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COMPARATIVE ANALYSIS OF EFFECTS OF CLIMATE-SMART AGRICULTURE PRACTICES AND CONVENTIONAL AGRICULTURE ON SELECTED SOIL PHYSICOCHEMICAL PROPERTIES IN NYIMBA DISTRICT, ZAMBIA

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Background. Many smallholder farmers in the developing world live in adverse poverty and rely on agriculture as their primary source of income and household food. In Zambia, agriculture production is the main activity for people in rural areas of the country. The study evaluated the effects of climate-smart practices: *Gliricidia sepium* alley cropping, conservation agriculture basin, ripping, and conventional agriculture cropland on selected physicochemical properties of soil among smallholder farmers' croplands in Nyimba district, Zambia.

Materials and Methods. Cropland under conservation agriculture basin, ripping, agroforestry gliricidia alleyed cropping, and conventional agriculture cropland hosting the practices for more than five years were considered for soil sample collection. Thirty (30) composite soil samples were collected: gliricidia alley cropping (n = 6), conservation agriculture ripping (n = 6), basin (n = 6), conventional agriculture one (n = 6), and conventional agriculture two (n = 6) following a zigzag pattern on soil surface depth of 0–30 cm. The collected composite soil samples were analyzed at the University of Zambia Soil Science Laboratory. Soil laboratory results were analyzed with Minitab Statistical Software version 17 for mean squares, standard deviations, and Tukey's LSD.

Results and Discussion. The study revealed significant effects ($p < 0.05$) of gliricidia alley cropping, conservation agriculture ripping, and basin on soil bulk density, porosity, power of hydrogen (pH), cation exchange capacity, available phosphorus, total nitrogen, exchangeable bases sodium, calcium, and potassium. Exchangeable base magnesium was recorded as insignificant across the considered practices off-course with minimal mean variations with conventional agriculture cropland.

Conclusion. The study shows that implementing climate-smart agriculture practices has the potential to improve crop productivity per hectare through reclaiming and amending depleted soil physicochemical properties in a mid and long run. This also indicates the importance of climate-smart agricultural practices implementation among smallholder farmers' cropping fields.

Keywords: agriculture practices, conservation basins, crop yield, depleted soils, households, ripping

INTRODUCTION

Climate change, which is the long-term alteration in Earth's climate and weather patterns, is a global issue affecting the environment, especially the agricultural sector (Le Treut *et al.*, 2007). Effects of climate change (CC) on agriculture production have been reported in Asia, Europe, South America, Latin America, and Sub-Saharan Africa among other places (Muluneh, 2021). In Sub-Sahara African countries including Zambia, CC is the main factor contributing to low output of livestock husbandry and crop husbandry among smallholder farmers (Karmaoui *et al.*, 2021). Agriculture production is the mainstay of most households in Zambia. However, the agriculture sector comprises 82 % of smallholder farmers (Zambia Statistics, 2022). These households depend on rain-fed smallholder farming systems and are characterized by poverty as well as vulnerability (CIAT & World Bank, 2017a; Chavula, 2022a). Smallholder rural farmers face several constraints that limit productivity and profitability, trapping the family in a cycle of poverty and food insecurity (Hussein & Suttie, 2016; Vroegindewey *et al.*; Chung *et al.*, 2019). According to the Ministry of Agriculture and the Ministry of Fisheries and Livestock's Second National Agriculture Policy (Chavula, 2022b), the agricultural industry generates about 10 % of Zambia's gross domestic product (GDP) and employs more than 70 % of the population. Despite the significant 10 % contribution of agriculture to Zambia's GDP, it experiences threats by climatic change and variability. Climate change affects 80 % of the smallholder agrarian farming households in Zambia (*i.e.* minimizing the industry contribution to poverty reduction, particularly in rural areas) (Chavula, 2022b).

P. Chavula *et al.* (2022b) further alluded to climate change as harming Zambia's rural poor farming households. Additionally, in the years 1960 and 2006, the average annual temperature in Zambia rose by 1.3 degrees Celsius. However, according to the Zambian Meteorological Department, extremely high temperatures ranging from 30 to 38 degrees Celsius were recorded around the country in 2004. Temperature extremes have also been reported, with clear detrimental effects on plant and animal physiology, growth, and productivity (Masson-Delmotte *et al.*, 2018). Climate change will almost certainly have a significant impact on the average yields of Zambia's major crops (maize, wheat, and sorghum), because agronomic conditions for these crops may worsen in large parts of the country (FANRPAN, 2017). Extreme weather events such as drought and flooding, on the other hand, are expected to have a higher impact on crop production (Alemaw & Matondo, 2020).

