Environmental Challenges 5 (2021) 100340

Contents lists available at ScienceDirect

Environmental Challenges

journal homepage: www.elsevier.com/locate/envc

The effect of minimum tillage and animal manure on maize yields and soil organic carbon in sub-Saharan Africa: A meta-analysis

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A B S T R A C T

In sub-Saharan Africa (SSA), diminishing soil fertility has been experienced from continuous cropping and low nutrient replacement. Organic inputs and minimum tillage are proposed to increase the declining fertility of the soil to increase crop growth and yields. We reviewed animal manure and minimum tillage use on maize yields and soil organic carbon (SOC) in SSA. This involved a meta-analysis on the influence of minimum tillage and animal manure on maize grain yields and SOC. The peer-reviewed publications on animal manure and minimum tillage influence on maize yields and SOC were selected from articles that contained one or multiples of the following keywords, 'tillage, minimum tillage, conventional tillage, organic, manure, animal manure' using ScienceDirect database. Reported data on maize yields and soil organic carbon were extracted from figures, tables, and text, of the selected studies. These studies were analyzed using R, and results were presented in a forest plot. Minimum tillage had no significant influence on maize yields and soil organic carbon. Animal manure significantly improved maize yields and soil organic carbon. The study underscored the importance of animal manure in improving maize yields and soil organic carbon in SSA. Animal manure application in maize cropping systems is plausible to increase maize yields and soil organic carbon in SSA.

1. Introduction

An increase in the global population has impacted food security due to agricultural intensification leading to soil degradation (Pradhan et al., 2017). Most farming in SSA is rain-fed dependent, facing numerous challenges such as; low soil quality, low earnings, limitations of land and labor, and the emerging climate variability issues (Rurinda et al., 2013; Mairura et al., 2021). Diminishing soil fertility is the main limiting factor in smallholder farming in the region's farmers' constraint (Ngoma et al., 2015). Nutrient removal from the soil has been observed due to continuous cropping and low nutrient replenishment in SSA (Moebius-Clune et al., 2011). This has diminished food production compared to Latin America, North America, China, and Australia, which have reported increased food production over time (Hazell and Wood, 2008). Low soil fertility resulting from land degradation is also due to rigorous tillage and crop residue removal, leaving the soil susceptible to erosion (Cerda et al., 2009). For instance, soil fertility decline in Kenya due to limited soil inputs and land degradation has been reported to pose a food security issue, especially in maize production (Karaya et al., 2012). Further, low and erratic rainfall worsens the situation in SSA (Cobo et al., 2009). Several studies proposed animal manure as an organic resource (Abuom et al., 2014; Shisanya et al., 2009; Mwaura et al., 2021), integrating inorganic with organic inputs and reducing tillage (Kiboi et al., 2019) as practices that could improve crop yields and soil quality.

Maize is a major cereal crop in SSA, mainly grown by subsistence farmers using household labor on relatively limited land sizes (Bedeke et al., 2019). Maize is grown in different climates as it has numerous cultivars, great returns on money, and nutritional values (Abate et al., 2015; Adimassu et al., 2014). For example, as a study in Northeast Nigeria reported, fast-growing maize cultivars can yield even in areas that experience low rainfall (Kamara et al., 2009). Most of the SSA region is experiencing climate stress due to climate variability, negatively impacting maize production (Lobell et al., 2011). Moreover, rapid soil degradation due to the increased human population, inaccessible agronomic consultation services (Falco, 2014), and inadequate soil nutrients resources (Ngetich et al., 2014) leading to reduced crop growth and production (Mulwa et al., 2017). Variation in the rainfall pattern in SSA has led to low maize production and, consequently, poverty (Akinnifesi et al., 2010). For instance, in Ethiopia, maize production in the Central Rift Valley has experienced temperature increases of 0.12–0.54 °C and high rainfall variability recently, and (Kassie et al., 2013) has challenged farmers who depend on rain for maize production. The increased demand for maize as a staple food for most SSA communities creates a need to improve yield per hectare on already existing

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https://doi.org/10.1016/j.envc.2021.100340
Received 17 August 2021; Received in revised form 19 October 2021; Accepted 19 October 2021

