Soil Biodiversity and productivity under conservation agriculture systems

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- Attaining food security for a growing population and alleviating poverty while sustaining agricultural systems under the current scenario of:
  - *Depleting natural resources,*
  - *Negative impacts of climatic variability,*
  - *Spiralling cost of inputs* and
  - *Volatile food prices;* are the major challenges.

- In addition to these challenges, the principal indicators of non-sustainability of agricultural systems include: *soil erosion, soil organic matter decline*, & *salinization,* through:
    - Intensive tillage induced soil organic matter decline, soil structural degradation, water & wind erosion, reduced water infiltration rates, surface sealing & crusting, soil compaction,
    - Insufficient return of organic material, & monocropping.

- Therefore, a paradigm shift in farming practices through elimination of unsustainable parts of conventional agriculture is crucial for future productivity gains while sustaining the natural resources.
- Conservation agriculture (CA), offers some solutions.

Conservation agriculture (CA)

- CA- is an approach to maintaining agro-ecosystems for improved sustained productivity, increased profits and food security while preserving and enhancing resource base and environment.

- It is characterized by three main principles:
    - ***Minimal mechanical soil disturbance.***
    - ***Permanent soil cover***
    - ***Crop diversification*** -

- The technologies of CA provide opportunities to reduce the cost of production, increase yields, increase crop diversification, improve efficient use of resources, and benefit the environment.

Minimum soil disturbance through reduced or zero till:

- Provides/maintains optimum proportions of respiration gases in the rooting-zone.
- Moderate organic matter oxidation.
- Enhance porosity for water movement, retention & release and limits the re-exposure of weed seeds and their germination.

Reduced (or minimum) tillage

A permanent soil cover*- through dead organic residues, mulch or live green manure of cover crops:*

- Protect the soil against deleterious effects of exposure to rain and sun.
- Provide the micro and macro organisms in the soil with a constant supply of “food”
- Moderate the microclimate (moisture & temperature) in the soil for optimal growth and development of soil organisms, including plant roots.
- In turn, it improves soil aggregation, soil biological activity and soil biodiversity and carbon sequestration.

Diversified crop rotations - through crop rotation or intercropping practices:

- Enables farmers to broaden their own diet, and sell a greater variety of produce.
- Different crops have different rooting depths, so draw nutrients and moisture from different layers and can be recycled.
- A diversity of crops in rotation leads to a diverse soil flora and fauna due to broaden diet.

- Cropping sequence and rotations involving legumes reduce rates of build-up of population of pest species, through life cycle disruption, biological nitrogen fixation, control of off-site pollution and enhancing biodiversity.

- Despite the widespread interest in CA, empirical evidence of the benefits of CA in SSA is limited. For instance, the magnitude and direction of effect by CA on soil fauna, however, remains unquantified, especially in low-input systems of Sub-Saharan Africa.
- Response of soil fauna to soil tillage, available crop residues, and cropping practices in the region is largely unclear yet such knowledge is imperative for environmental conservation, sustainability and improved ecosystem services.

- Therefore, the aim of this study was to evaluate the effect of CA and associated management practices on soil fauna richness and abundance.
- Specifically, the study assessed how conservation agriculture and its principal elements that encompass zero tillage, application of organic or inorganic inputs and cropping system, affect soil fauna richness and abundance.
- It was hypothesized that CA, organic or inorganic inputs and crop rotation and or mixed cropping would positively influence soil fauna richness and abundance.

