



Research article

Conservation agriculture-related practices contribute to maize (*Zea mays* L.) yield and soil improvement in Central MalawiHarrington Nyirenda^{a,*}, Victoria Balaka^b^a Ministry of Agriculture, Irrigation and Water Development, Salima Agricultural Development Division, Private Bag 1, Salima, Malawi^b Ministry of Agriculture, Irrigation and Water Development, Nkhotakota District Agriculture Office, P. O. Box 41, Nkhotakota, Malawi

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ABSTRACT

Conservation agriculture-related practices (CARP) improve soil fertility, maize yield, and profitability. A study was conducted to generate evidence on the benefits of CARP in the long-term (nine years) in Salima District, Central Malawi. The objectives of the study were 1) to compare the maize yields between farmer practice and CARP interventions in the long-term, 2) to compare soil fertility changes between farmer practice and CARP interventions in the long-term, and 3) to verify the intercropping efficiency of maize with groundnut using the land equivalent ratio (LER) and land equivalent coefficient (LEC). A guiding hypothesis was that the application of CARP improves soil condition and maize yield. Farmer practice (FP) and three CARP [Pit planting + mulching (PPM), Intercropping + mulching (INM), and Mulching (MC)] treatments were tested in the study. INM was also tested for intercropping efficiency. Maize yields in CARP (3.98–4.43 Mg ha⁻¹) were significantly higher ($p < 0.018$) than in FP (1.84 Mg ha⁻¹). Soil pH, soil organic carbon, soil organic matter, nitrogen, and bulk density were acceptable for the Malawian soil in CARP compared to FP, suggesting that CARP improved soil fertility properties. There was no significant difference in soil potassium concentration across the treatments ($p < 0.0642$). The land equivalent ratio for maize and groundnut intercropping in INM was 1.77, indicating beneficial intercropping efficiency. The benefit-cost ratios (BCR) for PPM, INM, and MC were 1.55, 1.90, and 2.26, respectively, indicating that CARP interventions were more profitable than FP (BCR = 0.15). It is concluded that CARP interventions contribute to increased crop yield, income, and soil fertility restoration in the agricultural land. The selection of a CARP intervention should depend on the farmer's main intention, either to maximize yield, soil fertility, income, or a combination.

1. Introduction

In Southern Africa, maize yield is mainly affected by variations in rainfall and inadequate use of inorganic fertilizer (Rusinamhodzi et al., 2011). Rainfall variation regimes are exacerbated by climate change (Kandji et al., 2006). Agricultural production is predominantly rainfed, which calls for the development of adaptation practices to changes in the rainfall regimes (Government of Malawi, 2017a). The use of inorganic fertilizers is expensive and not sustainable for most smallholder farmers in Southern Africa. The application of conservation agriculture-related practices (CARP) is promoted as an adaptation strategy to climate change for soil improvement and sustainable maize yield (Govaerts et al., 2009; Gotoso et al., 2011; Kaczan et al., 2013). Conservation agriculture (CA) is that sustainable agricultural system that employs minimum soil disturbance, soil cover, and crop rotation/associations (Hobbs et al.,

2007). CA adoption is considered low in most Sub-Saharan Africa (SSA), although high numbers of farmer groups (adopters) have been reported in South Africa, Ghana, Malawi, and Zambia (Giller et al., 2009; Ngwira et al., 2014). Studies should be conducted to widen understanding of the socioeconomic and ecological applicability of CA. In Malawi, most farmers practice two pillars of CA; minimum soil disturbance and crop residue retention (Ngwira et al., 2014; Government of Malawi, 2016; Government of Malawi 2017b). The present study focused on the broader application of CA (conservation agriculture-related practices) to build evidence-based information for its successful promotion among the maize growing communities. The acclaimed benefits of CARP (soil erosion control, improvement of soil processes, increased maize yield, reduction in production costs) need to be verified ecologically and contextually to enhance farmer to farmer learning (Govaerts et al., 2009).

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Maize is a major food crop in Southern Africa and contributes 80% of all staple food consumed in Malawi (Government of Malawi, 2017a). Most smallholder farmers grow maize as a sole crop, and the yield ranges from 1.5–1.7 Mg ha⁻¹ (Government of Malawi, 2019; FAO, 2020). Traditionally, where possible, farmers apply inorganic fertilizer of NPK (23:21+4S) and UREA for yield improvement. One bag (50 kg) of each fertilizer type is applied on a 0.4 ha. Some farmers use compost manure for general soil fertility improvement and agroforestry species such as *Faidherbia albida* and *Philenoptera violacea* for nitrogen enhancement in the soil (Beedy et al., 2015; Nyirenda et al., 2019). The common CARP practices include soil cover (using crop residues) and minimum soil disturbance (Kaczan et al., 2013). Changes in rainfall and the escalation of prices of inorganic fertilizers have been responsible for maize yield reduction among many smallholder farmers in Malawi (Kandji et al., 2006; Kabambe et al., 2018). The use of CARP is considered one of the solutions for these problems.

