

Short-term effects of soil fertility, tillage and residue management on soil organic carbon, aggregate stability and water infiltration on a sandy soil in urban agriculture, Harare

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Abstract

Manure is a key nutrient resource to urban farmers due to its multiple benefits, especially on inherently infertile sandy soils. Research on cattle manure in sub-Saharan Africa has mainly focused on its role in supplying N required by crops with little attention given to its multiple benefits such as its effects on other soil properties. The objective of this study was to determine short-term integration of soil fertility and water management practices on soil organic carbon (SOC), aggregate stability and water infiltration in urban agriculture (UA). An experiment was carried out on sandy soils fertilized with organic and inorganic fertilizers under conventional (CT) and zero tillage (ZT) systems with (5 t ha⁻¹) and without maize stover mulch. Cattle manure (1.26 % N) and Compound D (N:P:K = 7:6.1:5.8) were applied as basal fertilizers and NH₄NO₃ was applied at top dressing. Soil organic carbon and aggregate stability significantly (p<0.01) decreased with depth in all treatments. Fertilization and mulching significantly improved SOC and aggregate stability by at least 30% and 7% in surface layers and 41% and 8% in the 5-15 cm depth respectively. However, ZT had the highest SOC and Ima in surface layers than the subsurface layers while CT had a more uniform SOC distribution within the 0-30 cm soil profile and had significantly higher SOC than ZT in the 5-15 cm depth. Steady state infiltration rate varied significantly with tillage and fertilizer at p<0.01 and mulch at p<0.05. Mulching (p<0.05) and ZT (p<0.01) significantly improved steady state infiltration rates by at least 14% and 39% respectively. Only the fertilizer x tillage interaction significantly (p<0.01) affected steady state infiltration rates. The steady state infiltration rate was highest in ZT plots which received cattle manure and inorganic fertilizer (39.6 cmh⁻¹). Conventionally tilled plots had significantly (p<0.01) lower steady state infiltration rates compared to ZT

plots except for the unfertilized plots. It was concluded that integration of organic and inorganic fertilizers, mulching using crop residues and ZT over two seasons improved soil health through increase in SOC, aggregate stability and steady state infiltration rate.

Key words: Aggregate stability, infiltration, soil organic carbon, tillage, urban agriculture

Résumé

Le fumier est une ressource essentielle des éléments nutritifs pour les agriculteurs urbains en raison de ses multiples avantages, en particulier sur les sols sableux infertiles de manière inhérente. La recherche sur le fumier de bovins en Afrique Sub-Saharienne a principalement mis l'accent sur son rôle dans la fourniture de N nécessaire pour les cultures avec peu d'attention accordée à ses multiples avantages tels que ses effets sur les autres propriétés du sol. L'objectif de cette étude était de déterminer l'intégration à court terme de la fertilité des sols et les pratiques de gestion de l'eau sur le carbone organique du sol (SOC), la stabilité des agrégats et l'infiltration de l'eau dans l'agriculture urbaine. Une expérience a été réalisée sur des sols sableux fertilisés au moyen des engrais organiques et inorganiques sous les systèmes de labour classique (CT) et de labour zéro (ZT) avec (5 t ha⁻¹) et sans paillis faits de tiges de maïs. Le fumier de bovins (1,26% N) et le composé D (N: P: K = 7:6,1:5,8) ont été appliqués comme engrais basal et le NH₄NO₃ a été appliqué par revêtement supérieur. Le carbone organique du sol et la stabilité des agrégats ont diminué de façon significative ($p < 0,01$) avec la profondeur dans tous les traitements. La fertilisation et le paillage ont considérablement amélioré le SOC et la stabilité des agrégats d'au moins 30% et de 7% dans les couches superficielles et 41% et 8% dans la profondeur de 5-15 cm respectivement. Toutefois, le labour zéro (ZT) avait le SOC le plus élevé et plus d'Ima dans les couches superficielles que les couches du sous-sol alors que le labour classique (CT) avait une distribution plus uniforme de SOC dans le profil de sols à 0-30 cm et avait le SOC significativement plus élevé que ZT dans la profondeur de 5-15 cm. Le taux d'infiltration à l'état uniforme a varié de manière significative avec le labour et l'engrais à $p < 0,01$ et le paillis à $p < 0,05$. Le paillage ($p < 0,05$) et le ZT ($p < 0,01$) ont significativement amélioré les taux d'infiltration à l'état uniforme d'au moins 14% et 39% respectivement. Seule l'interaction engrais-labour a affecté significativement ($p < 0,01$) les taux d'infiltration à l'état uniforme. Le taux d'infiltration à l'état uniforme était le plus

élevé dans les parcelles de ZT qui ont reçu du fumier de bovins et des engrais minéraux (39,6 cmh⁻¹). Les parcelles conventionnellement labourées avaient significativement ($p < 0,01$) un plus faible taux d'infiltration à l'état stable par rapport aux parcelles de ZT sauf pour les parcelles non fertilisées. Il a été conclu que l'intégration des engrais organiques et inorganiques, le paillage à l'aide des résidus de récolte et le ZT durant deux saisons ont amélioré la santé des sols grâce à l'augmentation du carbone organique du sol, de la stabilité des agrégats et du taux d'infiltration à l'état uniforme.