Reduced crop production exacerbates food insecurity and nutrition; it is likely to have an impact on human life, especially on rural households living below the poverty line in Zambia. International Tropical Agriculture Centre (CIAT) and World Bank (2017a) reported Zambia faces climate change-related agricultural losses anticipated to total US$2.2–3.13 billion over the next 10–20 years. With the complexity of the socio-economic character of agricultural systems in Sub-Saharan Africa, integrated climate-smart agriculture (CSA) approaches have been promoted to maximize the benefits of CSA practices as well as adoption by smallholder farmers (Makate, 2019; Doumbia *et al.*, 2020). Climate-smart agriculture emerged in the late twentieth century in Zambia, when farmers began to face economic, ecological, and/or climate change challenges in line with their agriculture production. During this time, climate-smart agriculture practices primarily focused on assisting smallholder farmers in maintaining excess production levels, allowing them to become and remain active players in the agriculture industry (Karmaoui *et al*. 2021). The emergency of CSA focused on combating the adverse effects of climate change on agrarian households. The government of Zambia is conducting multiple CSA measures to repair degraded landscapes and improve farmers' resilience to climate change in conjunction with national and international research, and development partners (Ajayi *et al.*, 2007). It's worth noting that practices aimed at reducing or eliminating the negative effects of climate change have been developed over time. Adaptation, mitigation, and resilience measures are the terms used to describe these practices (Ajayi *et al.*, 2007). These practices address the loss of soil fertility and animal fodder shortage which government and non-governmental organizations have stimulated smallholder farmers to adopt (Karouach *et al.*, 2022). Climate-smart agriculture practices (e.g. organic farming, agroforestry, conservation agriculture, multi-cropping) are tailored to increase household income, agriculture productivity, climate change resilience, and mitigation through incorporating tree crops in farming systems and less synthetic fertilizer usage (Tadesse *et al.*, 2021).

The implementation of CSA practices and systems in highly degraded landscapes across various developing countries, such as Malawi, Ethiopia, Tanzania, Kenya, Nigeria, and Uganda, is based on this premise; soil and water conservation, grazing management, crop rotation, crop residue incorporation, and perennial-crop based agroforestry systems are all examples of CSA practices in these areas (Mizik, 2021). In terms of crop productivity, CSAPs focus on improving soil health and recovery from depleted nutrients (Ruheza *et al.*, 2012). According to the International Centre for Tropical Agriculture (CIAT) and World Bank (2017b), climate-smart agriculture practices are deemed an important tool in tackling food security issues (i.e. enhancement of soil fertility, fodder availability, water availability among others).

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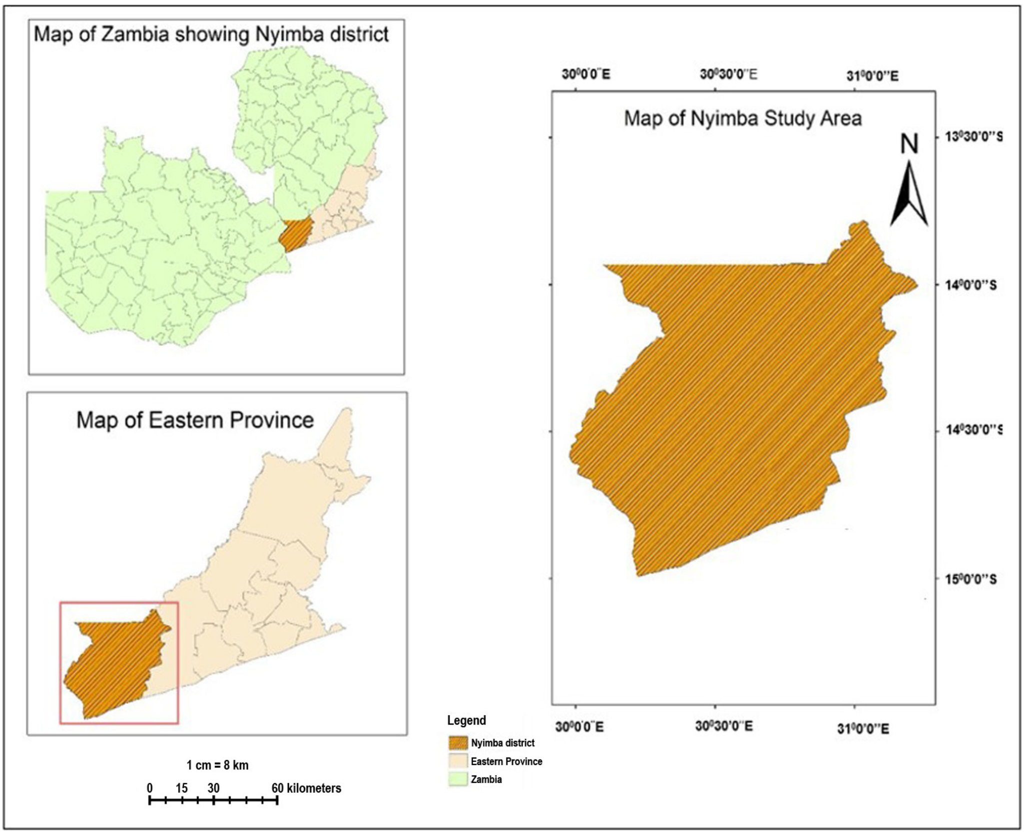
Therefore, studies conducted by D. Phiri *et al.* (2019); F. Alfani *et al.*(2021); J. Ngombe *et al.* (2014); CIAT and World Bank (2017b); I. K. Odubote and O. C. Ajayi (2020a); and H. Nkhuwa *et al.* (2020) investigated socio-economic impacts of CSA adoption among smallholder farmers in Zambia. These studies have reported the significant impacts of CSA adoption on the livelihoods of smallholder farmer adopters in Zambia. However, the studies had shortfalls and/or gaps in evaluating the effects of gliricidia alley cropping, conservation agriculture ripping, basin and conventional agriculture on selected soil physicochemical properties, and crop productivity among smallholder farmers in Nyimba district. However, this study unlike the past empirical studies evaluated the effects of agroforestry *Gliricidia sepium* alley cropping, conventional agriculture, and conservation agriculture (*i.e.*, ripping and basin) on selected soil physicochemical properties among smallholder farmers residing in the study area.