However, results from short-term (3–4 seasons) impacts of CARP have always been controversial and have drawn mixed reactions from farmers and technocrats on whether CARP is a sustainable intervention in this era of climate change (Sosola et al., 2011). This is due to variations in the impacts of short-term CARP interventions on soil condition and crop yields. For example, in Malawi (Ngwira et al., 2012) and Zambia (Muchabi et al., 2014), no significant increase in SOC and bulk density was observed after six and four years of CA practice, respectively. This provided the basis for the long-term present study. Since arable land-holding size is a challenge in Malawi, intercropping or crop associations in CARP are encouraged instead of rotations (Government of Malawi, 2012). The current promotion of intercropping is not based on the efficiency of the practice but on a general and blanket expectation that any legume contributes to improved cereal yield (Brooker et al., 2015). Specifically, the promotion of intercropping in CARP (commonly maize + groundnut) is promoted without verification of whether the crop combinations are socially (yield) and environmentally (resource use) beneficial and sustainable. This may explain the low adoption in all the CA principles. About 97% and 94% of farmers practicing CARP in Malawi adopted residue mulching and no-till, respectively, while only 45% and 29% practiced intercropping and rotations, respectively (Ngwira et al., 2014). Farmers need to be convinced on the need to practice intercropping rather than sole crops and whether the proposed intercropping is beneficial (Yilmaz et al., 2008). This information remains scanty due to limited studies on intercropping efficiency for CARP interventions in Malawi. Therefore, the present study focused on the following objectives: 1) To compare the maize yields between farmer practice and CARP interventions in the long-term, 2) To compare soil fertility changes between farmer practice and CARP interventions in the long-term, and 3) To verify the intercropping efficiency of maize and groundnut using the land equivalent ratio (LER) and land equivalent coefficient (LEC).

2. Materials and methods

2.1. Study area

The study was conducted in Salima District, Central Malawi, particularly in Tembwe Extension Planning Area (EPA) at Latitude 13, 46° S; and Longitude 34, 27° E, along the Lakeshore Plain Ecological Zone. The district has a population of 478,346 (Government of Malawi, 2018). It receives an annual average rainfall of 1,027 mm (Department of Climate Change and Meteorological Services, unpublished data) (Figure 1). The rainfall period runs from November to April. Soils are Chromic, Cambisols, or Haplic Luvisols with medium to fine texture and pH range of slight to medium acidic (Lorkeers, 1992; Nyirenda et al., 2019). The dominant crops include maize, groundnut, rice, and cotton (Government of Malawi, 2019). Salima District is among the top six districts in Malawi, highly affected by climate change (Government of Malawi, 2006).

2.2. Study design

There were four treatments, each covering an area of 0.1 ha. A treatment was replicated six times in a completely randomized block design (CRBD). The study was conducted for nine years. Malawi Hybrid 31 (MH31) variety for maize and CG7 variety for groundnut were used. Each season, the crops were planted towards the end of December (effective planting rains) and harvested towards May. The treatment details were as follows.

Farmer practice (FP): The plot comprised sole maize. This plot followed the traditional way of farming, i.e., farmer practice. Maize planting ridges were spaced at 75 cm. One (1) maize grain was planted per station at 25 cm apart. Under common farmer practice, ridge spacing and plant population are not strictly followed but they were followed to make the treatment comparable to others in this study. After harvesting the maize crop, the residues were either collected for firewood any time after harvesting or burnt from June to September as part of land preparation.

Pit planting + mulching (PPM): The treatment consisted of sole maize. No ridges were made; instead, planting pits of 30 cm × 30 cm × 20 cm (Government of Malawi, 2016) were used. The planting pits were spaced at 90 cm between rows and 70 cm between the centre of the pits. After digging, a pit was refilled up to 18 cm. Three (3) maize grains were planted 25 cm apart within the pit area (3 maize grains per pit). After harvesting, the maize crop residues were used as mulch on the plot. The same pits were used for three years before re-digging new ones. Pit digging and planting holes using a dibble was the only source of soil disturbance in this plot.

Intercropping + mulching (INM): The plot comprised maize intercropped with groundnut. There were no ridges in this plot. The plot had minimum soil tillage except for making a planting hole using a dibble. The maize planting rows were spaced at 75 cm. One (1) maize grain was planted per station along the planting rows, spaced at 25 cm. One groundnut seed was planted between the maize planting stations. After harvesting, maize and groundnut residues were used as mulch on this plot. Since maize was harvested about 10 days before groundnut, mulching of the plot with both crop residues was done soon after harvesting groundnut.