Mots clés: Stabilité des agrégats, infiltration, carbone organique du sol, labour, agriculture urbaine

Background

In Harare (Zimbabwe), 60% of food consumed by low-income groups is self-produced through urban agriculture (UA), (Toriro, 2007). However, crop production is largely rain-fed and it suffers from unpredictable rainfall regimes which are intensifying as climate change and variability impacts become more severe. In addition, crop production is limited by poor soil fertility aggravated by high costs of inorganic fertilizers. Urban farmers have resorted to using locally available organic fertilizers, especially farmyard manures for crop production. It is therefore imperative, to assess the impacts of the organic materials used by urban farmers on soil quality in an urban environment where plots tend to be small (20-200 m²) which may lead to over application of fertility amendments so as to maximize crop production without causing environmental degradation. Conventional tillage (CT), using hand hoes is the dominant tillage practice in Harare as compared to conservation tillage. Most urban farmers, estimated at 500 000 (Toriro, 2009) burn crop residues during land preparation. The study was carried out to determine short-term effects of integrated fertilizer, mulch and tillage on soil organic carbon, aggregate practice of stability and water infiltration in UA on sandy soils.

Literature Summary

Significant effects of both organic and inorganic fertilizers on SOC, aggregate stability and water infiltration have been reported (Mikha and Rice, 2004; Six *et al.*, 2006; Hati *et al.*, 2006). Burning crop residues releases greenhouse gases such as CO₂ and CO (West and Post, 2002; Ogle *et al.*, 2005) and volatilization of nutrients such as N (Asiamah *et al.*, 2000) rendering the soil infertile and reducing SOC which maintains soil resilience (Nyamadzawo *et al.*, 2008) as well as nutrient holding capacity (Mariscal *et al.*, 2007). Crop residues can

therefore be used as mulch since they have no competing uses (Mulumba and Lal, 2008; Giller *et al.*, 2009) in smallholder farming areas. Minimum tillage has been reported to increase SOC (Sainju *et al.*, 2002) as compared to CT which hastens SOC losses by creating oxidative soil environments (West and Post, 2002; Six *et al.*, 2006).

Study Description

The study site is located about 20 km from Harare city centre (18°S and 31°E) with granitic sands classified as ferrallitic cambisol (FAO, 1988). Maize, the test crop, was grown in the 2009/2010 and 2010/2011 summer seasons. Nitrogen was applied at 0 and 120 kg N ha⁻¹ (40 kg N ha⁻¹ applied as basal fertilizer + 80 kg N ha⁻¹ as top dressing fertilizer) for all treatments except controls. Maize stover mulch (M) was applied at 0 and 5 t ha⁻¹. Two tillage treatments were used, namely conventional (CT) and zero (ZT) tillage systems. A completely randomized block design was used. Soil samples for SOC and aggregate stability were taken after two cropping season as well as field measurements for water infiltration in the dry and winter month of June, 2011. The modified Walkely-Black and the double ring methods (Anderson and Ingram, 1993) were used to determine SOC and water infiltration respectively. Aggregate stability was determined using the Yoder apparatus (Barthes and Rose, 1996).

Research Application

Soil organic carbon significantly ($p < 0.01$) decreased with depth (Fig. 1 a) in all treatments. In surface layers (0-5 cm), SOC was on average, 14 % and 51 % higher than the sub-surface layers (5-15 and 15-30 cm, respectively). The fertilizer x depth, tillage x depth ($p < 0.01$) and mulch x depth ($p < 0.05$) interactions had significant effects on SOC. Soil organic carbon significantly ($p < 0.01$) decreased in the order manure + inorganic fertilizer > sole inorganic fertilizer > no fertilizer at each soil depth except for the fertilized treatments in the 15-30 cm depth. The mulching x depth and tillage x depth interactions significantly affected SOC in the 0-5 and 5-15 cm depths. However, ZT significantly increased SOC in the 0-5 cm depth only since CT plots had significantly ($p < 0.01$) higher SOC than ZT plots in the 5-15 cm depth (Fig. 1 a). Fertilizer application significantly ($p < 0.01$) improved SOC by 30% and 41% on average compared to unfertilized plots in the 0-5 and 5-15 cm depths, respectively. However, combining CM and inorganic fertilizer significantly improved SOC by ~12%, in both the 0-5 and 5-15 cm depths compared to sole inorganic fertilizer. Mulching significantly ($p < 0.01$) increased SOC by 7% and 8% in the 0-5 and 5-15 cm depths, respectively. Zero tillage significantly improved SOC