Materials and Methods: Study sites

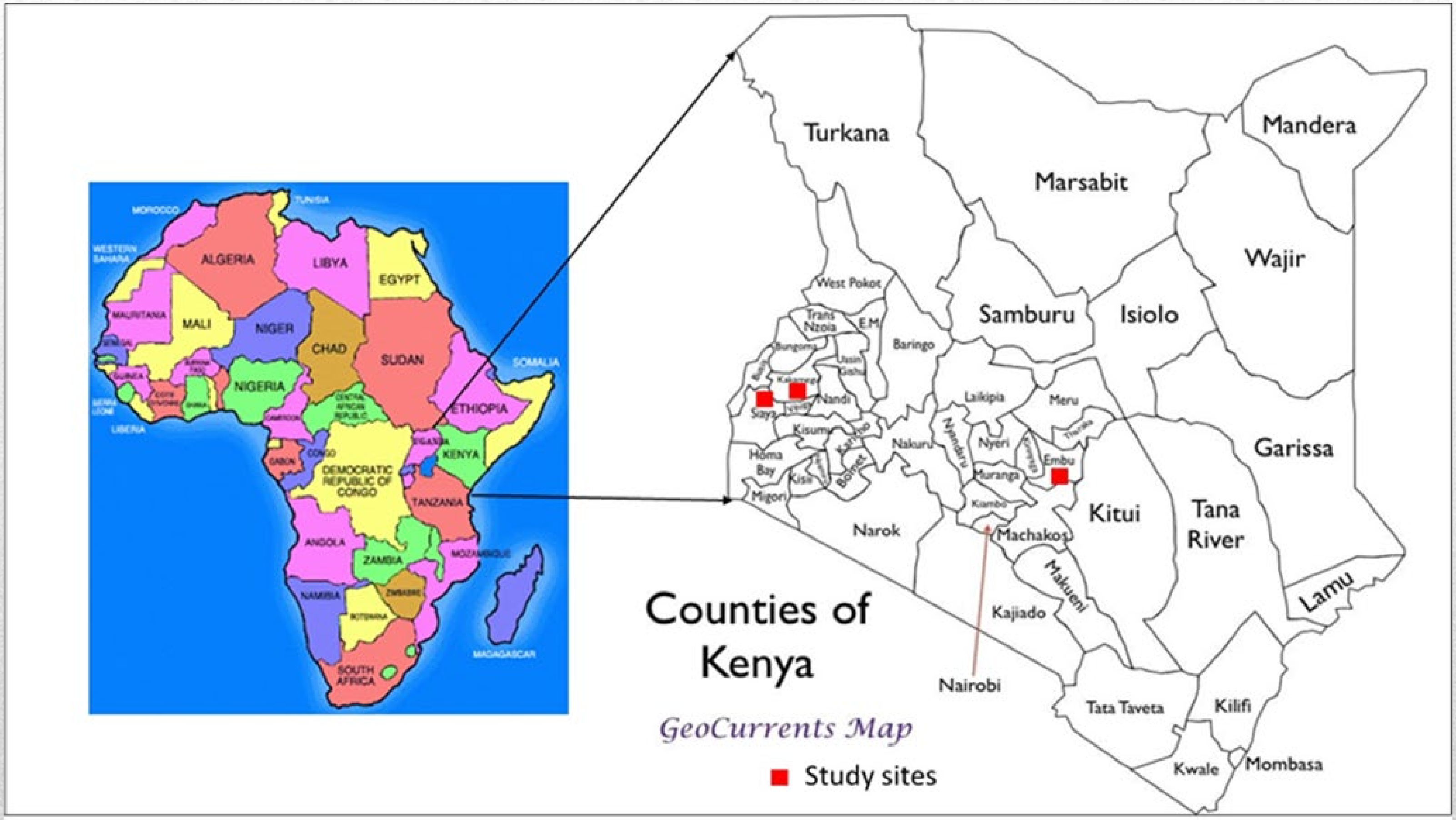


Plate 1. Map showing location of the study sites.

Table 1. Location, climatic and soil characteristics of the study sites.

Parameter	Embu	Kakamega	Nyabeda
Year established	MT-2010	MT-2010	LT-2003
Agro-climatic zone	Humid	Sub-humid	Sub-humid
Agro-ecological zone	Upper midland 3	Upper midland 1	lower midland 2
Latitude	00° 33.18’ S	0° 16.96’ N	0° 07' N
Longitude	037° 53.27’ E	34 46.07' E	34° 24' E
Altitude (m.a.s.l.)	1420	1534	1420
Total annual rainfall (mm)	1250	1978	1800[a]
Daily temperatures (°C):			
Mean	20	21	23.2
Minimum	16 - 21	11	14
Maximum	21-28	26	31
Soil type	Humic Nitisols[b]	Eutric Nitisol[c]	Ferralsol[c]
Sand:silt:clay ratio	3:22:75	13:34:53	15:21:64
pH (water)	3.88	5.40	5.08
Extractable K (me $100g^{-1}$)	0.27	0.70	0.10
P (mg P kg^{-1})	16.13	3.40	2.99
Ca (cmolc kg^{-1})	2.15	0.93	4.69*
Mg (cmolc kg^{-1})	0.45	0.05	1.68*
Total SOC (%)	3.70	4.10	1.35
Total Nitrogen (%)	0.37	0.30	0.15

*value obtained in meq $100g^{-1}$ of soil; [a]2002-2008 period; [b]see Jaetzold et al. (2007) for details; [c]see Jaetzold and Schmidt (2006) for details. MT-medium-term, LT-long-term.