Mulching (MC): Sole maize was planted under minimum tillage except for making a planting hole using a dibble. One maize grain was planted per station, spaced at 25 cm and 75 cm between rows. After harvesting, maize crop residues were used as mulch in this plot.

In addition to the four main treatments (FP, PPM, INM, and MC) above, a separate sole groundnut plot (SSG) was set for the same period of the study. This plot was meant for the calculation of LER and LEC for INM treatment. It followed the same replication mode as other plots. Maize yield in INM and MC and the groundnut yield from INM and SSG

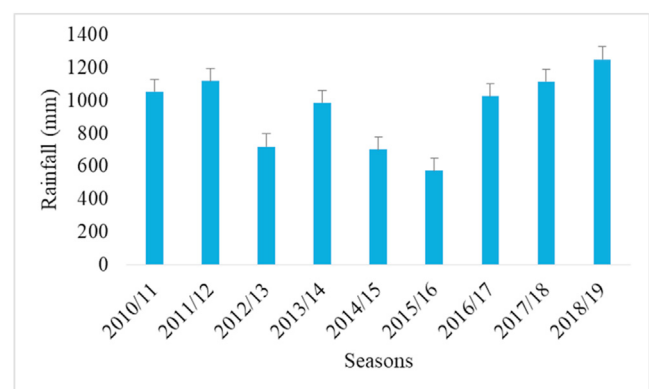


Figure 1. Mean seasonal rainfall (November to April) in the study area in Salima District, Central Malawi. The mean rainfall for the nine year period was 948.4 mm with a standard deviation of 228.9. (Department of Climate Change and Meteorological Services, Malawi Office, unpublished data).

were used to compute LER for INM. INM and MC were best comparable for LER and LEC because the only difference between them was groundnut (intercropping) in INM. In SSG, CG7 groundnut variety was used on 0.1 ha. The ridges were 75 cm apart, and one grain was planted per station at 15 cm apart on the ridge (Kabambe et al., 2018).

2.2.1. Trial management

Crops were planted on the same dates after the first planting rains. All the recommended crop management practices, including weeding and fertilizer application, were applied. In the maize plots, 23:21:0+4S (100 kg N:P: K ha⁻¹) was applied as a basal dressing at seeding while 100 kg of UREA (46% N) was applied as a top dressing, approximately 21 days after the planting date (Kabambe et al., 2018; Ministry of Agriculture, Irrigation and Water Development, 2018). In FP and groundnut (SSG) treatments, a hoe was used for weeding, while in CARP treatments, weeds were controlled by uprooting using hands as soon as weeds appeared.

2.3. Data collection

2.3.1. Soil samples collection, handling, and preparation

For a baseline, soil sampling was done in November 2010/11 (before planting), while in the study seasons, it was done in May (soon after harvesting). One composite soil sample was collected from each replicate plot. This sample (1 kg) comprised soil from five points on the plot (Anderson and Ingram, 1993). In FP, soil samples were collected on the ridge, while in CARP plots, they were collected between the maize planting stations since there were no ridges in these plots. The soil samples were obtained at a depth of 0–15 cm, generally described as top fertile soil (Brady and Weil, 1999) and where changes in SOC are easily detected (Arshad et al., 1996). Soil samples were collected using an auger of 4.5 cm in diameter. The soil samples for bulk density were collected using cores to maintain field soil conditions (Brady and Weil, 1999). The cores were 5 cm in diameter but long enough to sample in the 15 cm depth. All the individual samples were stored in plastic bags and sealed for transportation to the laboratory. Apart from the bulk density samples, the rest of the samples were air-dried in a room with good ventilation. These samples were sieved to remove materials greater than 2 mm. For each sample, a 2 mm sample of about 250 g was maintained for analysis. The samples were analyzed for bulk density (BD) in g cm⁻³, total soil organic carbon (SOC), total soil organic matter (SOM), soil pH (pH), total nitrogen (N), concentrations of potassium (K) (Cmol kg⁻¹) and phosphorus (P) in ug g⁻¹. All BD samples were dried at 105 °C in an oven for 24 h or until a constant weight was attained (Anderson and Ingram, 1993). Bulk density was calculated as the weight of dry soil divided by the volume of a core in g cm⁻³ (Brady and Weil 1999), and the result was recorded in two decimal places. The soil pH (water) (Kotrba and Schilling 2017) was measured using a pH meter on a scale of 0–14 pH, and the reading was taken to the nearest 0.5 unit (Kalra, 1995). Total SOC content was analysed following Walkley-Black procedures (Nelson and Sommer, 1982; Schumacher 2002), while SOM by dichromate oxidation method (Kalra, 1995) and was expressed as a percentage. To detect the changes in SOC over time, the total SOC ha⁻¹ at 9 years was multiplied by the quotient of initial/new BD (Agriculture and Food, 2020). This was to ensure that the assessment was done at the same soil mass (Davidson and Ackerman, 1993). Total N was determined following procedures by the Kjeldal method (Bremner and Keeney, 1966) and was expressed as a percentage, whereas P by Bray and Kurtz No. 1 extractant method (Bray and Kurtz, 1945) and K by flame photometer reading.