MATERIAL AND METHODS

Study area location. The study was conducted in Nyimba district of Eastern Province Zambia. The district is situated 334 km East of Lusaka, the capital city of Zambia. In the South, the district borders with Mozambique, in the North with Muchinga province, in the West with Lusaka province, and in the East with Petauke district. The district lies between latitude (13°30′1019″ and 14°55′81426″ South) and longitude (30°48′5047″ and 31°48′20252″ East) (see **Figure**).



Map of study area. Source: Author's sketch using Arc GIS

Climate, soil, and topography. Zambia as a country is divided into three (3) agro-ecological zones (*i.e.*, Zone I, Zone II (IIa and IIb), and Zone III), of which Nyimba district falls in Zone I. Agro-ecological zone I covers the Zambezi and Luangwa River basins' Southern and Eastern rift valleys. It also stretches to parts of Zambia's Western and

Southern provinces in the South (Gumbo *et al*., 2016). The district's average annual rainfall ranges between 600 mm to 900 mm; the wettest months are December to February, with a distinct dry season from May to November. The annual mean temperature is 24.2 °C, whereas the daily temperature range is 10.3 °C to 36.5 °C. Topographically the district is composed of hills and plateaus, soils are characterized as Lithosol-Cambisols, whereas in the valleys, soils are classified as Fluvisol-Vertisols (Gumbo *et al*., 2016). The elevation varies from 450–1000 m at the Luangwa River valley bottom and extends to the plateau near the Nyimba district centre, and even higher on the mountain tops in the district's western part.

Land use and farming systems. According to the population and housing census of 2010, the total land area of the Nyimba district is around 10,500 square kilometers. Therefore, with an average household income, 82 % of the district's population is rural. Most of these rural households are comprised of mixed agriculture in which predominates the local agricultural section. The district's smallholder farmers, however, engage in some form of shifting agriculture and/or traditional kind of agriculture practices. The principal crops grown are the following: banana (*Musa* sp.), haricot bean (*Phaseolus vulgaris*), cowpea (*Vigna unguiculata* spp.), finger millet (*Eleusine coracana*), peanut (*Arachis hypogaea*), and soybean (*Glycine max*). The district's agriculture pattern differs from that of other districts due to the topography of the land. A cropping system is present there; besides, crop growing smallholder farmers are involved in livestock production of cattle, goats, chickens, ducks, and doves. For household financial advantage, smallholder farmer households also produce charcoal, lumber, firewood, and NTFPs from the miombo woodland in addition to agricultural activities.

Site selection. A reconnaissance was conducted in the study area to collect basic information and a general overview of the study area before soil sample collection. The information gathered during the exploration included CSA host farmers' households, size of cultivated land, years of CSA implementation, exact cropland location, and slope gradient. The location of each field or cropland was captured using the geographic positioning system (GPS), and coordinates were recorded on the tablet. Thus, the reconnaissance focused on identifying croplands under selected CSA for the study (*i.e*., gliricidia alley cropping, conservation agriculture basin and ripping).

Characteristics of croplands. *Gliricidia sepium* agroforestry alley cropping was considered in this study as it is the common practice in the study area. However, the study preferred alley cropping croplands hosting the practice for more than five (5) years since its inception. The agroforestry alley cropping system involves planting in rows of trees at wide spacing with a companion crop grown in the alley ways between the rows. *Gliricidia sepium* alley tree species are cut back and leaves are incorporated into the soil as green leaf manure or as mulch to improve soil moisture retention. Tree species components in gliricidia alley cropping are trimmed to avoid shading of companion crops evident in the study area. The study also considered the conservation agriculture minimum tillage (*i.e.,* ripping and basin) which involves less disruption of soil. In return, this increases soil infiltration and reduces soil erosion as well as crop yields. Ripping lines are made by agricultural rippers, and basins (planting holes) are made by Chaka hoes and normal hoes. In this study, the conservation agricultural basin and ripping croplands hosting the practices for more than five (5) years were preferred. This study likewise considered conventional agricultural cropland adjacent to conservation agriculture ripping, basin, and gliricidia alley cropping bearing the same slope and soil type characteristics. Conventional agriculture is defined as an agricultural practice that uses chemicals such as fertilizers to improve crop yields.