Table 2. Treatment selected and descriptions.

Treatment	**Tillage**	**Cropping**	**Organic input**	**Inorganic input**
Embu medium-term trial				
1- CTMBi-CR	Conventional	Maize-beans intercrop	None	80 kg N, 111 P_2O_5
2- CASB+CR	Zero	Sole beans	Beans residues	20 kg N, 51 kg P_2O_5
3- CASM+CR	Zero	Sole maize	Maize residues	60 kg N, 60 kg P_2O_5
4- CAMBi+CR	Zero	Maize-beans intercrop	Maize and beans residues	80 kg N, 111 P_2O_5
Kakamega medium-term trial				
1. FP (Farmer practice)	Conventional	Sole maize	None	None
2. CTMBi+CR	Conventional	Maize-bean intercrop	2 t/ha maize residues	50N, 25P
3. CAMBi+CR	Zero	Maize-bean intercrop	2 t/ha maize residues	50N, 25P
Nyabeda long-term trial				
1. FP (Farmer practice)	Conventional	Sole maize	None	None
2. CTMSr+CR	Conventional	Maize-soybean rotation	2 t/ha maize residues	60 kg N/ha-Urea
3. CAMSr+CR	Zero	Maize-soybean rotation	2 t/ha maize residues	60 kg N/ha-Urea
4. CAMSi+CR	Zero	Maize-soybean intercrop	2 t/ha maize residues	60 kg P/ha-TSP

Abbreviations: **CT** = Conventional till; **CA** = Conservation agriculture (Zero till); **FP** = Farmer practice; **SM** = Sole maize; **SB** = Sole beans; **MBi** = Maize bean intercrop; **MSi** = Maize-soybean intercrop; **MSr** = Maize-soybean rotation **CR** = Crop residue; **N** = Nitrogen; **+/-** denotes with or without crop residues and with or without nitrogen.

Soil fauna sampling

Macrofauna: Monoliths of size 25 cm × 25 cm × 30 cm, were excavated 8 weeks (in December 2015 in eastern Kenya and June-July 2016 in western Kenya) after planting crops in the season (Swift and Bignell, 2001; Bignell et al 2008): At each observation, one sample was taken randomly from each plot and monolith dug with a spade and hoe to a 30 cm soil depth (Plate 2).

Plate 2. Soil monolith excavation and macrofauna sampling

Mesofauna: Soil samples were collected for mesofauna observations using a metallic core of 10 cm diameter up to 30 cm depth (and at same 0-15 or 15−30 cm depths as macrofauna). One sample was taken in each plot at each sampling. The samples were taken to the CIAT laboratory where mesofauna groups were extracted using the behavioural or dynamic method with Berlese-Tullgren as the basic apparatus (Plate 3) (Southwood, 1995).