Maize and groundnut yields were measured as a subsample per plot. To eliminate the border effects (Tandzi and Mutengwa 2019), only 1,000 maize plants and 1,000 groundnut plants were harvested from the middle rows of the plot for yield estimation. The harvested area was measured for yield-area extrapolation (Ngwira et al., 2012). The maize and groundnut were dried off-field, initially unshelled. They were later

shelled to properly monitor appropriate moisture levels for yield measurement. The maize and groundnut were measured for yield determination at a moisture content of 13% (Akinnifesi et al., 2006) and 8% (Kabambe et al., 2018), respectively. The prevailing prices (details under section 2.4.3) for maize and groundnut were collected for the economic analysis of the treatments.

2.4. Data analysis

2.4.1. Soil, maize, and groundnut data

Data for maize and groundnut yields, SOC, SOM, N, K, pH, P, BD were tested for homoscedasticity (Levene test) and normality (Shapiro-Wilk normality test) in R Statistical Software Version 3.4.2 (R Development Core Team, 2017). Only potassium did not meet both conditions. Where normality and homoscedasticity were observed, one-way ANOVA and Tukey honest significant difference (HSD) test were performed to compare means while Kruskal-Wallis, a non-parametric test, was computed for potassium. The significant difference was at $p < 0.05$ level. A regression analysis was computed to assess maize yield trends across the seasons and relate SOC with BD. The other soil parameters were computed as average after nine years in a one-way ANOVA. This was so because the knowledge on the beneficial duration of CARP is critical for the adoption of full CA interventions in Southern Africa (Mango et al., 2017) and that the annual additions of SOC into the soil is a measure of the contribution of CARP in climate change mitigation (Amundson and Biardeau, 2018), hence the interest.

2.4.2. Intercropping efficiency

LER and LEC were computed to determine maize and groundnut intercropping efficiency. LER is used to verify if the intercropping maximises environmental resources for improved yield and soil conditions compared to sole cropping (Mead and Willey, 1980; Dhima et al., 2007). Intercropping is considered beneficial if an LER value exceeds 1 and non-beneficial if it falls below 1 (Ofori and Stern, 1987; Caballero et al., 1995; Dhima et al., 2007; Yilmaz et al., 2008). For LEC, the intercropping is considered non-beneficial if the value of LEC falls below 0.25 (Kheroar and Patra, 2013). The LER for INM and MC plots was computed using the formula:

$LER_{legume} = (Y_{gm}/Y_g)$ and $LER_{maize} = (Y_{mg}/Y_m)$ where Y_g and Y_m represent legume and maize yields as sole crops, respectively, whereas Y_{mg} and Y_{gm} represent yields of maize and legume as intercrops respectively. The final LER was calculated as: $LER (LER_{maize} + LER_{legume})$. The Land Equivalent Coefficient was calculated using the formula: $LEC = (Y_{gm}/Y_g) \times (Y_{mg}/Y_m)$. The meanings of terms are the same as in LER (Kheroar and Patra, 2013).

2.4.3. Economic analysis

The average prevailing prices of inputs were used to determine production costs/cultivation costs (Gross costs) as recorded by the extension staff in the study area. The prevailing market prices for maize (US\$ 0.26 kg⁻¹) and groundnut (US\$ 0.77 kg⁻¹) were used to calculate the Gross Returns per treatment. The Net Returns per treatment were calculated by subtracting the cost of production/cultivation (Gross costs) from the Gross Returns (Yilmaz et al., 2008). The Benefit-Cost Ratio (BCR) and labor productivity (LP) were computed among the treatments to determine the profitability of the interventions (Kheroar and Patra, 2013; FAO, 2017). BCR was calculated by dividing the Net Returns by the Gross Costs. The time taken to complete an activity (weeding, fertilizer application, mulching, planting, digging and filling up pits, harvesting etc.) was recorded and averaged for each activity (Ngwira et al., 2012). This was used to calculate labour productivity. Labour productivity was estimated by dividing the Gross Returns by time (hours) spent (Ibarrola-Rivas et al., 2016). This approach neutralises variations in the type and regimes of labour and allows for better comparison among different

production practices/systems (Ngwira et al., 2012; FAO, 2017).

