Annual Technical report on Sustainable Intensification of Maize-Legume Cropping Systems for Food Security in Eastern and Southern Africa (SIMLESA-II) activities carried out by CIAT

Period: July 2016 to June 2017

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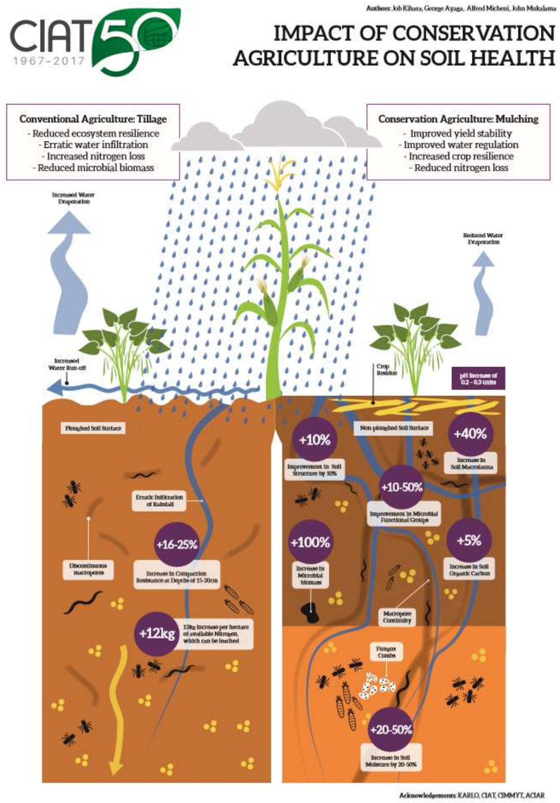
During the reporting period, CIAT organized and facilitated shipping of soil samples for several exploratory CA trial fields from Malawi to Nairobi and pre-processed these for chemical analyses. Also, CIAT sampled and analyzed soils for mineral nitrogen from SIMLESA trials in Eastern and Western Kenya, and undertaken in-depth soil biology investigations with regard to presence and diversity of microbial, meso- and macro-fauna in two trials in Western Kenya (one is a 6-year and the second a 13-year old trial). The data from the latter have been analyzed jointly with similar data from Eastern Kenya taken during the previous reporting period. At the same time, lysimeters to measure leachates have been installed in the 6-yr KALRO Kakamega trial, as well as temperature loggers in CIAT's 13-yr CA trial in western Kenya. We provide here activities undertaken during July 2016 and June 2017 reporting period.

Activity 2.1.1: On farm exploratory trials

Four hundred and seven soil samples for 0-5 cm, 5-20 cm and 20-50 cm depths for the mid-altitudes of Malawi for five sites namely Salima, Ntcheu, Lilongwe, Kasungu and Mchinji taken from on-farm exploratory trials have been pre-processed and 263 of them (from 28 fields) queued for analysis in CIAT labs. These are specifically selected for treatment consistencies and potential for comparisons; they include (1) conventional ridge and furrow, (2) CA dibble stick no herbicide and (3) CA dibble stick maize phase of the maize-soya rotation, and have been implemented for 4-5 years. For Tanzania, a sampling frame to assess changes in soils under conservation tillage and conventional tillage has been developed and will cover 9 farms in Karatu, northern Tanzania. The sampling arrangement, considering farmers as replicates, was arrived at during a visit made to these exploratory trials in Karatu, Tanzania in June 2017.

Activity 2.2.1: On station long term trials

A summary of CA effects on soils was made and presented as an infographic during Simlesa annual meeting held at Mt Meru hotel at Arusha, Tanzania in June 2017. The infograph, titled *Impact of conservation agriculture on soil health is below and available* online at http://hdl.handle.net/10568/82545.



Soil cover under reduced tillage increases macropore continuity, soil aggregation/structure, soil water infiltration, reduces erosion, regulates soils temperatures, improves habitats and abundance of soil fauna (40% more macrofauna abundance and 10- 50% increase in microbial functional groups) and the residues regulate available mineral N. Conventional tillage predisposes up to 12 kg of nitrogen to leaching and potentially underground.