Soil sample collection and preparation. Subsoil samples were collected from six (6) croplands of agroforestry gliricidia alley cropping, conservation agriculture (*i.e.,* basin and ripping) and conventional agriculture were identified in the reconnaissance survey. The identified fields were adjacent to each other and fell on the same slope gradient of 0–10 %. Sub-soil samples were collected from a depth of 0–30 cm (surface soil). Eight to ten surface soil (0–30 cm depth) subsamples were randomly collected in a zig-zag pattern from each identified cropland. Then these soil sub-samples were mixed thoroughly to obtain a 1-kilogram composite soil sample and packed in a polybag. The procedure was repeated to obtain the required thirty (30) composite soil samples; six (6) for each practice for laboratory analysis.

Laboratory analysis. Soil pH (soil reaction) was measured by the pH meter, whereas organic carbon and organic matter were determined using the Walkley–Black method (Motsara & Roy, 2008) plants, water and fertilizers (mineral, organic and biofertilizers. Total nitrogen (TN) was determined by using the Kjeldahl procedure [wet oxidation procedure] (Belay, 2018). Likewise, Bray 1's method for acidic soils method was adopted in this study to determine available phosphorous. The method was aided by the photoelectric cells in the spectrophotometer analytical instrument (Horta & Torrent, 2007). As for exchangeable bases determination (*i.e.* calcium, magnesium, sodium, and potassium), the leachate Flame Atomic Absorption (FAAS) and Flame Emission Spectrometry (FES) were used (Horta & Torrent, 2007). Lastly, the Compulsive Exchange Method of Gillman and Sumpter (Fauzlah *et al*., 1997) was applied to examine soil samples' cation exchange capacity (CEC). It is a recommended method by Soil Science of America because it is a highly repeatable, precise, direct measure of soil CEC. The method determines CEC at the pH and ionic strength of the soil.

Soil bulk density was determined from the undisturbed soil samples following the laboratory standard method (Prikner *et al.*, 2004). Whereas, particle density of the soil is considered the average estimate of 2.65 g/cm^3 as particle densities for soils range from 2.60 g/cm^3 to 2.75 g/cm^3 for minerals. Total solid soil porosity (f %) was estimated from the values of bulk density (P_b) and particle density (P_d) as tabulated below;

$$f(\%) = \left(1 - \frac{P_b}{P_d}\right) \cdot 100$$

f (%) denotes porosity whilst P_b is the bulk density and P_d is the particle density.

Data analysis. Analysis of variance (ANOVA) with Tukey's least significant difference (LSD) test was performed with Minitab version 17 to determine the significance of the state of soil after practicing gliricidia alley cropping, conservation agriculture basin and ripping against conventional agriculture, for selected soil physicochemical properties at ($p < 0.05$). The results are reported as inferential and descriptive statistics, the means, standard deviations, and compare the mean square differences across treatments.

RESULTS AND DISCUSSION

Effects of climate-smart agriculture practices on soil bulk density and total porosity. In the study area, significant bulk density (*Pb*) at *p*-value ($p < 0.05$) was recorded, the highest mean was observed in CV1 (1.69 g/cm^3), CV2 (1.61 g/cm^3), ripping (1.31 g/cm^3), and basin (1.05 g/cm^3) (Table 1). The recorded results tend to prove that CSA (*i.e*., agroforestry *Gliricidia sepium* alley cropping, conservation agriculture ripping and basin) have bulk density which is generally suitable for agriculture crop production since pore space percentage has a greater potential to store water and allow roots to grow more readily (https://soilquality.org.au). A study by E. O. Alamu *et al*. (2023) found *Gliricidia sepium* alley cropping to decrease the soil bulk density and improve soil porosity significantly for crop growth in the study area. A similar study by Senarathne and Udumann (2023) reported planting *Gliricidia sepium* in alley cropping to have significant effects on soil bulk densities.

Soil total porosity (*f* %) was computed from the recorded bulk density results and the standard value of particle density of soil 2.65 g/cm^3 (Kassam *et al*., 2020). The result across the treatment indicated a significant ($p < 0.05$) difference among the agroforestry gliricidia alley cropping, conservation agriculture basin and ripping and conventional agriculture in the study area (Table 1). Hereafter, porosity mean values were recorded in conservation agriculture basin (60.25 %), gliricidia alley cropping (56.73 %), ripping (50.69 %), CV2 (39.43 %), and CV1 (36.34 %) respectively (Table 1). The results clearly show that CSA in the long run will have more impacts on soil porosity hence improving crop productivity by providing sufficient oxygen and moisture to support crop growth, and reclaiming their physical properties. This is supported by S. Doumbia *et al.* (2020) who proved the effects of gliricidia alley cropping to enhance soil pH, organic matter, soil organic carbon percentage, soil porosity, and organic nitrogen in maize croplands. A. Kumar *et al*. (2020) also found alley cropped gliricidia sepium tree species to affect soil bulk density, organic matter, organic carbon and porosity of the soil, reported as significant.