3. Results

3.1. Maize yield and land equivalent ratio

The findings showed that CARP increased maize production in Salima District, Central Malawi. The average maize yield recorded in the treatments for FP, PPM, MC, and INM were 1.84 Mg ha⁻¹, 3.99 Mg ha⁻¹, 3.98 Mg ha⁻¹, and 4.43 Mg ha⁻¹, respectively. The yields among CARP were not significantly different but were all significantly higher than that of FP (Table 1). The average yield for groundnut was 1.91 Mg ha⁻¹. The LER and LEC in INM were 1.77 (>1) and 0.73 (>0.25), respectively. This indicates that intercropping of maize and groundnut maximised environmental resources for improved maize yield.

From the first season (2010/11), to the last season (2018/19), the maize yield in CARP varied between years but increased over time (Figure 2). The yield change (decrease) in FP was not significant ($p = 0.5330$, $R^2 = 7$) over years. In PPM ($p = 0.0172$, $R^2 = 52$), INM ($p = 0.0139$, $R^2 = 55$) and MC ($p = 0.0205$, $R^2 = 50$), significant maize yield increases were registered over time.

3.2. Soil condition

By the end of the study, SOC, SOM, pH, and nitrogen had improved in CARP treatments than in the FP. The specific details are reported in Table 2. SOM and SOC were highest in INM and lowest in FP. After nine years, FP had 17.5 Mg C ha⁻¹ while INM, PPM, and MC had 50.6, 41.0, and 42.2 Mg C ha⁻¹, respectively, from the initial SOC amount (38.1 Mg C ha⁻¹). The FP registered an annual loss of 2.3 Mg C ha⁻¹ while INM, PPM, and MC had an annual SOC gain of 1.4, 0.3, and 0.5 Mg C ha⁻¹, respectively. These annual changes were significantly different ($p = 0.0001$). Nitrogen was highest in INM and lowest in FP. Phosphorus decreased from FP to CARP treatments. There was no significant difference for potassium across the treatments ($p = 0.0642$), although actual amounts were highest in FP (0.30 Cmol kg⁻¹) and lowest in MC (0.26 Cmol kg⁻¹). The FP had acidic (pH 5.3) soils compared to CARP treatments (pH 6.4–6.9). The bulk density increased significantly from CARP to FP treatment with the lowest value in INM. The use of residues in CARP was meant to improve SOC and SOM and reduce soil compaction. A linkage was made on these three components where it was observed that a decrease in BD was associated with high SOC (Figure 3).

3.3. Economic potential of CARP

All CARP treatments were profitable interventions ($p < 0.0001$) compared to the FP (Table 3). However, within the CARP treatments, MC was the most profitable intervention (BCR 2.26) while PPM was the least (BCR 1.55). The study showed that FP was not a profitable option (BCR 0.15). MC had the highest labour productivity seconded by INM. There was a gain of US\$11.5 in one hour for MC compared to US\$1.3 in FP.

Table 1. The average maize yields (Mg ha⁻¹) across different treatments in Salima District, Central Malawi. The significant difference was at $p < 0.05$. Similar letters along a column show no significant difference.

Treatments	Maize yield (Mg ha ⁻¹)
Farmer practice (FP)	1.84 ± 0.021a
Mulching (MC)	3.98 ± 0.011b
Pit planting + mulch (PPM)	3.99 ± 0.024b
Interplanting + mulch (INM)	4.43 ± 0.13b
Mean	3.56
Standard deviation	1.16
P-value	0.018

4. Discussion

4.1. Soil nutrients, bulk density, and maize yield

SOM plays important role in moderating soil temperature, pH, and moisture (Prasad and Power, 1997; Brady and Weil, 1999). An increase of 2.9–12.5 Mg C ha⁻¹ (0.3–1.4 Mg C ha⁻¹ annually) in SOC among CARP treatments may be attributed to the accumulation of SOM from the crop residues over time. In CARP treatments where soil disturbance was minimal, biological activities on litter/residue possibly increased, resulting in high production and stability in SOM and SOC (FAO, 2005). The decrease in SOC in FP could be related to the compacted soils due to tillage at the same depth over time (Davidson and Ackerman 1993; Arshad et al., 1996), limited residues, and changed microclimates such as increased surface or soil temperature. In bare soils, the surface temperature reduces moisture in the soil and litter, preventing decomposing microbes from acting on detritus matter, unlike in mulched fields where high moisture content promotes residue decomposition by microbes, resulting in high SOM and SOC release (William 1998).