Soil aggregation analysis has been undertaken for 2 SIMLESA on-station trials; one in KALRO-Embu and the other in KALRO-Kakamega, in addition to CIAT long-term experiment. Practicing CA improved soil structure in the long-term Kakamega and CIAT sites as shown by the elevated aggregate mean weight diameter and geometric mean diameter (Table 1). These are consistent with more macroaggregates and lower microaggregates and silt + clay in CA compared to CT system. The effects in the short-term SIMLESA Site (Embu) were less clear likely due to the short period under CA practices (Table 2). Here, Depth and 'Depth × treatment' interaction had significant effects ($p \leq 0.05$) on aggregate MWD. The MWD of these soils was lower ($p \leq 0.05$) at 15-20 cm when compared to that of other depths (Table 1). Application of 5 tons of residues and 80 kg N ha^{-1} (5R+80N) in zero tillage led to 18.6% higher (despite not significant) aggregate MWD compared to conventional tillage treatments. As with MWD, Depth ($p \leq 0.01$) and depth × treatment interaction ($p \leq 0.05$) significantly affected the large macroaggregates. In Both sites, silt+ clay reduced with increased depth and was higher in conventional tillage compared to reduced tillage systems.

Increased macroaggregation is associated with enhanced macropore geometry, improved soil aeration, infiltration and active stimulation of soil fauna diversity and abundance and generally healthy soils. Tillage practices in conventional systems are associated with macroaggregate dissociation and disruption of macropore continuity and a corresponding increase in microaggregate and silt + clay levels at the lower depth leading to reduced poor soil structure. This exposes the intra-aggregate particulate organic matter to action by soil microbes leading to short-term but intensive carbon and nitrogen mineralization that declines soil fertility with time, and may not synchronize with plant nutrient demand.

Table 1. Mean weight diameter (MWD) and geometric mean diameter (GMD) in different treatments in a 6-yr and a 13-yr trial in western Kenya as observed in 2017

Site	Treatment code	MWD		GMD	
		A	B	A	B
CIAT	CT+6ON +60P, +R, -L, MS Rotation	1.03c	1.51ab	0.49d	0.73b
CIAT	RT+6ON +60P, +R, -L, MS Rotation	1.38b	1.66ab	0.65c	0.94ab
CIAT	RT+60N +60P, -R, -L, MS Rotation	1.32b	1.45b	0.65c	0.75b
Kakamega	CT+75N +25P, -R, MB Intercropping	1.41b	1.67ab	0.83b	1.05a
Kakamega	RT+75N +25P, +R, MB Intercropping	1.60a	1.72a	0.94a	1.06a
LSD		0.19		0.17	

MWD= Mean weight diameter, GMD= Geometric mean diameter, A = 0-5 cm depth, B = 5-15 cm depth. Means followed by the same letters in each column are not significantly different from each other.

Table 2 Effects on treatment on aggregate Mean Weight Diameter (MWD), Geometric Mean Diameter (GMD) in a 3-yr trial in Embu (Humic nitisols) as observed in 2016

	Mean Weight Diameter (mm)				Geometric Mean Diameter **(mm)**			
Treatments	**Depth (cm)**							
	0-5	**5-10**	**10-15**	**15-20**	**0-5**	**5-10**	**10-15**	**15-20**
CT0R+0N	1.55^{ab}	1.9^{b}	1.5^{b}	1.23^{a}	0.83^{ab}	0.99^{a}	0.60^{a}	0.78^{a}
CT0R+80N	1.55^{ab}	1.87^{b}	1.6^{ab}	1.24^{a}	0.61^{a}	0.75^{a}	0.8^{ab}	0.87^{a}
CT3R+80N	1.35^{a}	1.4^{a}	1.61^{a}	1.43^{a}	0.73^{ab}	0.73^{a}	0.9^{ab}	0.81^{a}
ZT3R+80N	1.53^{a}	1.33^{a}	2.0^{b}	1.33^{a}	0.76^{ab}	0.7^{a}	1.09^{b}	0.73^{a}
ZT3R+120N	1.9^{b}	1.6^{ab}	1.23^{a}	1.2^{a}	1.0^{b}	0.85^{a}	0.68^{a}	0.71^{a}
ZT5R+80N	2.0^{b}	1.7^{ab}	1.83^{ab}	1.53^{a}	1.1^{b}	0.87^{a}	0.9^{ab}	0.83^{a}