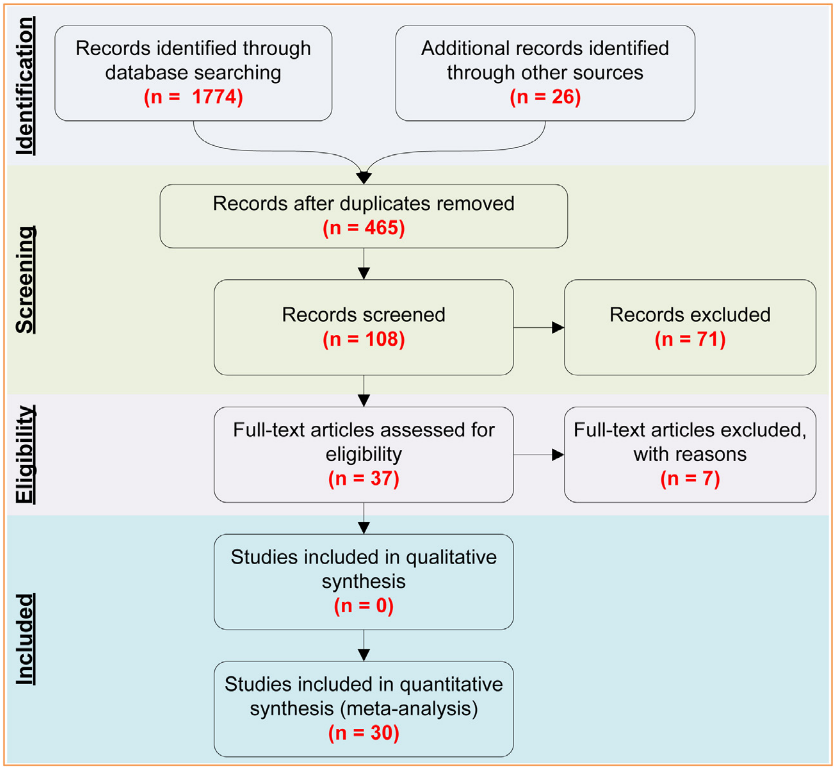

Fig. 1. Preferred reporting items for systematic reviews and meta-analyses (PRISMA) for minimum tillage and animal manure studies in sub-Saharan Africa.

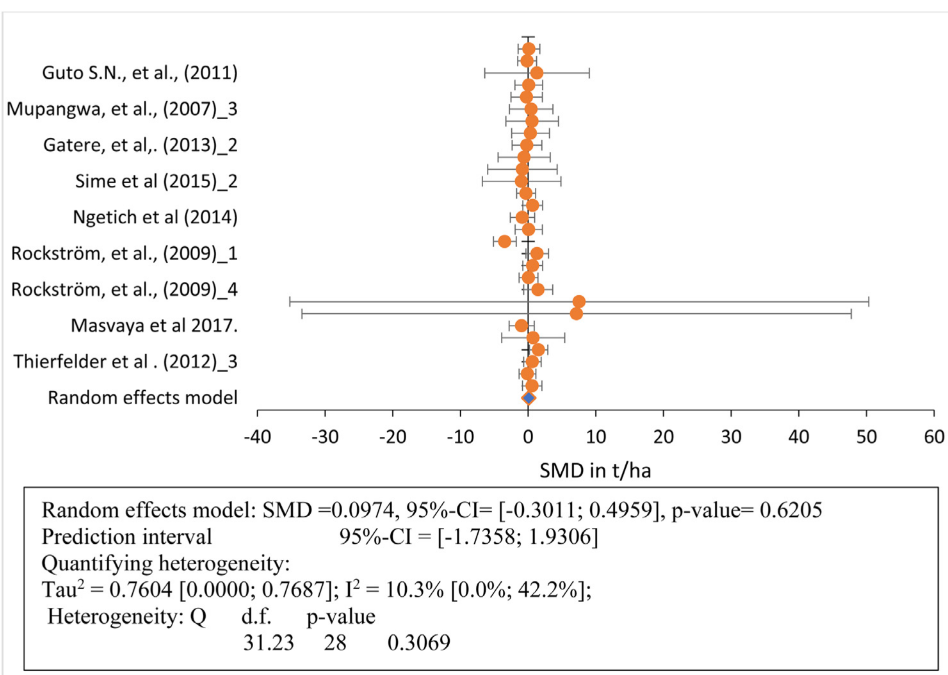

Fig. 2. Forest plot for the effect of minimum tillage on maize yields in SSA. SMD = Standardized mean difference the overlap across SDM indicates no significant differences. 95% CI = confidence interval indicating a 95% confidence that the mean of the population range between - 0.03and 0.50 t/ha. I^2 (Higgins and Thompson, 2002). τ^2 = tau^2 Q = Cochran's statistic, $d.\ f$ = degrees of freedom, $p \leq 0.05$.

farming land by the small-scale holders (Adamtey et al., 2016) through agricultural management strategies.