The significant reduction in BD in CARP could be related to the increased SOM in the Sandy clay loam soil, which responded favorably when subjected to organic means of soil fertility improvement (Riven-shield and Bassuk, 2007) and the long-term practicing of CARP. Moreover, the combined multi-crop root system in INM could be responsible for breaking up the soil at different depths, resulting in BD reduction, resulting in BD reduction, resulting in BD reduction. An increase in SOM, SOC, and a decrease in bulk density provide a conducive environment (root penetration, water movement) for plant growth and development (FAO, 2005). This could explain the increased annual gain in SOC in the CARP treatments compared to the FP. However, the findings of this study have shown that CARP associated with intercropping (maize + groundnut) returns significantly higher SOC (1.4 Mg C ha⁻¹ y⁻¹) than pure stand (maize only) CARP interventions which return about 0.3–0.5 Mg C ha⁻¹ y⁻¹. The present study differs from those of Ngwira et al. (2012), who found no significant difference in SOC status after six years under CA (of sole maize and maize with legumes-pigeon pea and cowpea) and the farmers' practice in south and central Malawi. In Zambia, Muchabi et al. (2014) did not observe a significant reduction in BD after four years of CA but registered a significant reduction of BD from 1.38 to 1.14 g cm⁻³ (0.24 g cm⁻³ decrease) after seven years. The present study registered a decreased range of 0.43–0.62 g cm⁻³ of BD. The findings could mean that CARP should be practiced for long-term to attain significant improvement in SOM, SOC, and BD.

The decayed residues from leguminous groundnut and root nodules in INM could be responsible for the high nitrogen increase in the treatment (Galloway et al., 2004; Laue and Patterson, 1981). These provide cushioning effect for many smallholder farmers who can not afford expensive inorganic inputs in most African countries (Druilhe and Barreiro-Hurle, 2012). Potassium might have been increased in the FP by seasonal burning from June to September as part of land preparation. Burning facilitates potash/ash accumulation (Pachon et al., 2013). Phosphorus showed high variability across the treatments. This may result from low extraction by the maize crop, as evidenced by its low yields, especially in the FP. The high values in FP could be attributed to the fact that crops use about 10–30% only in the season of application and the rest in subsequent years and that crops require more phosphorus than nitrogen and potassium (Ludwick, 1998). Phosphorus availability and uptake by plants largely depend on the interrelationship between the mycorrhizae and SOM rather than simple absorption from the soil solution (Trappe and Bollen, 1979). It could be possible that unstable interrelationship between mycorrhizae and SOM due to seasonal disturbance and shortage of SOM in FP, limited use by the maize crop might have accumulated the nutrient hence high values in FP. Moreover, a pH of less than 6.0, as was the case in FP, makes phosphorus bind with iron, which further reduces its availability to plants (Ludwick 1998). However, both potassium and phosphorus might have been well supplied due to the

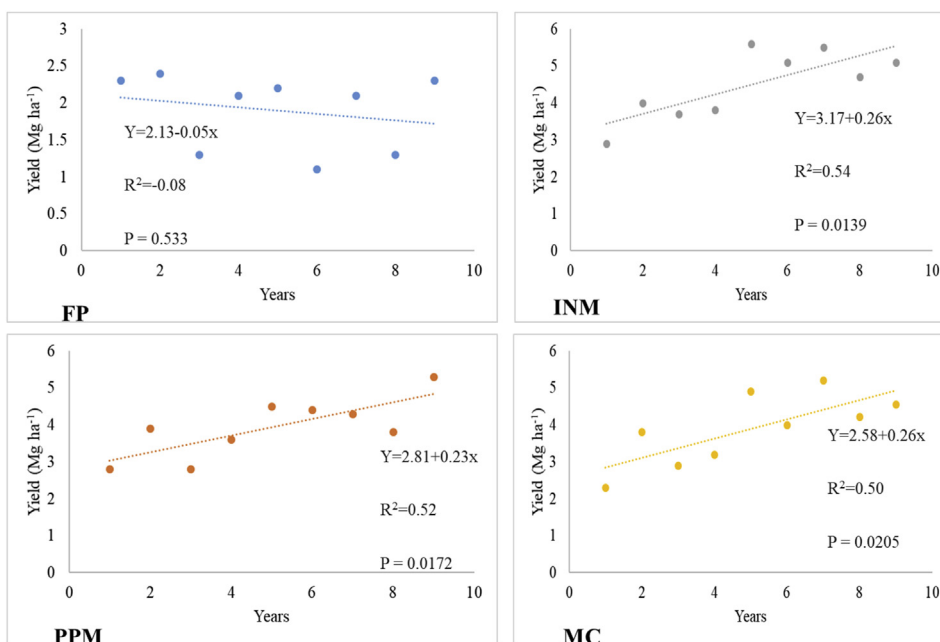


Figure 2. Maize yield (Mg ha⁻¹) trend across the treatments in Salima District, Central Malawi. (FP = farmer practice, INM = interplanting + mulch, PPM = pit planting + mulch, MC = mulching).

consistent use of inorganic fertilizers, hence their accumulation. According to the Department of Agricultural Research Services (nd.), the FP had adequate phosphorus amounts while CARP plots had low levels because it was below 8 ug/g for Malawian soils.