Effects of long-term and short-term CA practices on soil temperature trends (0-5 cm depth: As mentioned in the earlier report, temperature had been assessed for a whole season in Embu trials and the process is still ongoing in western Kenya. From Embu site, both long-term and short-term trials had similar response to temperature changes. Conventional tillage system had the highest temperature recorded when compared to zero tillage systems (Figure 2). Variations in soil temperature was highest under conventional tillage and decreased with residue application. Unlike with 3 tons of residues, increasing the residue rates to 5 tons ha^{-1} resulted in the most stable soil temperatures when compared to the rest of the treatments thus demonstrating insulation benefits of soil cover. Due to lack of surface cover, conventional tillage systems are exposed to direct solar radiation that may lead to high soil moisture losses and also affect thermal sensitive soil microbial processes and fauna. Soil temperature assessments are on-going in the 13-yr CA trial in Nyabeda, western Kenya.

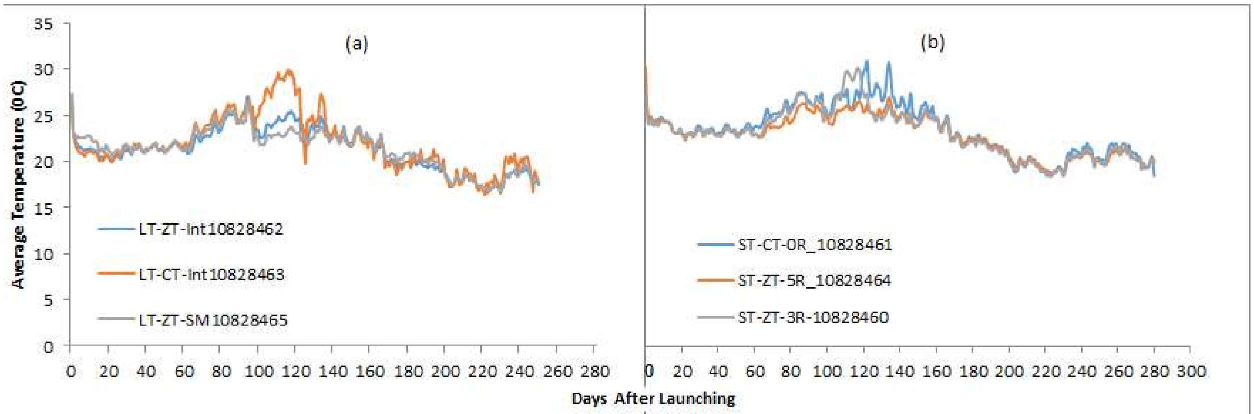


Figure 2: Top soil temperature patterns at 0-5 cm for Embu long-term (a) and short-term trial (b) during 2015/2016 period.

Greenhouse gas emission in Western Kenya long-term trials: Greenhouse gas emission measurements have been undertaken for 2 seasons. Preliminary analysis of nitrous oxide (N_20) and denitrification potentials do not show a consistent trend. Nevertheless, the emissions decreased with time (high at beginning of season) following the declining effect of the applied fertilizers where applied during the early crop establishment period. Also, rainfall occurrence was more frequent during the early season which increased the rate of nitrification.