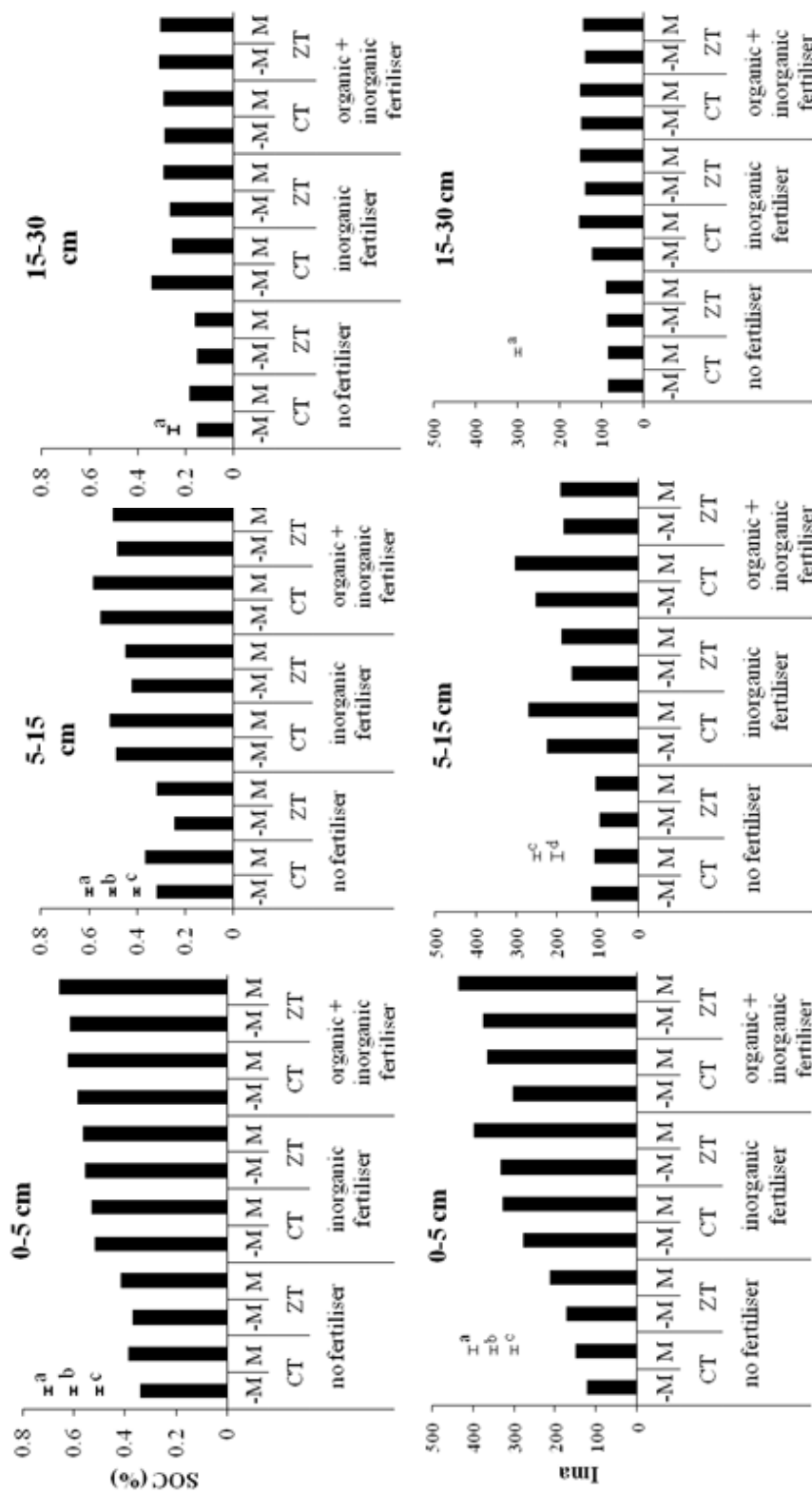


Figure 1. Short-term fertilizer, tillage and residue management effects on (a) soil organic carbon (SOC) and (b) macro aggregation indices (Ima) in different soil depths in a sandy soil. Bars show LSDs for factors (a) fertilizer, (b) tillage, (c) mulch and, (d) fertilizer x tillage interaction at p<0.05. CT- conventional, ZT-zero tillage, M-with 5 t ha⁻¹ maize stover mulch, -M – without mulch.

by 5 % in the 0-5 cm depth at $p < 0.05$. However, CT plots (SOC = 0.47 %) had significantly ($p < 0.01$) higher SOC than ZT plots (SOC = 0.4 %) in the 5-15 cm depth. There was a sharp decline in (51 % on average) SOC from the 0-5 to the 5-15 cm depth. In the 15-30 cm depth fertilizer, application significantly ($p < 0.01$) improved SOC by 43-45 %.