The soil pH in FP was within an acidic level (pH 5.3), while the CARP treatments had suitable levels (pH 5.8–7.5) for many crops (Brady and Weil, 1999). Soil health is deemed unproductive for crop production if the soil pH reaches ≤ 5.5 (Karlen et al., 2003; Munthali, 2007; Njoloma et al., 2016). Low soil pH in FP could be due to unsystematic burning (Chungu et al., 2019). pH increases significantly only if burning occurs at high temperatures to achieve complete combustion of vegetative residues (Arocena and Opio, 2003). The non-replenishment of organic materials would also be responsible for the low pH in the FP since less alkaline cations could be released during burning (Santana et al., 2018). There is a positive correlation between pH and SOM (Chungu et al., 2019); therefore, with the decreasing SOM in FP, pH would not be expected to increase even after occasional burning. Since all the treatments got the same application rates of inorganic fertilizers, the improved yield in CARP treatments in the present study may be attributed to the improved soil fertility and possibly stable soil moisture conditions due to residue use and intercropping. Other studies in Southern Africa showed that CARP increased maize yield (from 0.51 Mg ha⁻¹ to 3.6 Mg ha⁻¹) and SOC in the long-term (5–8 years) (Gotoso et al., 2011; Rusinamhodzi et al., 2011; Thierfelder et al., 2013). The current study recorded 3.98 Mg ha⁻¹ to 4.43 Mg ha⁻¹ in CARP and 1.84 Mg ha⁻¹ in FP.

4.2. Intercropping efficiency (LER and LEC)

The present study has confirmed that maize intercropped with groundnut produce high yield. Therefore, the study has parried away fears from some farmers with perceptions that such intercropping compromises the yield of the main crop (Liu et al., 2018). In India, Kheroar and Patra (2013) reported similar findings where they recorded higher maize yield (4.58–4.83 Mg ha⁻¹) in a maize-groundnut intercropping than in sole maize treatment. They observed that the maize plants in intercropping had the least number of barren stalks. Intercropping of maize with common bean and maize with cowpea had a LER of 1.24 and 1.61, respectively, with higher maize yield than in monoculture in Elbistan, Turkey (Yilmaz et al., 2008).

4.3. Economic advantages of CARP interventions

Apart from ridging, activities such as weeding significantly reduced CARP treatments, especially after the third year. The reduced workload, resource needs, and improved soil conditions in CARP treatments, may explain their profitability despite the upward price changes for production inputs along the study period. The deteriorating soil conditions, increased operations (weeding, ridging), low yield may be responsible for non-profitability of the FP treatment. However, among the CARP treatments, activities such as digging pits every three years in PPM, the planting and harvesting of two crops in INM may be responsible for the

Table 2. The average soil parameters in the four treatments, Salima District, Central Malawi INM = interplanting + mulch, FP = farmer practice, PPM = pit planting + mulch, MC = mulching, BL = baseline data, SOC = soil organic carbon, OM = organic matter, N = nitrogen, P = phosphorus, BD = bulk density, SD = Standard deviation from the Mean. Significant difference at $p < 0.05$). Similar letters along a column show no significant difference.

Treatment	pH	%N	%SOC	%SOM	BD (g cm ⁻³)	P (ug g ⁻¹)	K (Cmol kg ⁻¹)
FP	5.3a	0.08a	0.86b	1.21b	1.67b	20.51b	0.30a
BL	6.5b	0.40a	1.87a	1.75a	1.36a	12.02a	0.28a
INM	6.9c	1.09b	2.48c	2.85c	1.05c	3.97c	0.27a
PPM	6.7c	0.44a	2.01c	2.24c	1.24ac	8.28c	0.28a
MC	6.4b	0.51a	2.24c	2.44c	1.18c	4.73c	0.26a
Mean	6.3	0.5	1.89	2.1	1.3	9.9	0.261
SD	0.622	0.367	0.621	0.633	0.24	6.74	0.014
P value	0.006	0.016	0.005	0.012	0.014	0.019	0.0642