Soil hydraulic conductivity (Ks): measurements of soil hydraulic conductivity were undertaken at V11 stage in Embu and Selian (SARI-Arusha) at 2 suctions (-2 and -6 cm sec^{-2}). As yet, no treatment effect has been noted; only slight differences with elevated infiltration in conventional tillage likely due to measurements 3-4 weeks after soil disturbance (i.e., highly porous surface soils; Figure 3). But we also noted that infiltration rates under the conventional tillage decreased with length of time since tillage operation. This assessment should be followed at different times within a season to fully understand the temporal trends.

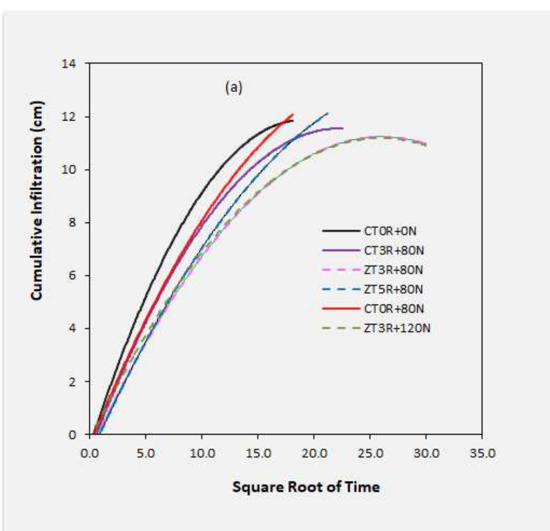


Figure 3: Hydraulic conductivity at -2 cm sec-2 in the soils of Embu short-term trial year at 2016 cropping season

Penetration resistance (N/m²)

Soil penetration resistance was significantly affected by depth, sampling time (at V11, R 1 and R6), tillage x time and time x depth treatment interactions. Soil resistance varied from 171 N/m^2 at top 0-5 cm to 343 N/m^2 at 15-20 cm (during the R1 growth stage); the 3 depths of 15-20, 20-25 and 25-30 had higher values ($P<0.05$) than at other depths (significantly higher than depths <10 cm and >35 cm; Figure 4). At top soil depth of 0-5 cm and 5-10 cm, treatments under ZT have a higher soil resistance compared to CT systems.