Effects of climate-smart agriculture practices on soil pH, organic carbon, organic matter, total nitrogen and available phosphorous. Soil pH (0–14) variations were recorded significant – *p*-value of 0.0001 ($p < 0.05$), lower in CV1 (4.82), and CV2 (5.16), whilst higher mean values were obtained from gliricidia alley cropping (5.58), conservation agriculture basin (5.6) and ripping (5.63) (Table 1). The lowest mean soil pH values recorded in CV1 and CV2 indicate soil activity due to the decomposition of organic matter, and heavy usage of acid-forming blended chemical fertilizers (Kumari *et al.*, 2019). The blended chemical fertilizers mainly used in the study area are D-compound (basal dressing) and Urea (top dressing). Blended D-compound fertilizers contain combinations of nitrogen, phosphorous, potassium, and sulphur in some cases, while Urea is a nitrogen fertilizer with an NPK with 46 % nitrogen. According to G. Sellan *et al.* (2020), soil pH ranging from 6.2–6.7 is slightly acidic, neutral ranges from 6.7–7.3 whilst moderate basic ranges from 7.3–7–9. The crop required pH ranges from 6 to 7 which supports plant growth (Ghazali *et al.*, 2020). Nevertheless, some crop's pH requirements are above and below the stated range (Ranieri *et al.*, 2021). Generally, the study recorded the soil pH to be moderately acidic in the study area among gliricidia alley cropping, conservation agriculture basin, and ripping and strongly acidic in conventional agricultural croplands (CV1 and CV2) (Hazelton & Murphy, 2016). The topographic situation of the area could influence the recorded results due to accumulation of organic matter and sediments from the steep slopes, especially during rainy season (Palm *et al.*, 2014).

Effects of climate-smart agricultural practices on soil organic matter and organic carbon. The study recorded highly significant 0.0001 ($p < 0.001$) SOM with the highest mean in gliricidia alley cropping (4.91 %), conservation agriculture basin

(4.31 %), and ripping (3.53 %), CV1 and CV2 in the study area (Table 1). B. W. Murphy *et al.* (2014) in their study also recorded very high soil organic matter in gliricidia alley cropping, conservation agriculture ripping, and basin, indicating the effectiveness of these practices. The mean values for SOC recorded in the study area were highly significant ($p < 0.001$) between gliricidia alley cropping (2.45 %), conservation agriculture basin (2.15 %), ripping (1.77 %), while CV1 (1.05 %) and CV2 (1.01 %) (Table 1). The slope of the croplands could have contributed to SOC and SOM of the soil due to soil moisture saturation, topography, and organic matter decomposition from crop residues (Neina & Agyarko-Mintah, 2022). A study by M. Mhete *et al.* (2020) found similar results, on significant build-up of SOC and SOM among CA host croplands. Nonetheless, the research recommended that crop residue management should be more proactively pursued in areas where CA practices are implemented. In a study by N. Sithole *et al.* (2020), average SOC did vary across gliricidia alley cropping treatments meaning that top soil disturbances affect the accumulation of organic matter especially in open grazed farmlands with frequent bushfires and water runoffs. Other researchers have stated that where CSA are implemented, they often lead to greater SOC accumulation than CV and stubble retention alone. The effects are due to soil management that changes soil properties and CA systems, which have an interactive effect and synergic effect if incorporated together at once (Lejissa *et al.*, 2022). C. Okonkwo *et al.* (2009) and V. Martinsen *et al.* (2014) alluded that in regions with favorable biomass production, negative yields are not observed in CA practices. This is due to the contribution of CA to soil physicochemical properties through minimum soil disturbance and crop residues that significantly contribute to SOM and SOC, and in turn influence soil BD.

T. L. Beedy *et al.* (2010) supported the significant and positive impacts of *Gliricidia sepium* alley cropping on SOM as compared to the maize sole field. Soil organic matter enhanced maize yields and increased soil nutrients over the mid and long-term cycle. V. Ivezić *et al.* (2022) maintained that gliricidia alley cropping integration in farmland increases SOC and SOM with time. The findings suggested that the maximum benefits of SOC occurs after approximately a decade of alley-cropping practices adoption and/or implementation. M. Oelbermann *et al.* (2004) found similar results – the quantified SOC pool inputs of alley cropping were 16 %–23 % higher than those of the sole crop (control).

Soil total nitrogen (TN) was recorded significant in total nitrogen across the treatments (Table 1). The highest mean value recorded in gliricidia alley cropping (0.49), conservation agriculture basin (0.4), and ripping (0.34) followed by CV2 (0.29) and CV1 0.25) respectively, statistically significant ($p < 0.05$) (Table 1). According to P. Hazelton and B. Murphy (2016), conservation agriculture ripping and basin recorded moderate TN while gliricidia alley cropping recorded high soil TN content. P. Hazelton and B. Murphy (2016), interpreted total nitrogen results from the analysis in the following categories very high >0.5 %, high 0.25–0.50, moderate 0.15–0.25, low 0.05–0.15, and very low <0.05. This is an indication that climate-smart agricultural practices are significantly contributing to soil productivity. Y. N. Bohoussou *et al.* (2022) observed a significant increase in SOC and total nitrogen stock within all the individual components of CA compared to conventional agricultural practices. J. B. Naab *et al.* (2017) also found similar results where organic carbon and soil total nitrogen were higher in CA compared to CV practices. The minimal mean differences could be influenced by the study area site condition, especially the occurrences of high alternating temperatures, decomposition of weathered material from higher slopes, erosion (runoffs especially in rainy season), and bulk density affected by compaction from open grazing livestock.