Soil organic carbon (SOC) suggests the inherent fertility of the soil SOC stores nutrients, adds to soil aeration, improves the rate of infiltration of water, and the ability of soil to store water (Naresh et al., 2017). The amount of SOC is influenced by management practices, soil properties, temperature, rainfall, the extent and kind of soil inputs, and land use (Fantappiè et al., 2010; Farina et al., 2011). Agricultural practices such as minimum tillage increase soil quality by enhancing microbial community and activity (Ghimire et al., 2014) and increases root biomass production, which leads to SOC protection (Franzluebbers, 2007). Further, minimum tillage improves soil organic matter by decreasing the exposure of SOM to microbial degradation (Yang et al., 2015). An increase in fine roots and microbial biomass increases SOC amounts (Ghimire et al., 2014). Animal manure influences the microbial biomass pool, increases microbial activities, and impacts microbial communities (Zhang et al., 2012). This is brought about by high C inputs and native microbes from the manure (Blagodatskaya et al., 2009).

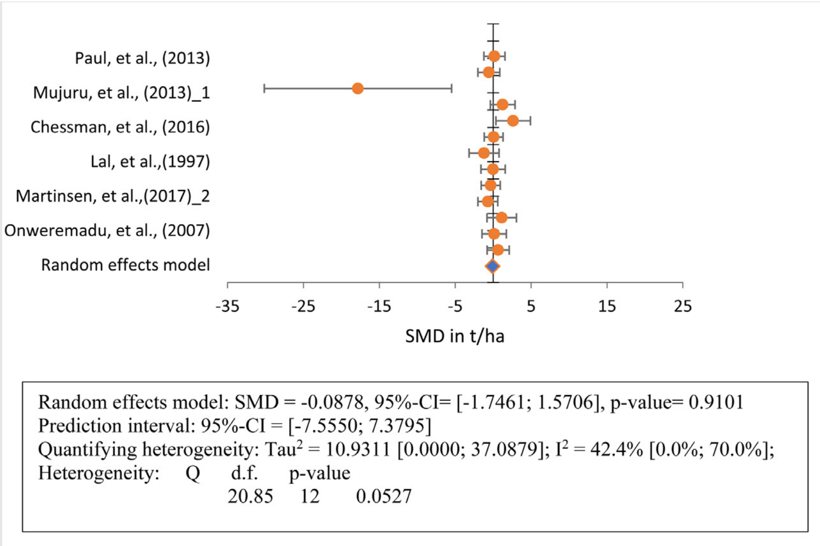

Fig. 3. Forest plot on the effect of minimum tillage on soil organic carbon (SOC) in SSA. SMD = Standardized mean difference the overlap across SDM indicates no significant differences. 95% CI = confidence interval indicating a 95% confidence that the mean of the population range between - 1.75 and 1.57 t/ha. I^2 (Higgins and Thompson, 2002), τ^2 = tau^2, Q = Cochran's statistic, $d.f$ = degrees of freedom, $p \leq 0.05$.

1.1. *Tillage influence on maize yields and soil organic carbon*

Different tillage methods have different outcomes on crop production and soil health. Minimum or reduced tillage involves minimal soil disturbance, which results in several advantages. Minimum tillage augments soil's physicochemical and biological properties through reduced soil erosion, thus allowing soil organic matter buildup (Bescansa et al., 2006; Cardoso et al., 2013). It also decreases compaction, reduces erosion and runoff, and conserves soil microbial activity (Sauvadet et al., 2018). However, it's difficult to control weeds when minimum tillage is used, thus, heavy reliance on herbicides (Melander et al., 2013). Also, crops grown under minimum tillage are more adaptive to climate variations and have higher yields than conventional tillage (Busari et al., 2018). On the other hand, conventional tillage, which farmers in SSA commonly practice, control weeds and allows for effective sowing and planting operations (Jin et al., 2007). In conventional tillage, decomposition of organic matter is promoted through disturbance of the aggregates in the soil and enhanced aeration and even distribution of carbon sources in the soil (Martníez et al., 2017). Moreover, conventional tillage speeds up microbial activity on the protected organic carbon, accelerating nutrient cycling (Tian et al., 2016).

Most smallholder farmers in SSA practice some form of minimum tillage, which has shown increased yields. Studies have reported that minimum tillage yields less in an experimental study's initial stages than conventional tillage (Das and Bauer, 2012). For example, Pittelkow et al. (2015) showed that maize yields reduced with less than five years of minimum tillage but increased over time. A review by Giller et al. (2009) reported that less or no yields are observed when minimum tillage is used in the short term. The initial yield decrease could be attributed to short duration of experimentation (Lechenet et al., 2016). The period needed by the personnel to obtain the required expertise to run the experiments and also the agricultural system to adapt to the experiment (Dignac et al., 2017; Pittelkow et al., 2015). Further, short-lived challenges related to soil structure change, residue retention, *N*-availability, weed management, and soil compaction could be reported at the beginning of modification to reduced tillage (Derpsch et al., 2014). Studies have shown greater maize yields when minimum tillage is practiced over 3 to 4 years. For instance, in Ethiopia, Rockström et al. (2009) reported improved maize yields of 40% over conventional tillage in a 4-year study, while Ngwira et al. (2012) indicated maize yields increased by 29% in minimum tillage to conventional tillage in a 3-year study in Malawi.