Aggregate stability. There was a significant ($p < 0.05$) decrease in aggregate stability (Fig. 1 b) with depth in all treatments. Macro-aggregation indices (Ima) in surface layers (0-5 cm) were between 6-55 % and 160-300 % higher than the sub-surface layers (5-15 and 15-30 cm, respectively). The fertilizer x depth and tillage x depth interactions had significant effects on aggregate stability at $p < 0.01$. All factors significantly ($p < 0.01$) affected aggregate stability in all soil depths except tillage and mulching in the 15-30 cm layer (Fig. 1 b). However, aggregate stability was not significantly affected by all factor interactions ($p > 0.05$), except the fertilizer x tillage interaction in the 5-15 cm layer at $p < 0.01$ (Fig. 1 b).

In surface layers (0-5 cm) macro-aggregation indices in inorganic fertilizer and inorganic + organic fertilizer were between 23-46 % and 59-71 % higher than the unfertilized plots, respectively. The same fertilizer treatments had 36-65 % and 43-69 % higher Ima than the fertilizer controls in the 5-15 cm depth, respectively. Tillage and mulching improved aggregate stability by at most 72 and 79 % respectively in the surface layers. On the other hand, CT plots had significantly ($p < 0.01$) higher aggregate stability than ZT plots, 27 % on average, in the 5-15 cm depth. In addition, mulching improved aggregate stability significantly ($p < 0.05$). Furthermore, CT significantly ($p < 0.05$) improved aggregate stability than ZT except in unfertilized plots. There was, however, a significant ($p < 0.01$) fertilizer effect on aggregate stability in the 15-30 cm depth. The controls (no fertilizer applied) had significantly lower Ima than fertilized plots.

Steady state infiltration rate. Steady state infiltration rate varied significantly with tillage and fertilizer at $p < 0.01$ and mulch at $p < 0.05$ (Fig. 2). Fertilizer application improved steady state infiltration rates by 50-56 % as compared to unfertilized plots controls. Combining cattle manure (CM) and inorganic fertilizer improved steady state infiltration rates by at least 10% than sole application of inorganic fertilizer, though it was statistically insignificant ($p > 0.05$). Mulching ($p < 0.05$) and ZT ($p < 0.01$)

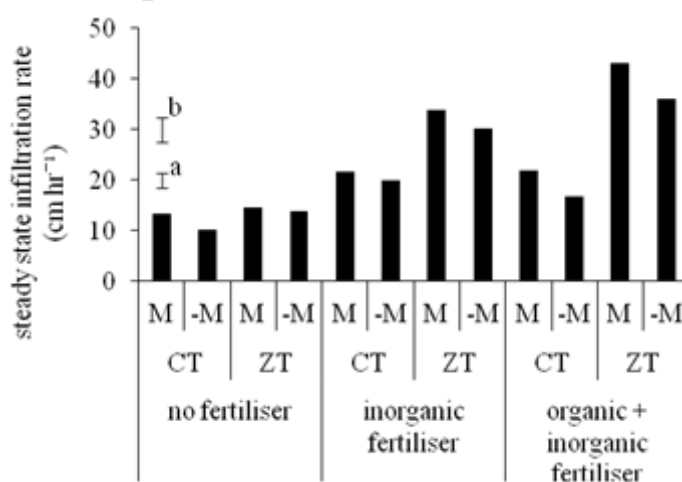


Figure 2. Short-term effects fertiliser, tillage and residue management on steady state infiltration rate using the Kostikov-type model in a sandy soil. Bars show LSDs for factors (a) mulch ($p < 0.05$) and, (b) fertiliser x tillage interaction ($p < 0.01$). CT-conventional, ZT-zero tillage, M-with 5 t ha⁻¹ maize stover mulch, -M – without mulch.

significantly improved steady state infiltration rates by at least 14% and 39% respectively. Of all the possible factor interactions, only the fertilizer x tillage interaction significantly ($p < 0.01$) affected steady state infiltration rate in sandy soils. The steady state infiltration rate was highest in ZT plots which received CM and inorganic fertilizer (39.6 cm h⁻¹). Conventionally tilled plots had significantly ($p < 0.01$) lower steady state infiltration rates compared to ZT plots except for plots that were not fertilized controls.

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