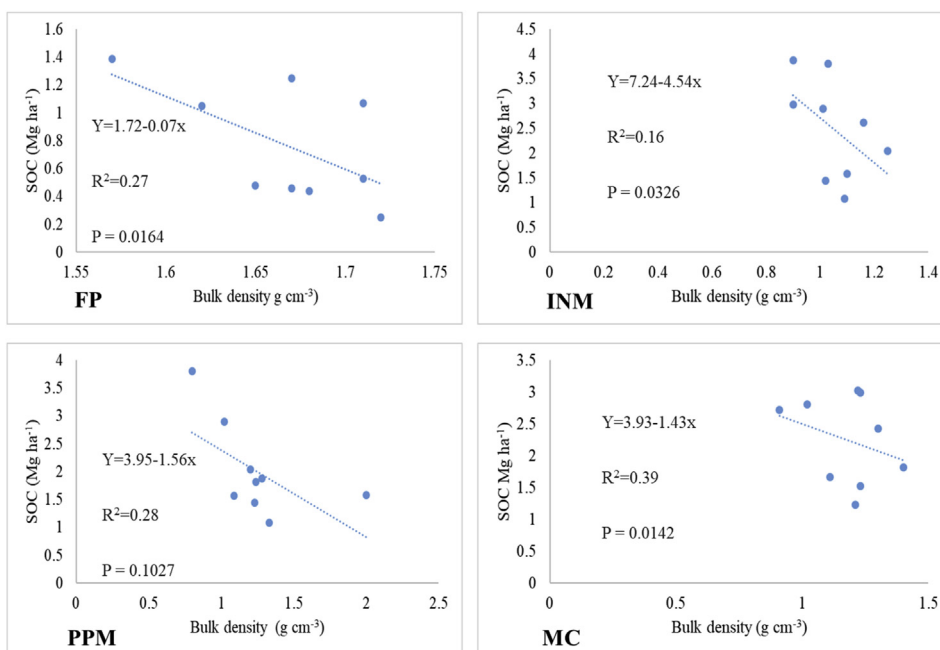


Figure 3. Relationship between soil organic carbon (SOC) and soil bulk density (BD) across the treatments in Salima District, Central Malawi (FP = farmer practice, INM = interplanting + mulch, PPM = pit planting + mulch, MC = mulching).

lower BCR than in MC. Naab et al. (2017) reported a 34% increase in Net Returns in CARP interventions compared to conventional practices in Ghana. They also reported a 53% reduction in variable costs in CARP interventions, which increased profitability (BCR 1.70) unlike in conventional practices. Ngwira et al. (2012), reported a 3 to 33 times higher Gross Margin for conservation agriculture than in farmer practice in Malawi from 2005/06 to 2011/12 seasons. The current study has established an 11 to 21 times higher Gross Margin in CARP than in FP. The CARP interventions are viable approaches for adaptation to effects of climate change experienced in the agriculture sector. Therefore, CARP interventions provide a win-win situation for soil fertility improvement, food security, and farmers' income.

5. Conclusion

Conservation agriculture-related practices contribute to maize yield increase and soil fertility improvement. Maize yield ranged from 3.98 to 4.43 Mg ha⁻¹ in conservation agriculture-related practices compared to 1.84 Mg ha⁻¹ in FP. The soil pH, SOC, SOM, nitrogen, bulk density were at acceptable levels in CARP interventions compared to the FP, suggesting that CARP improved the soil properties since most of the soil parameters had significantly improved compared to the baseline FP. Only phosphorus amount was significantly adequate in FP compared to CARP. The use of maize and groundnut intercropping maximised the use of environmental resources, which increased the maize yield. This was evidenced by high LER (1.77) and LEC (0.73) values. MC was the most

Table 3. Gross Costs, Gross Returns, Net Returns, Labour productivity and Benefit-Cost Ratio for conservation agriculture related practices and farmer practice (average data for nine years) ha⁻¹. INM = interplanting + mulch, FP = farmer practice, PPM = pit planting + mulch, MC = mulching, NPK and UREA are fertilizers. The exchange rate was 1US\$ = MK720; MK = Malawi Kwacha).

Summarised Components	FP (US\$)	INM (US\$)	PPM (US\$)	MC (US\$)
Maize seed cost	41.7	41.7	41.7	41.7
UREA cost	26.5	26.5	26.5	26.5
NPK (23:21:0+4S)	26.5	26.5	26.5	26.5
Groundnut seed cost	0	138.9	0	0
Ridging cost	34.7	0	0	0
Digging pits costs	0	0	52	0
Planting cost	23.3	48.9	34.7	34.7
Weeding cost	42.7	33.3	13.9	13.9
Harvesting cost	43.4	86.8	43.4	43.4
Gross Costs	239.9	402.7	238.9	186.8
Gross Returns	275	1168.5	609.6	608
Net Returns	35.1	765.8	370.7	421.3
Time spent (hours)	210	122.4	110.4	52.8
Benefit Cost Ratio	0.15	1.90	1.55	2.26
Labour productivity	1.3	9.5	5.5	11.5

profitable option with the highest BCR of 2.26, while INM was the most beneficial for soil fertility improvement with annual retention of 1.4 Mg C ha⁻¹. This study affirmed the proposed hypothesis that the application of CARP improves soil condition and maize yield. Farmers are advised to adopt conservation agriculture-related practices for soil fertility improvement, high maize yield, and profitability.

Declarations

Author contribution statement

Harrington Nyirenda: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Victoria Balaka: Analyzed and interpreted the data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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