Conventional tillage usually out yields minimum tillage due to *N* mineralization's speeding up from soil organic matter due to soil disturbance and microbial degradation of exposed protected organic matter due to soil structure disruption (Balesdent et al., 2000). For example, in Zimbabwe, Masvaya et al. (2017), comparing minimum tillage with conventional tillage, there was a depressed maize grain yield by 4–60% when minimum tillage was used. A study in Nepal by Balesdent et al. (2000), after two years, showed conventional tillage yielded more maize yields than minimum tillage. The authors attributed this to limitations in the root development in the early stages of growth, leading to less nutrient availability in the minimum tillage plots. There's an increase in maize yields over time when minimum tillage is used, and conventional tillage yields decrease due to lessening soil fertility brought about by low soil nutrients and organic carbon (Okeyo et al., 2014).

Improving soil health and enabling sustainability in farming by increasing and maintaining soil organic carbon is essential (Jarecki et al., 2018). Organic and inorganic soil inputs influence soil carbon as a study by Jiang et al. (2014) indicated that frequent mineral fertilizers' addition might reduce SOC, as *C* inputs from organic matter are less than *C* decomposed by micro-organisms. On the contrary, manure application can supply nutrients to the soil (He et al., 2015), improving SOC content (Cerda et al., 2009). Inorganic fertilizers' use increased root biomass in the soil, increasing SOC (Tian et al., 2015). Inorganics might decrease *C* content compared to soils with no added inputs (Shimizu et al., 2009). Therefore, judicious application of mineral and organic soil inputs increases the SOC stocks (Ghosh et al., 2015).

Soil organic matter interaction with soil inputs affects soil inputs' nutrients mineralization/ immobilization (Dignac et al., 2017). The type and the amount of soil organic materials and soil disturbance influence *C* storage in minimum tillage practice (de Moraes Sá et al., 2008). Additionally, carbon amounts are influenced by the tillage methods used and the amount of carbon inputs which were limiting (0.1–1 g C kg^{-1} soil yr^{-1}) but not by a great scale (~2 Mgha^{-1}) (Chessman et al., 2016). Minimum tillage adds SOC amounts in the upper layers of some soil occures when where there are high amounts of roots and surface litter (Powlson et al., 2012). Additionally, minimum tillage enhances SOC storage more than conventional tillage. For instance, Liu et al. (2014) observed that the accumulation of SOC in 0–60 cms was higher in reduced tillage (50.2 t C ha^{-1}) than (46.3 t C ha^{-1}) in conventional tillage. The studyby Enfors et al. (2011). pointed out that minimum tillage and manure increased SOC by 1.2% compared with conventional tillage. Studies under minimum tillage conducted for a longer period show increased soil *C* stocks (Govaerts et al., 2009). This is because the soils un-

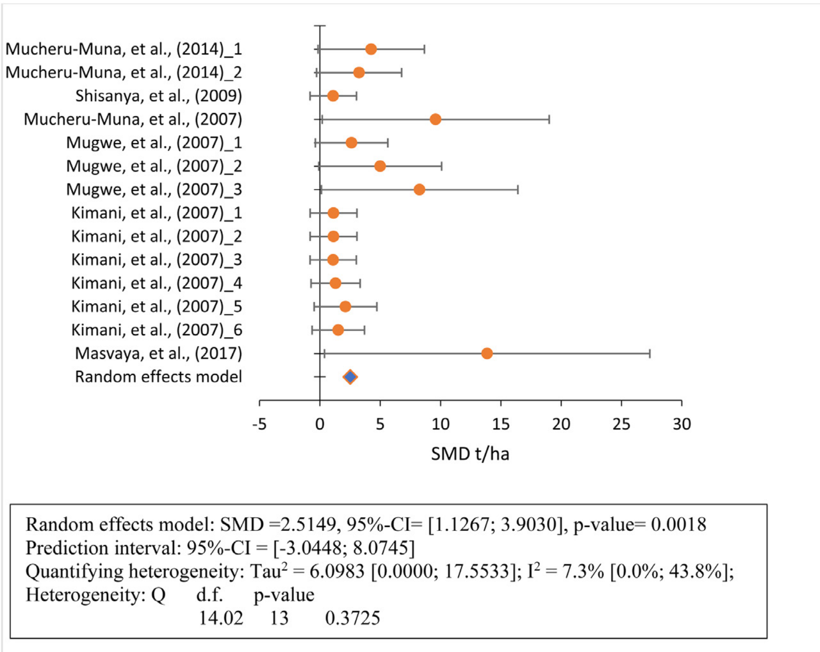

Fig. 4. Forest plot on animal manure's effect on maize yields in the SSA. SMD = Standardized mean difference the overlap across SDM indicates no significant differences. 95% CI = confidence interval indicating a 95% confidence that the mean of the population range between 1.13 and 3.90 t/ha. I2 (Higgins and Thompson, 2002), τ^2 = tau^2, Q = Cochran's statistic, $d.\ f$ = degrees of freedom, $p \leq 0.05$.