Concerning soil available phosphorus, the study recorded statistically significant results in the study area (Table 1). The highest mean from gliricidia alley cropping (39.3 mg/kg), CV2 (10.78 mg/kg), conservation agriculture ripping (10.34 mg/kg), and CV1 (9.87 mg/kg), and lowest in basin (9.45 mg/kg). The recorded mean values for conservation agriculture basin, ripping, and gliricidia alley cropping ripping indicate sufficient available phosphorus for crop growth and development (Table 1) (Patinha *et al*., 2015) for their element solid-phase distribution using selective sequential extraction method and for the BS of these elements using a physiologically based extraction test. The study showed that the concentrations of Zn were higher than Pb, but both are site-specific. The sequential extraction test shows that the exchangeable and acid-soluble phases are important bearing phases for Pb and Zn whilst the BA test revealed a high proportion of total concentration of elements for absorption (ranging from 22.5 % to 84.1 % for Pb and 28.7 % to 86.3 % for Zn. A study by W. Makumba *et al.* (2006) recorded similar results, with variations implying that alley-cropping tree species take up native soil nutrients (*i.e.* P, Ca^{2+}, Mg^{2+}, and K^{+}) from the soil nutrient pool and pump it to the surface. The net soil nutrient decrease in the gliricidia alley cropping simultaneously increases soil nutrient export through the decomposition of leaf biomass. Hence, the adoption of conservation agriculture basin, ripping, and agroforestry gliricidia alley cropping in the study area is an alternative to maintain soil available phosphorus for crop production.

Effects of climate-smart agricultural practices on soil exchangeable bases and cation exchange capacity. Significant variations were observed for exchangeable Ca^{2+} ($p < 0.05$) due to the effects of gliricidia alley cropping, conservation agriculture ripping and basin (Table 2). The highest mean value was obtained from gliricidia alley cropping (1.16 $cmol_{(+)}$/kg), ripping (1.31 $cmol_{(+)}$/kg), CV1 (1.08 $cmol_{(+)}$/kg), CV2 (0.52 $cmol_{(+)}$/kg) and basin (0.46 $cmol_{(+)}$/kg) respectively (Table 2). A study by C. Okonkwo *et al.* (2009) produced similar significant results, as variations were seen in Ca^{2+} farmland where gliricidia alley cropping was practiced. J. Ferdush *et al.* (2019) also recorded statistically significant results of exchangeable Ca^{2+} on alley cropping of gliricidia in smallholder farmers' farming systems.

However, statistically insignificant results were recorded for exchangeable Mg^{2+} among gliricidia alley cropping, conservation agriculture ripping, and basins versus conventional agriculture croplands. The highest mean value was obtained from ripping (0.24 $cmol_{(+)}$/kg), gliricidia alley cropping (0.23 $cmol_{(+)}$/kg), CV2 (0.19 $cmol_{(+)}$/kg), CV1 (0.18 $cmol_{(+)}$/kg) and basin (0.13 $cmol_{(+)}$/kg) respectively (Table 2). The study also found that exchangeable Na^{+} was highly significant ($p < 0.001$) across the selected practices. The mean values ranging from CV1 (0.04 $cmol_{(+)}$/kg), gliricidia alley cropping (0.04 $cmol_{(+)}$/kg), ripping (0.04 $cmol_{(+)}$/kg), CV2 (0.02 $cmol_{(+)}$/kg) and basin (0.02 $cmol_{(+)}$/kg) (Table 2). The results, elucidate the positive effects that CSA has on soil chemical properties to support crop growth. In the long run, exchangeable Mg^{2+} and Na^{+} can be enhanced with good land management practices as well as integrated soil nutrient management. L. T. Lejissa *et al.* (2022) produced statistically significant results ($p < 0.05$) for exchangeable sodium, magnesium, calcium, and potassium, and concluded that CSA aid in good soil nutrient management as compared to conventional tillage typologies.

The study also recorded statistically significant exchangeable K^{+} at ($p < 0.1$), the highest amount (mean value) of exchangeable K^{+} was recorded in gliricidia alley cropping (0.05 $cmol_{(+)}$/kg), CV1 (0.05 $cmol_{(+)}$/kg), conservation agriculture ripping (0.05 $cmol_{(+)}$/kg),

Table 1. **Soil bulk density, total porosity, soil pH, organic carbon, organic matter, total nitrogen, and available phosphorus under different croplands**