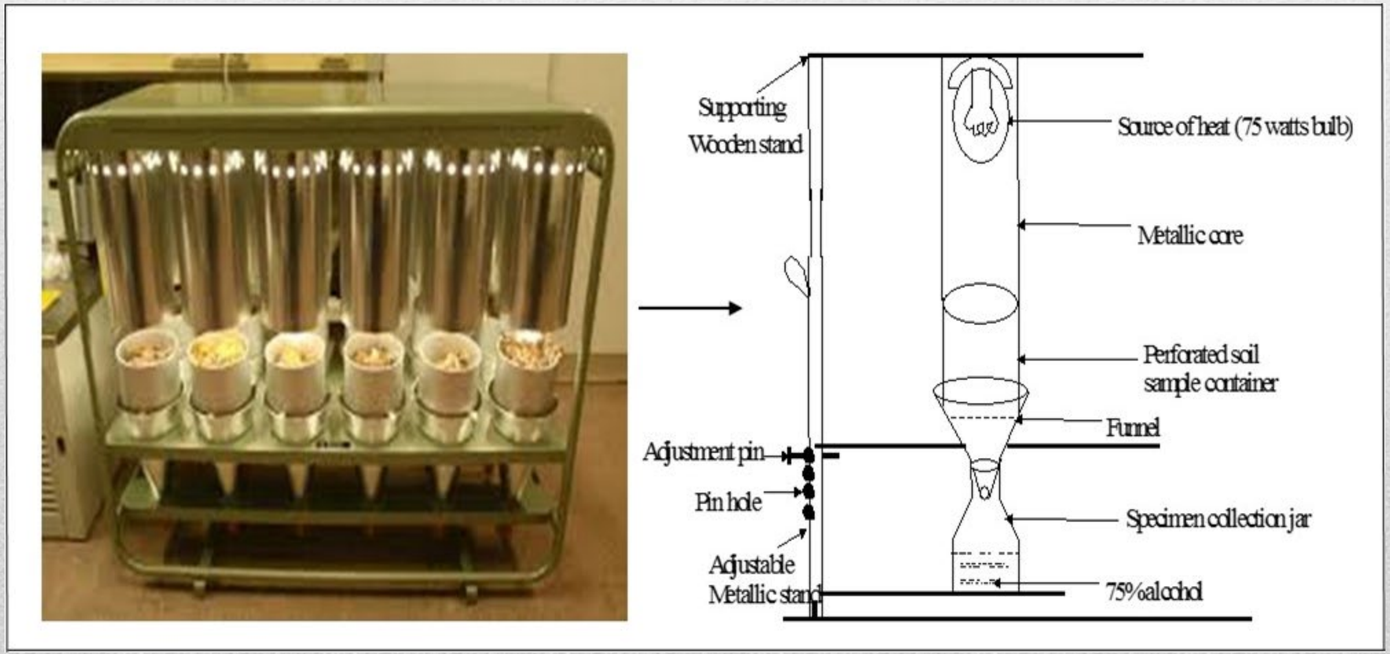


Plate 3. Photo and sketch diagram showing the Berlese-Tullgren apparatus.

- The soil fauna collected were preserved in 75% alcohol for subsequent identification at the Soil microbiology laboratory of CIAT, ICIPE Duduville Campus, Nairobi, Kenya.
- Earthworms were killed in 75% alcohol and fixed in 4% formaldehyde. In the laboratory, counting was done. Species richness, and number of different categories of animals were expressed per metre square.

Statistical analyses

- The data obtained on soil fauna richness and abundance and soil chemical properties were subjected to analysis of variance (ANOVA) with GenStat 17.1 (2015).
- Levene’s test was used to test for homogeneity of variances (Field 2005) and data transformed where necessary before further analysis.
- Linear Mixed Model was fitted by Restricted Maximum Likelihood (RELM) procedure using the Genstat package (Bates et al., 2015; Kuznetsova et al., 2014). Treatments were included in the model as fixed factors, whereas block was defined as a random factor.
- The statistical significance was determined at $p \leq 0.05$ and levels of significance among the different treatments were evaluated using Fischer´s least significance difference (LSD).