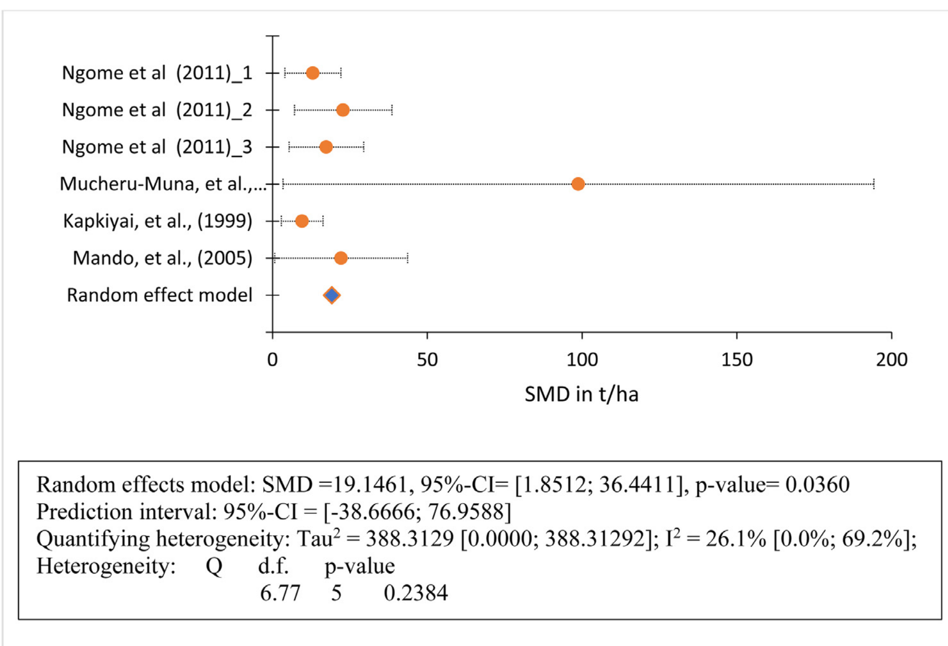

Fig. 5. Forest plot on animal manure's effect on soil organic carbon (SOC) in SSA. SMD = Standardized mean difference the overlap across SDM indicates no significant differences. 95% CI = confidence interval indicating a 95% confidence that the mean of the population range between 1.85 and 36.44 t/ha. I^2 (Higgins and Thompson, 2002), τ^2 = tau^2, Q = Cochran's statistic, $d.\ f$ = degrees of freedom, $p \leq 0.05$.

der minimum tillage are less exposed to erosion, leaching, and volatilization of ammonia (Onweremadu et al., 2007).

1.2. *Animal manure effects on SOC and crop yields*

The application of manure provides carbon and other nutrients that the plants take up. For instance, studies done in Kenya showed that most manure used by farmers has less than 1% nitrogen (Giller et al., 1997). Manure is used by most households (80%) in Kenya's central highlands (Makokha et al., 2001). Further, 90% of them get manure from households, and the remaining 10% is bought or handed free, but this is not enough as a source of nutrients to their farms (Makokha et al., 2001). In Western Kenya, animal manure adoption is limited by its low availability and quality (Odendo et al., 2007). In addition, soil organic matter from manure has a unique role in forming stable humus fractions through humification and is responsible for nutrient cycling in the soil (Yang et al., 2016). Animal manure usually releases macro and micronutrients steadily to the soil during the cropping period (Adediran et al., 2005). Decomposition of manure may provide organic acids accelerating acidification, leading to leaching of Ca from the soil, especially in low fertility soils (Zaujec et al., 2009).

Soil organic matter (SOM) pools are affected by manure application, which generates soil dissolved organic *C* in large amounts (Abalos et al., 2013). This is intensely associated with microbes and enzyme activities (Kiikkilä et al., 2014). The incorporation of manure adds high carbon inputs to the soil, which provide energy for micro-organisms and increase *C* immobilization. For example, the addition of manure increased yearly *C* amount than inorganic fertilizer in Japan (Shimizu et al., 2009). Further, a SOC balance was reported after manure application in a study by Mori and Hojito (2015). The addition of organic amendments increases SOC stocks. Carbon stocks in the world at 0–20 cms depth improved 240–460 Kg C $ha^{-1}yr^{-1}$ after ten years of addition of manure (Gattinger et al., 2012). Further, a 30% rise in SOC in 0–15 cm depth of soil when manure was added (Zavattaro et al., 2017). Manure application could further add SOC concentration due to added organic *C* inputs in manure (Zhao et al., 2014). Further, after the addition of manure for four years, a 25% C was stored in the soil carbon pool (Eghball, 2002). Conversely, recent studies have shown a decrease in SOC with the application of animal manure to nutrient mining (Naresh et al., 2017; Wang et al., 2015).