Treatment	P_b (g/cm^3)	*f* (%)	pH	OC (%)	OM (%)	TN (%)	Av. P (mg/kg)
Ripping	$1.31^{b} \pm 0.0677^{**}$	$50.69^{b} \pm 2.56^{**}$	$5.63^{a} \pm 0.0809^{**}$	$1.77^{b} \pm 0.1608^{**}$	$3.53^{b} \pm 0.322^{**}$	$0.34^{a} \pm 0.0646^{***}$	$10.34^{b} \pm 3.924^{**}$
Basin	$1.05^{c} \pm 0.0787^{**}$	$60.25^{a} \pm 2.97^{**}$	$5.6^{a} \pm 0.1691^{**}$	$2.15^{a} \pm 0.1814^{**}$	$4.31^{a} \pm 0.363^{**}$	$0.4^{a} \pm 0.0898^{***}$	$9.55^{b} \pm 10.77^{**}$
CV1	$1.69^{a} \pm 0.0991^{**}$	$36.34^{c} \pm 3.72^{**}$	$5.16^{b} \pm 0.273^{**}$	$1.05^{a} \pm 0.0927^{**}$	$2.09^{c} \pm 0.1853^{**}$	$0.25^{b} \pm 0.1872^{***}$	$9.87^{b} \pm 11.99^{**}$
Alley C.	$1.15^{c} \pm 0.0896$**	$56.73^{a} \pm 3.38^{**}$	$5.58^{a} \pm 0.2135^{**}$	$2.45^{c} \pm 0.277$**	$4.91^{a} \pm 0.553^{**}$	$0.49^{b} \pm 0.1781^{***}$	$36.72^{a} \pm 32.53$**
CV2	$1.61^{a} \pm 0.0677$**	$39.43^{c} \pm 2.55^{**}$	$4.82^{c} \pm 0.2106^{**}$	$1.01^{c} \pm 0.257^{**}$	$2.01^{c} \pm 0.515^{**}$	$0.29^{a} \pm 0.2234^{***}$	$10.78^{b} \pm 8.29^{**}$

Comments: CV1 – Conventional agriculture (field with no CSAP) adjacent to Basin and Ripping; CV2 – Conventional agriculture (field with no CSAP) adjacent to gliricidia Alley cropping. While g/cm^3 grams per cubic centimeters, mg – mili-grams. Significance levels: *** 1 %, ** 5 % and * 10 %

Table 2. **Exchangeable bases, and cation exchange capacity under different croplands**

Treatment	Ca^{2+} cmol$_{(+)}$/kg	Mg^{2+} cmol$_{(+)}$/kg	K^{+} cmol$_{(+)}$/kg	Na^{+} cmol$_{(+)}$/kg	CEC (cmol$_{(+)}$/kg
Ripping	$1.31^{a} \pm 0.45$**	$0.24^{a} \pm 0.10$	$0.05^{b} \pm 0.01$*	$0.04^{a} \pm 0.01$**	$18.50^{a} \pm 4.46$**
Basin	$0.46^{b} \pm 0.33$**	$0.13^{a} \pm 0.11$	$0.04^{b} \pm 0.03$*	$0.02^{b} \pm 0.01$**	$22.33^{b} \pm 3.88$**
CV1	$1.08^{a} \pm 0.28$**	$0.18^{a} \pm 0.04$	$0.05^{b} \pm 0.02$*	$0.04^{b} \pm 0.01$**	$14.00^{c} \pm 4.29$**
Alley C.	$1.16^{c} \pm 0.22$**	$0.23^{a} \pm 0.08$	$0.05^{a} \pm 5.10$*	$0.04^{c} \pm 0.01$**	$9.33^{c} \pm 2.422^{**}$
CV2	$0.51^{b} \pm 0.18$**	$0.19^{a} \pm 0.09$	$0.03^{b} \pm 0.02$*	$0.03^{a} \pm 0.01$**	$10.00^{c} \pm 2.83^{**}$

Comments: CV1 – Convention Agriculture (field with no CSAP) adjacent to Basin and Ripping; CV2 – Conventional Agriculture (field with no CSAP) adjacent to gliricidia Alley cropping. Significance levels: ***1 %, **5 % and *10 %

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Table 3. **Correlation probability; the correlations are estimated by the row-wise method**

Soil Properties	TN (%)	OC (%)	OM (%)	Pb (g/cm^3)	*f* (%)	pH (0–14)	Av. P (mg/kg)	Na^+ (cmol$_{(+)}$/kg)	K^+ (cmol$_{(+)}$/kg)	Mg^{2+} (cmol$_{(+)}$/kg)	Ca^{2+} (cmol$_{(+)}$/kg)	CEC (cmol$_{(+)}$/kg
TN(%)	<.0001											
SOC (%)	0.0298	<.0001										
SOM (%)	0.0298	<.0001	<.0001									
ρb (g/cm^3)	0.0098	<.0001	<.0001	<.0001								
f (%)	0.0097	<.0001	<.0001	<.0001	<.0001							
pH(0-14)	0.0233	<.0001	<.0001	<.0001	<.0001	<.0001						
Av. P (mg/kg)	0.8073	0.0012	0.0012	0.0177	0.0178	0.0241	<.0001					
Na^+ (cmol$_{(+)}$/kg)	0.8909	0.6884	0.6884	0.5467	0.5505	0.6744	0.0193	<.0001				
K^+ (cmol$_{(+)}$/kg)	0.6923	0.8662	0.8662	0.8991	0.9045	0.0859	0.4444	0.0247	<.0001			
Mg^{2+} (cmol$_{(+)}$/kg)	0.4024	0.3554	0.3554	0.2608	0.2644	0.5528	0.6781	0.0042	0.0907	<.0001		
Ca^{2+} (cmol$_{(+)}$/kg)	0.9560	0.8119	0.8119	0.6765	0.6809	0.1706	0.4111	0.0013	0.0242	<.0001	<.0001	
CEC (cmol$_{(+)}$/kg	0.0044	0.0003	0.0003	<.0001	<.0001	0.0035	0.7832	0.2116	0.6731	0.9614	0.8419	<.0001