Results

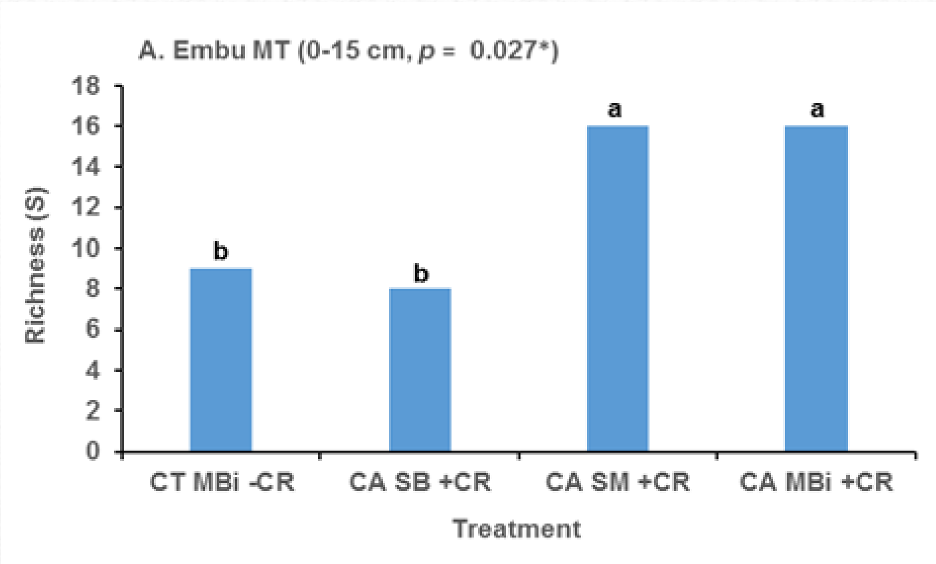
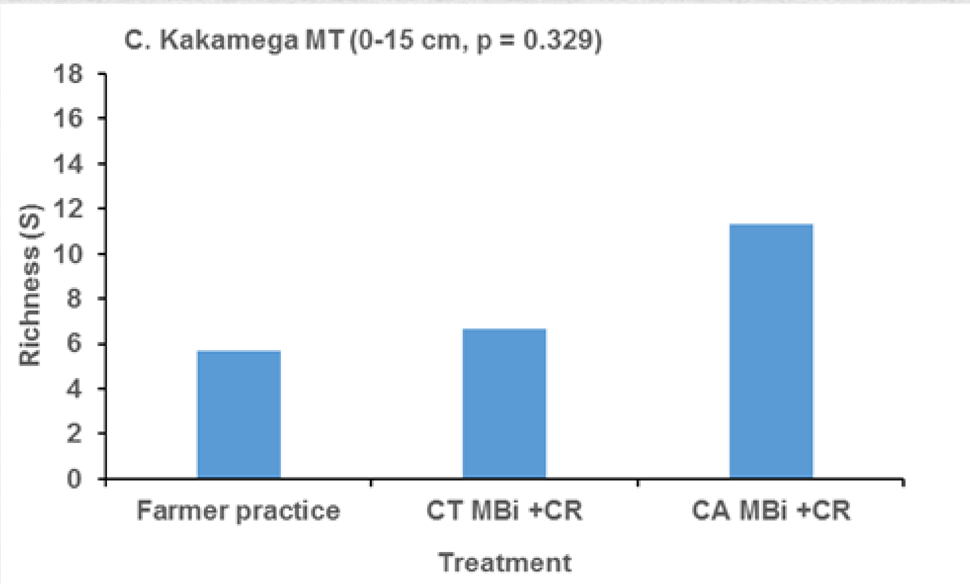
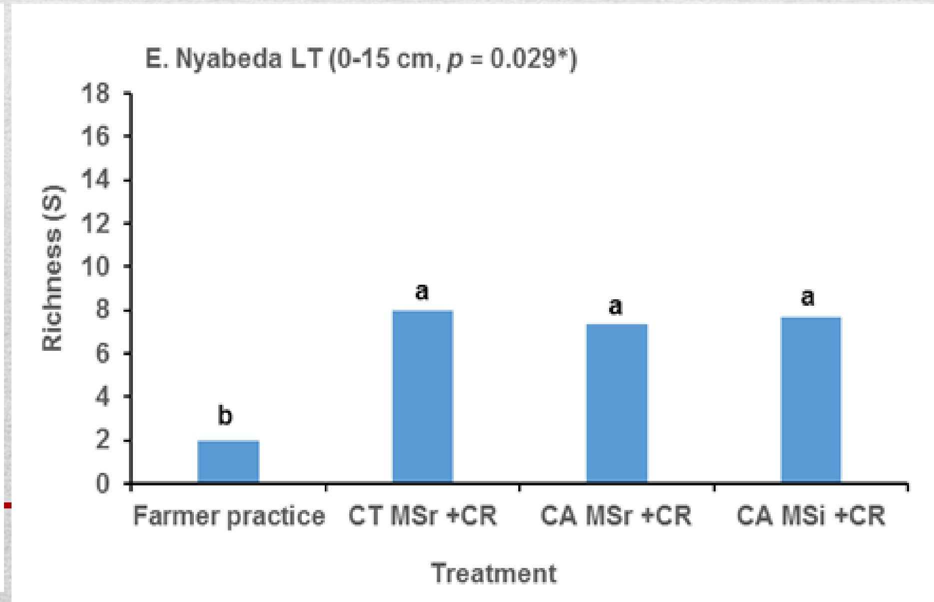


Figure 1. Soil macrofauna diversity (richness) across trials of Embu, Kakamega and Nyabeda. **MT** = Medium-term, **LT** = Long-term; **CT** = Conventional till; **CA** = Conservation agriculture (Zero till); **SM** = Sole maize; **SB** = Sole beans; **MBi** = Maize bean intercrop; **MSi** = Maize-soybean intercrop; **MSr** = Maize-soybean rotation **CR** = Crop residue.





Note

- No treatment effect on macrofauna diversity (richness) was noted at lower depths as well as for abundance at both depths for all sites.

- No treatment effect for soil mesofauna diversity at both depths (for all sites).