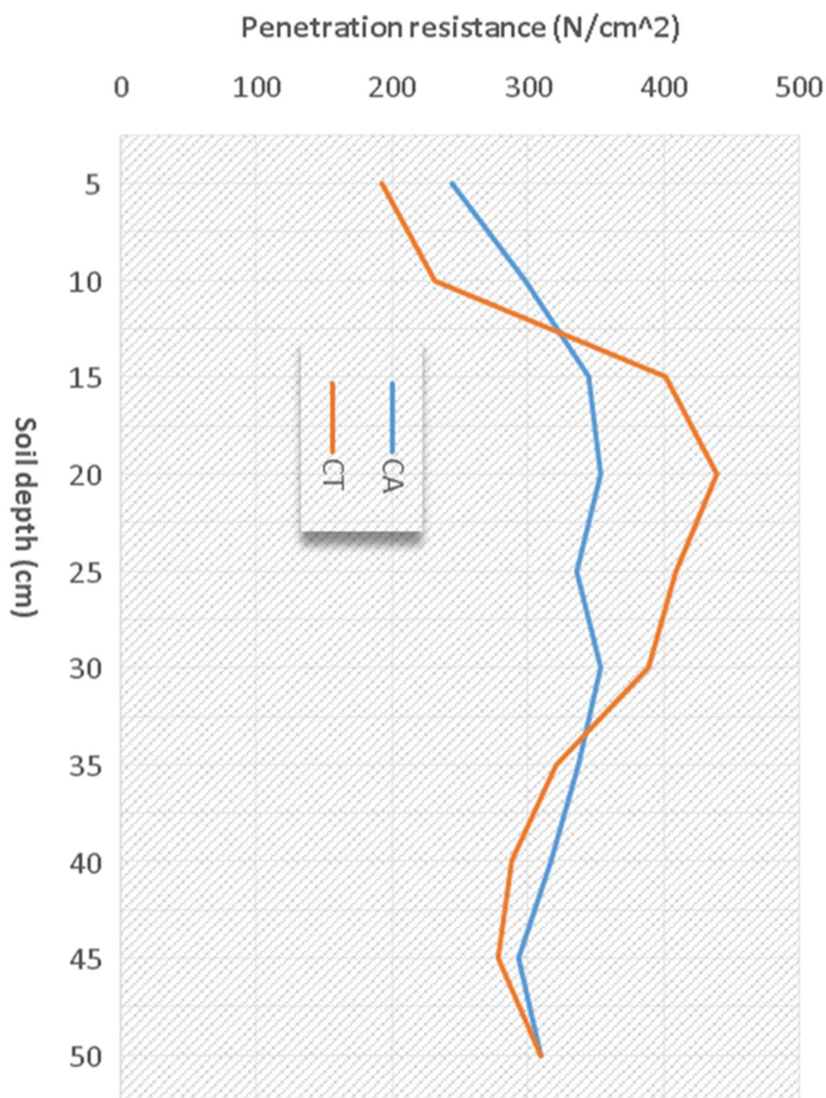


Figure 3: Effects of tillage on soil penetration resistance as observed at R1 stage in Embu

Residue availability for CA practices: Results and progress of the relay-cropping trial designed jointly by CIAT, CIMMYT and Mozambican national partners are reported by the national partners. In general, the relay crops establish and provide excellent soil cover, a good solution to the termite problem in this region of Mozambique. However, the trial on relay-intercropping with lablab established in Tanzania (Babati), initiated to compare with results from the trial in Mozambique was affected by poor growth of the relays due to severe soil moisture constraints. The trial is ongoing.

CIAT continues to undertake soil sampling and conduct assessments based on the specific soil-related questions for CA systems framed based on SIMLESA-2 project document. With regard to residue x N interactions, CIAT continues to work together with KALRO and is undertaking sampling in two newly established trials (one in Embu and Kakamega) which offers excellent opportunity to study this aspect. In line with this, soil sampling for mineral N (including from leaching), carbon and soil functional groups analysis has been undertaken for the long-term trials in western Kenya (one at KALRO-Kakamega and another at 13-yr CIAT CA trial).

Effects of tillage and residue management on soil fauna were shown for two experiments in Embu, eastern Kenya in the previous report. In this report, we show similar work done in two additional trials in western Kenya (a 6-year trial in KALRO Kakamega and 13-year trial managed by CIAT in Nyabeda, Siaya County; Table 4). This makes a total of 4 conservation agriculture trials implemented for 3 to 13 years that have now been fully characterized and treatment effects with regard to soil meso- and macrofauna determined. Methods and approaches are similar to those reported earlier for Embu.

Overall, a total of 59 macrofauna species classified into 15 major groups were found across the trials. The long-term trial had relatively higher species richness compared to the short-term trial, with number of species being 32 in Nyabeda and 27 in Kakamega. Previously, these had been 38 in the Embu long-term trial and 25 in Embu short-term. For mesofauna groups, 17 species classified into six major groups were observed across the four trials, and the western Kenya sites (Nyabeda and Kakamega) had relatively higher mesofauna richness compared to the eastern Kenya (Embu) sites. The specific groups and their abundance in the different sites has been documented in a submitted journal publication[1].

The combinations of tillage practice, organic residues and cropping system had significant effect on macrofauna taxonomic richness ($p < 0.05$) largely at the top 0-15 cm soil depth than at the lower 15-30 cm soil depth in most of the study sites. At Nyabeda, macrofauna richness was significantly higher in both conventional (CTMSr+CR) and zero till (ZTMSr+CR) practices under maize-soybean rotation, but both with crop residues added than conventional (typical farmer's practice) till without inputs. At Kakamega, no significant differences were noted for macrofauna mean richness mean abundance among the treatments at both 0-15 cm and 15-30 cm soil depths. In addition, no significant differences were noted for mesofauna mean richness among the treatments at both 0-15 cm and 15-30 cm soil depths in all study sites except Nyabeda. As expected, soil fauna richness reduced with depth where these were nearly ≤50 % that of top soil for each of the treatments.