Soil organic carbon amounts are an essential guide for different crop yields (Tian et al., 2016). Some studies have indicated that adding manure for a long time results in residual effect, leading to greater amounts of nutrients available for crops (Cerda et al., 2009). This is ascribed to manure slowly releasing nutrients in the soil (Yang et al., 2015). Manures add nutrients by generating plant-based acids that bind with the aluminum, diminishing its toxicity, thereby increasing the nutrients for crop growth (Nziguheba et al., 1998). Organic soil inputs addition to the soil improves soil health and yields (Shahid et al., 2013). Increased organic *C* input related to high yields augments SOC stocks by 32–87%, and that an average increase in maize yields 7–10% and 8–15% in the 2nd and 3rd year of organic manure application compared with inorganic manure application (Zhang et al., 2016). A 2% maize yield increase in 4 years and a 10% increase in 9 years was reported (Cai et al., 2019). Moreover, maize yields increased by 430 kg/ha, and yield variability reduced by 3.5% when SOC content of the topsoil (0–20 cm) increased by 1% (Pan et al., 2006). However, other studies have reported that organic inputs use lead to lower soil *C* (Leifeld et al., 2013).

In combination with inorganic soil inputs, the addition of organics improves the release of nutrients and uptake by plants (Palm et al., 1997), resulting in improved yields. This is true, as fertilizers increase crop yields and yield large crop residues that impact the soil fertility and the organic resources can restore the degraded soils, allowing fertilizer use efficiency (Vanlauwe et al., 2010). Further, increasing the farmyard manure application rate increased maize yields (Kihanda, 1996). The addition of inorganic fertilizer with farmyard manure augmented maize yields to more than 3.5 t ha^{-1}. Therefore, an assessment of animal manure use in enhancing and maintaining SOC and improving the amount of soil nutrients that would support crop growth and enhance SSA yields is prudent. Further, an assessment of minimum tillage as an agricultural practice affects SOC amounts, and maize yields in SSA are required. Thus, this review's objective was to assess the influence of minimum tillage and soil inputs, particularly animal manure, on soil organic carbon and maize yields in SSA.

2. Data retrieval and analysis

We used peer-reviewed journal papers focusing on the influence of minimum tillage and animal manure on SOC and maize yields. We searched for the studies reviewed from the ScienceDirect database (www.sciencedirect.com). The keywords used to narrow the search included "tillage," "manure," "soil organic matter," "yields," and to narrow the search further "minimum tillage and or reduced tillage," "animal manure," "maize yields," "soil organic carbon" were included. Truncations were used for the words organic, manure in the search. This was to cater to the plural and continuous tense of these words: Organic *, (organic, organics), manure* (manure, manures, manuring). The inclusion criteria were as follows; (1) Randomized complete block design (RCBD) as the experimental design, (2) area of coverage is Sub- Saharan Africa as the region/area of coverage, (3) the test crop is maize intercropped or as a mono-crop. (4) Minimum tillage as a treatment and conventional tillage served as the control (5) soil input as animal manure. The exclusion criteria used were for; (1) the studies with no control, (2) conference proceedings, (3) scientific correspondence (4) posters, and (5) reviews. We obtained abstracts of the studies identified that fit the above criteria. The process yielded 30 studies, as summarized in Fig. 1.

Reported data on maize grain yields and SOC were extracted from figures and or tables from the studies. The mean of the intervention and the mean of the SOC control (Mg/ha), and the yields (t ha-1) for minimum tillage and animal manure were tabulated in Microsoft Excel ™. Additional information extracted from the studies included the number of replications, the experimentation period or the reported duration of the experiment, soil type, coordinates of the study sites, textural class of the soil, trial type (on station or on-farm), experimental sites, and country in which the study was carried out (Table 1).