Comments: Soil total nitrogen was found to be in positive association or correlation with several soil parameters. Accordingly, (r = 0.3971*) with SOM, (r = 0.3971*) with SOC, (r = 0.501**) with CEC, and negatively correlated with soil porosity (r = -0.4646**), and (r = 0.4131*) with soil pH (Table 2). Soil organic matter (SOM and SOC) was found to have a negative correlation with Pb (r = -0.9242***) and positively correlated with Av. P (r = 0.5620**), and CEC (r = 0.6095***). Soil Pb showed a negative relationship with *f* % (r = -1.00***), pH (r = -0.745***) and CEC (r = -0.7315***). Soil potential hydrogen (pH) was recorded with a positive relationship Av. P (r = 0.4109*), CEC (r = 0.5168**) and *f* % (r=0.7381***). Available phosphorous showed a positive relationship with *f* % (r = 0.4295*) and Na^+ (r=0.4248*). Exchangeable base Na^+ is positively associated with exchangeable K^+ (r = 0.4093***), Mg^{2+} (r = 0.5077**), Ca^{2+} (r = 0.5590**) respectively. Furthermore, exchangeable Mg^{2+} is positively correlated with (r = 0.7255***). The pairwise correlation clearly indicates the interactive effects that climate-smart agriculture practices have on soil physicochemical properties, therefore, with good soil management practices, soil productivity can be enhanced in the study area basin (0.04 cmol$_{(+)}$/kg) and CV2 (0.03 cmol$_{(+)}$/kg) (Table 2). Agroforestry gliricidia alley cropping showed a significant contribution of K^+ in the soil as conservation agriculture ripping and basin with notable differences against conventional agriculture croplands. Available K+ in the soil is affected by soil pH, calcium-rich areas of the field, and soil aeration (Walmsley *et al.*, 2019). However, this study recorded rich Ca^{2+} in the area and acidic soils that contributed to the recorded levels of available K^+. A study by G. Schroth *et al.* (1995) indicated that alley cropping of Gliricidia sepium foliar had an influence on K^+ levels in the soil in the long run.

Cation exchange capacity: variations in cation exchange capacity (CEC) statistically significant at ($p < 0.05$) (Table 2). However, the highest mean value recorded in the conservation agriculture basin (22.33 cmol$_{(+)}$/kg), ripping (18.50 cmol$_{(+)}$/kg), CV1 (14.00 cmol$_{(+)}$/kg), CV2 (10.00 cmol$_{(+)}$/kg) and gliricidia alley cropping (9.33 cmol$_{(+)}$/kg) respectively (Table 2). Conservation agriculture ripping and basin as well as gliricidia alley cropping practices improved soil CEC as compared to conventional agriculture. As such, CSA influence soil CEC; a soil property that capacitates the supply of nutrient cations to the soil solution for crop uptake, especially exchangeable bases. In a study by D. Kumari *et al.* (2019), the same results were obtained showing that CA improved the soil CEC across the other soil treatments. The variations of CEC in the practices are influenced by soil type, soil pH, and soil organic matter content (Goswami *et al.*, 2020).

CONCLUSION

In conclusion, the problem of soil fertility loss faced by smallholder farmers and low crop productivity can be approached by adoption of climate-smart agricultural practices. However, the study recorded significant variations in selected soil physicochemical properties of agroforestry gliricidia alley cropping, ripping, basin, and conventional agriculture croplands. The study results proved that climate-smart agriculture practices have the potential to reclaim and amend degraded soils. Therefore, climate-smart agriculture practices such as gliricidia alley cropping, conservation agriculture basin, and ripping have a triple-win situation increasing crop productivity, climate change mitigation as well and adaption. Therefore, these climate-smart agriculture practices can improve smallholder farmers' livelihoods through enhanced crop productivity per hectare.

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COMPLIANCE WITH ETHICAL STANDARDS

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be interpreted as a potential conflict of interest.

Animal Studies: This article does not contain any studies with vertebrate animal and human subjects performed by any of the authors.

AUTHOR CONTRIBUTIONS

Conceptualization, [C.P.]; methodology, [C.P.]; validation, [C.P.; S.C.]; formal analysis, [C.P.].; investigation, [C.P.]; data curation, [C.P.]; writing – original draft preparation, [C.P.; F.S.]; writing – review and editing, [F.S.; C.P.; S.C.]; supervision, [F.S.; S.C.]; funding acquisition, [C.P.].

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