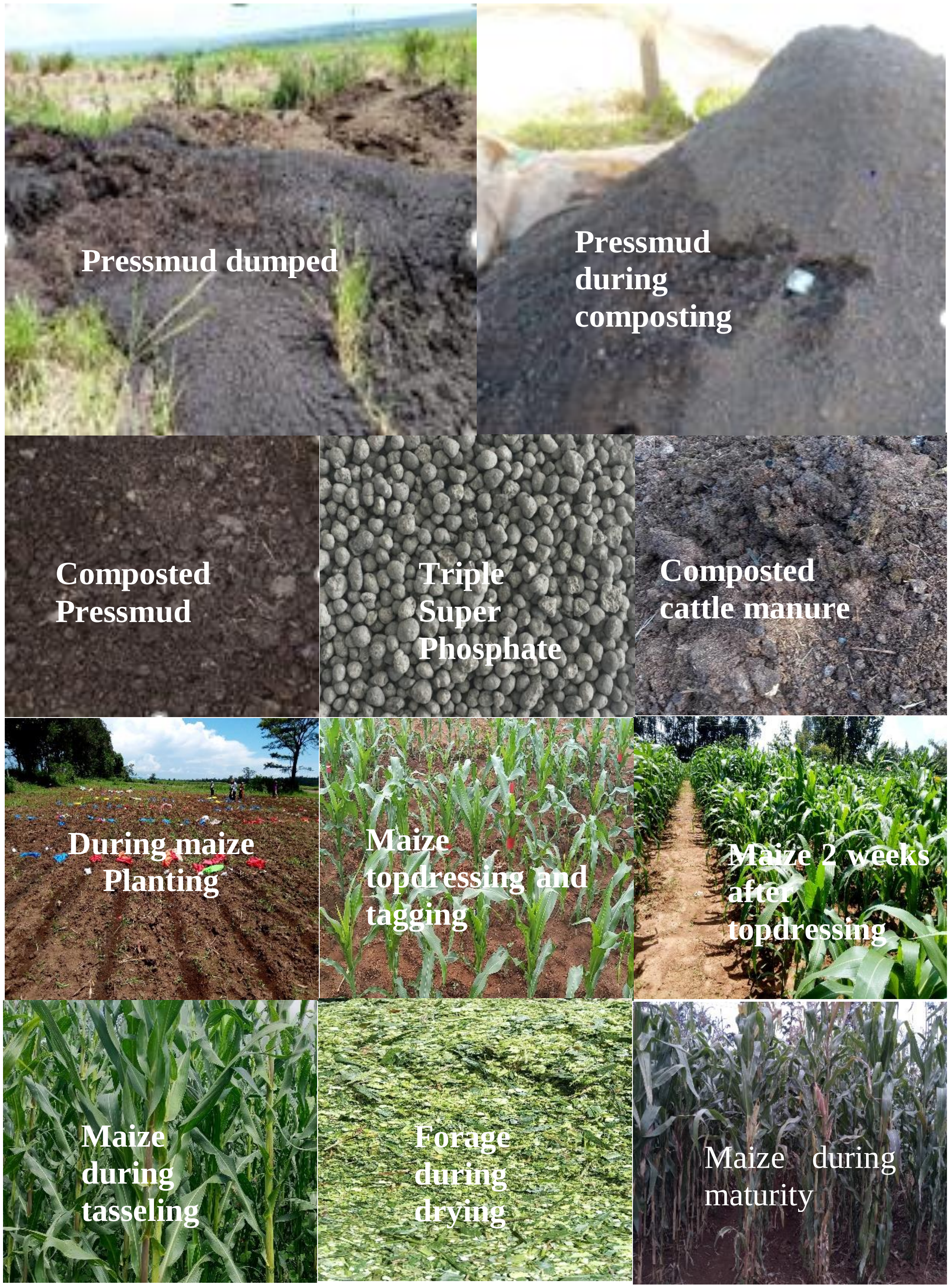
Appendix XXXII: Effects of soil amendments Forage quality NDF of maize fields at Bumula and Kiboss in Western Kenya during the maize growing season of 2021

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replication stratum	2	12.53	6.26	0.37	
site	1	75.01	75.01	4.41	0.040
Treatment	13	651.75	50.13	2.95	0.003
Site.Treatment	13	288.11	22.16	1.30	0.240
Residual	54	918.52	17.01		
Total	83	1945.92			

Appendix XXXIII: Effects of soil amendments Forage quality CP of maize fields at Bumula and Kiboss in Western Kenya during the maize growing season of 2021

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replication stratum	2	3.0715	1.5357	3.02	
site	1	1.7329	1.7329	3.41	0.070
Treatment	13	41.1749	3.1673	6.23	<.001
Site.Treatment	13	14.8874	1.1452	2.25	0.019
Residual	54	27.4417	0.5082		
Total	83	88.3083			

Appendix XXXIV: Selected pictures from composing to maize maturity



Appendix XXXV: Similarity Report