Some of the articles used had more than one site, and therefore, the sites are treated as study areas for comparison. Meta-analysis using R was done on the data collected (R, 2015). First, the data from the Microsoft Excel ™ was arranged according to sites that were used as the unique identifier. The studies described data in similar units. Therefore, Hedges' g standardized mean difference (SMD) was used as the weighted amount of studies, maintaining (Mg/ha and t/ha), which were essential for the random effect model (Hunter and Schmidt, 2000). The sample size, denoted as *N*, was used as the replicates of the studies. The heterogeneity was measured using three parameters; Cochran's statistic (*Q*), Higgin's & Thompson's I^2, and Tau squared (τ^2). (1) Cochran's *Q* statistic (chi-square statistic) is the variance amongst the experimental weighted sizes and the fixed effect model approximation of the weighted size. (2) Higgins and Thompson (2002)'s I^2 is the proportion of unpredictability in the weighted sizes, which is not caused by an error in sampling which results from *Q*. (3) Tau squared (τ^2) is the variations within the studies in our meta-analysis and was done using Sidik and Jonkman (2007) and Hartung and Knapp (2001a,2001b) adjustment for the random effect model. A summary effect estimate was done using the random effect model (Schwarzer et al., 2015) that assumes that the studies are not homogenous and that the sample is part of a larger population of studies. A forest plot was drawn, showing how every study's weighted approximations were spread near a null value and around the overall weighted estimations. Twenty-nine (29) and fifteen (15) study sites were used to obtain forest plots on minimum tillage and animal manure effects on maize yields. Six (6) and thirteen (13) study sites were used to obtain forest plots on the influence of minimum tillage and animal manure on SOC.

3. Results and discussions

3.1. Minimum tillage effects on maize yields

Minimum tillage had no significance (p = 0.62) influence on the maize yields (Fig. 2). The results show no considerable variance in maize yields in minimum tillage and conventional tillage as the control (farmers' practice). This concurs with Atreya et al. (2006) study indicating minimum tillage did not influence maize yields. In other studies, maize yield output in minimum tillage was insignificant compared with conventional tillage (Ngetich et al., 2014; Nziguheba et al., 1998). Further, changes in soil structure, surface residue retention, and N availability may interfere with the introduction of minimum tillage in a cropping system (de Moraes Sá et al., 2008). A study in South Africa reported reduced maize yields in minimum tillage plots Swanepoel et al. (2018) and attributed this to the topsoil compaction (Taylor et al., 2012). This could have reduced root penetration, infiltration, and water storage,

Table 1
Characteristics used in selecting minimum tillage and animal manure studies in sub-Saharan Africa ($n = 64$). The number and percentage of the study sites are shown for each of the categories.

Characteristics	Number of study sites	% of the study sites
Number of replications		
1–10	56	90
> 10	8	10
Number of seasons		
1–10	61	98
> 10	3	2
Units in which maize yields were originally reported[b]		
Kg/ha	19	44
t/ha	15	35
Mg/ha	9	21
Units in which SOC content was originally reported[b]		
Mg/ha	7	37
Kg/mg^2	4	21
g/kg	3	16
Others (Kg/m^3, mg/g, t/ha)	5	26
Soil type[a]		
Humic Nitisols	19	29
Cambisols	6	9
Eutric Arenosols	4	6
Ferrasols	4	6
Acrisols	4	6
Soil textural class[a]		
Clay	30	48
Sandy	6	10
Sandy loam	13	21
Trial type		
On-farm	37	60
On-station	25	40
Study countries[a]		
Kenya	29	47
Zimbabwe	10	16
Zambia	9	15
Minimum tillage practices[a]		
Hand pulling, only planting holes are open	14	33
Ripping	13	31
Planting basins	12	29

[a] Only the top choices of the characteristics are shown.
[b] Units before conversion as they appear in the studies.

leading to the lower root and plant proliferation and, consequently, yields (Tadesse et al., 1996). Further, a study in Ethiopia reported that minimum tillage had lower yields (13–20%) than conventional tillage (Sime et al., 2015). The authors attributed this to increased weed infestation in the minimum tillage plots and the short study period. Minimum tillage in the short term resulted in low or no yields but could result in higher yields in the long run (Giller et al., 2009). However, some studies have reported maize yields to increase in the short term. For example, in a three to four-year study in Ethiopia, maize yielded higher in minimum tillage than conventional tillage (Ito et al., 2007; Rockström et al., 2009). A three to ten-year study gave similar results in Malawi (Ngwira et al., 2012).

3.2. Minimum tillage on soil organic carbon

Minimum tillage had no significant (p = 0.91) effect on soil organic carbon (Fig. 3). The 95% CI ranged from - 1.7461 to 1.5706 t/ha. The present analysis shows that minimum tillage, which is the intervention, does not impact the SOC. This is documented in various studies that recorded no increase in SOC amounts after minimum tillage was implemented as an agricultural practice. For example, Sheehy et al. (2015) study showed no significant change in SOC.Further, Büchi et al. (2017) reported that in a 44-year trial, 0–20 cm depth, there was no considerable decrease in SOC in minimum tillage treatment. This may possibly be ascribed to the experiments' duration as SOC and soil properties change slowly Büchi et al. (2017) since several years are required for balance after the change of the tillage system. Other factors, type of soil, and weather patterns Wiesmeier et al. (2015) could influence the amount of SOC in minimum tillage treatment by inducing residue decomposition rate and the turnover of SOC. This study's results are contrary to other studies. For example, Prasad et al. (2016) indicates that reducing tillage intensity increased the organic carbon. Previous studies in Zambia and Zimbabwe showed increased *C* stocks, 0–30cms depth, converted from conventional tillage practices to conservation agriculture in four years (Thierfelder and Wall, 2010, 2012). Improvement of the amount and maintaining the carbon in the soil would lead to improved soil quality.