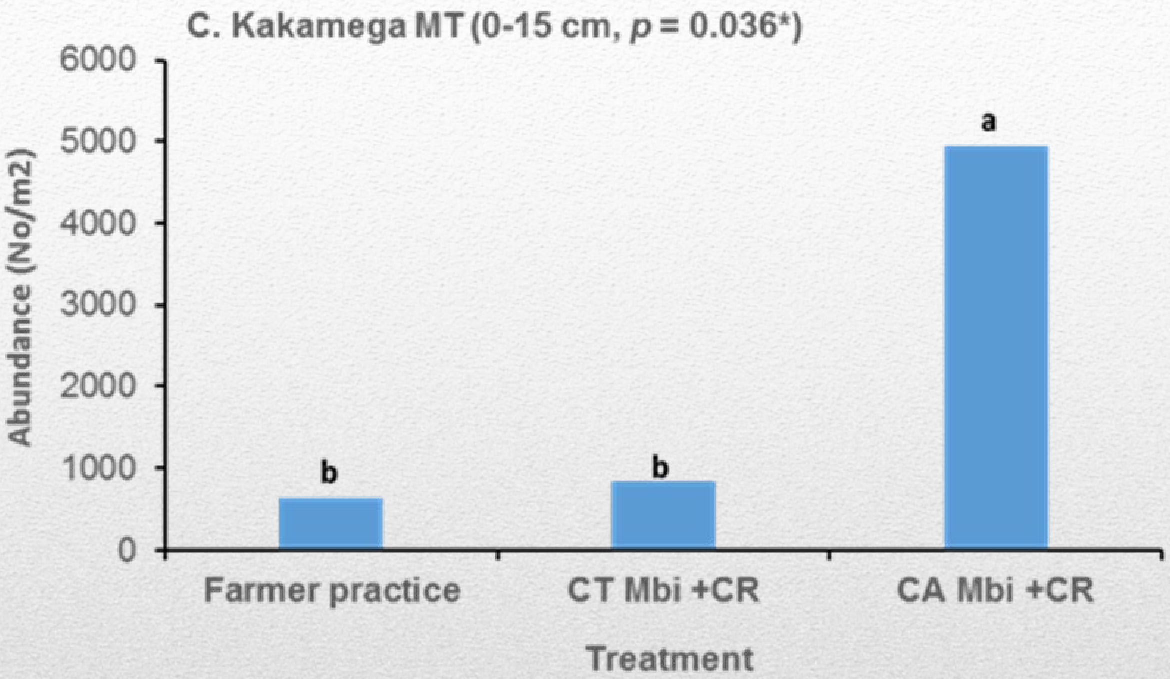


Figure 2. Soil mesofauna abundance across trial Kakamega, **MT** = Medium-term; **CT** = Conventional till; **CA** = Conservation agriculture (Zero till); **SM** = Sole maize; **SB** = Sole beans; **MBi** = Maize bean intercrop; **MSi** = Maize-soybean intercrop; **MSr** = Maize-soybean rotation **CR** = Crop residue.

- Except for Kakamega with high mesofauna abundance at top depth, no significant treatment effect was recorded at all depths for all the other sites.

Conclusions

- In agreement with our hypothesis, higher macrofauna taxonomic richness and mesofauna was recorded in CA than in CT without residues.
- This study demonstrated that:
  - Medium to long-term addition of organic residues enhances soil fauna richness and abundance,
  - CA increases soil fauna taxonomic richness and abundance compared with CT, and
  - CA under maize-bean intercropping, rotation and sole maize cropping systems promote soil fauna richness and abundance compared with sole legume (common beans).

- We conclude that adoption of CA is important in enhancing richness of soil fauna.
- Given the numerous challenges faced by smallholder farmers of SSA in the adoption of CA, who in most cases rarely practice all the three CA principles simultaneously, we propose a further study that will determine the effects and interactions between each of the CA components on soil fauna richness and abundance.

Constraints for adoption of conservation agriculture

Despite the perceived benefits of CA, there are still **constraints for promotion of CA technologies**, among them:

- Competition of crop residues between CA use and livestock feeding or for fuel,
- Burning of crop residues as land preparation tool,
- Lack of knowledge about the potential of CA among agriculturists, extension agents and farmers.
    - *Strengthened knowledge and information sharing mechanisms are needed.*
- Availability of skilled and scientific manpower: and overcoming the bias or mind set about tillage.
    - *In view of this, there is the need to develop the policy frame and strategies is to promote CA in the region.*

Acknowledgements

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