3.3. Effects of animal manure on maize yields

Animal manure significantly ($p = 0.0018$) influenced the maize grain yields (Fig. 4). The 95% confidence interval ranged from 1.1267 to 3.9030 t/ha. All the study sites showed an increase in yields when animal manure was used as a soil input. This could be attributed to the organic input (animal manure), which is acknowledged to increase soil physicochemical and biological properties, improving the nutrients available for plant growth (Giacometti et al., 2013). Manure improves the soil's physical condition resulting in higher nutrient uptake by the soil leading to increased yields (Mando et al., 2005). Further, Kimani et al. (2007) study showed maize yields increase under manure application. Further, increased nutrients due to the addition of manure led to improved maize yields (Mucheru-Muna et al., 2014). A two-year study in Benin by Tovihoudji et al. (2017) reported that animal manure application significantly improved maize yields as opposed to no animal manure plots in both years. In China, Yang et al. (2004) indicated that the addition of manure considerably augmented macronutrient absorption by maize plants, instigated transfer and relocation of nutrients to the grains. A manure application study in India reported that maize yields were higher by 60% than plots with no inputs (Rasool et al., 2008). Therefore, as shown in the analysis, animal manure would be used to improve maize yields in sub-Saharan Africa.

3.4. Animal manure on soil organic carbon

Animal manure significantly ($p = 0.04$) influenced the soil organic carbon in SSA (Fig. 5). The findings underscored the importance of animal manure in enhancing soil health through improved SOC. This may be endorsed because the use of animal manure as a soil fertility intervention enhances soil organic matter buildup. This corroborated with Tittonell et al. (2005) looking at the heterogeneity in soil fertility management in Western Kenya, indicating that household priorities and production strategies determined the variation in the adoption of organic resources. Further, farmers in Aludeka used less cattle manure in their farms because they had a smaller cattle population and were less efficient in collecting the manure as they allowed free grazing (Tittonell et al., 2005). This resulted in less cattle manure being available for applying to the soil. However, once applied, the animal manure improves soil organic carbon in the soil.

Further, this scenario of low adoption of soil fertility improvement strategies is validated because most of the farmers in SSA are resource-constrained, leading to low uptake of soil fertility improvement technologies such as the choice to use these technologies is dictated by biophysical attributes, socioeconomic situations that do vary, leading to different farming systems in one area (Yengoh, 2012). A high economic return was recorded when sole manure was used as input (Ngetich et al., 2014; Mwaura et al., 2021). This was attributed to the availability of manure in the farms and the lower cost related to its use, leading to increased SOC. This meta-analysis showed that most of the studies showed that animal manure increased SOC and agrees with agrees with Li et al. (2018)'s study which recorded that treatments that received animal manure had higher SOC than mineral fertilizer and no input treatments. Further, these SOC concentrations increased with organic manure incorporation rates due to a large amount of recalcitrant organic compounds in manure (Liu et al., 2014). The SOC increase can further be ascribed to slow decomposition rate of organic manure (Zhou et al., 2015). In addition, SOC concentration after a long-term experiment with cattle manure increased by 20% (Blanco-Canqui et al., 2017).

4. Conclusion

The meta-analysis showed that animal manure interventions can improve maize yields and soil organic carbon in SSA. The improvement of maize yields in SSA would improve livelihoods and increase incomes among households. Soil fertility improvement is made possible in the long run through these interventions improving the soil's quality by maintaining the nutrients present in the soil. However, minimum tillage showed no significant influence on soil organic carbon and maize yields. Our study focused on the sole implementation of minimum tillage, which is promoted under the umbrella of conservation agriculture. Therefore, evaluation of conservation agriculture's influence on soil organic carbon and maize yields is requisite. Our findings underscored the importance of animal manure in improving soil health and agricultural productivity. Therefore, animal manure should be promoted among smallholder farmers in SSA for improved soil health and crop yields.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

The authors acknowledge the Swiss Agency for Development and Cooperation (SDC) and Swiss National Science Foundation (SNSF) in the Swiss Programme for Research on Global Issues for Development (R4D program) for providing financial support (Grant No. 400540–152224) through the Organic Resource Management for Soil Fertility project to conduct the trials. We appreciate the smallholder farmers from Tharaka-Nithi and Murang'a Counties who participated in the study. We also wish to thank the area chiefs and agricultural extension officers in the two sites who linked us with the members and ensured the smooth running of the survey in their respective jurisdictions. Lastly, we appreciate all the enumerators who participated in data collection.

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