Table 4. Macrofauna and mesofauna diversity (richness) across long-term and short-term trials of Embu, Nyabeda and Kakamega

Macrofauna			Mesofauna		
			-Nyabeda-		
Treatment	**0-15 cm**	**15-30 cm**	**Treatment**	**0-15 cm**	**15-30cm**
Farmer practice	2b	3.7ab	Farmer practice	4.3	3.0

CTMSr+CR	8a	5.3a	CTMSr+CR	5.3	5.7
ZTMSr+CR	7a	2.7b	ZTMSr+CR	4.3	2.3
ZTMSi+CR	5ab	2.7b	ZTMSi+CR	4.7	3.3
***p*-value**	**0.038***	**0.050***	***p*-value**	0.429	0.125
---Kakamega---					
Farmer practice	5.7	5.0	Farmer practice	2.0	2.0
CTMBi+CR	6.7	5.3	CTMBi+CR	3.7	3.7
ZTMBi+CR	11.3	7.0	ZTMBi+CR	5.7	2.3
***p*-value**	0.384	0.417	***p*-value**	0.058	0.502

Across sites, and in both (0-15 and 15-30 cm) soil depths, no significant effect of tillage, cropping and organic inputs on soil macrofauna and mesofauna abundance were observed except for Kakamega. Here, maize-bean intercrop system under zero till with residue applied (ZTMBi+CR) had significantly higher mesofauna abundance than the convention till with similar management (CTMBi+CR) practices or conventional till (farmers practice) without any inputs (Table 5).

Table 5. Macrofauna and mesofauna abundance across long-term and short-term trials of Embu, Nyabeda and Kakamega

Macrofauna			Mesofauna		
---Nyabeda---					
Treatment	**0-15 cm**	**15-30cm**	**Treatment**	**0-15 cm**	**15-30cm**
Farmer practice	107	203	Farmer practice	1814	970
CTMSr+CR	672	133	CTMSr+CR	4219	3080
ZTMSi+CR	395	107	ZTMSi+CR	4684	1224
ZTMSr+CR	496	149	ZTMSr+CR	2954	759
***p*-value**	0.203	0.927	***p*-value**	0.321	0.318
---Kakamega---					
Farmer practice	219	171	Farmer practice	633b	338
CTMBi+CR	336	192	CTMBi+CR	844b	1224
ZTMBi+CR	1163	272	ZTMBi+CR	4937a	1097
***p*-value**	0.089	0.546	***p*-value**	**0.030***	0.372

A site ordination by PCA/RDA biplot, representing the correlation square of the first two axes is presented in Figure 5. These axes separated objects (soil fauna groups) as a function of management (tillage, cropping system and residue application) practices across sites. Sum of all canonical eigenvalues reveal that management practices explained 34% of the total variation observed in macrofauna abundance and 52% of that in mesofauna abundance. The test on all canonical axes indicated treatment and site effects to be highly significant ($p < 0.001$). In other words, management affected most of the soil fauna groups as shown by the site effect upon both axes. Overall, the projection of soil fauna groups on the principal component analysis (PCA/RDA) ordination axes indicates that conservation (zero) till systems with crop residues added had on average higher soil fauna abundance than the conventional till systems, especially those without crop residues applied (Figure 5A and 5B). Further, the ordination plots show Eastern Kenya (Embu) sites opposing Western Kenya (Nyabeda and Kakamega) sites along axis 2 for the macrofauna groups (Figure 5A), and also along axis 1 for mesofauna groups (Figure 5B). Generally macrofauna groups were on average more abundant in the Eastern Kenya sites than in Western Kenya sites, but on the contrary, a reverse trend was observed for mesofauna groups.

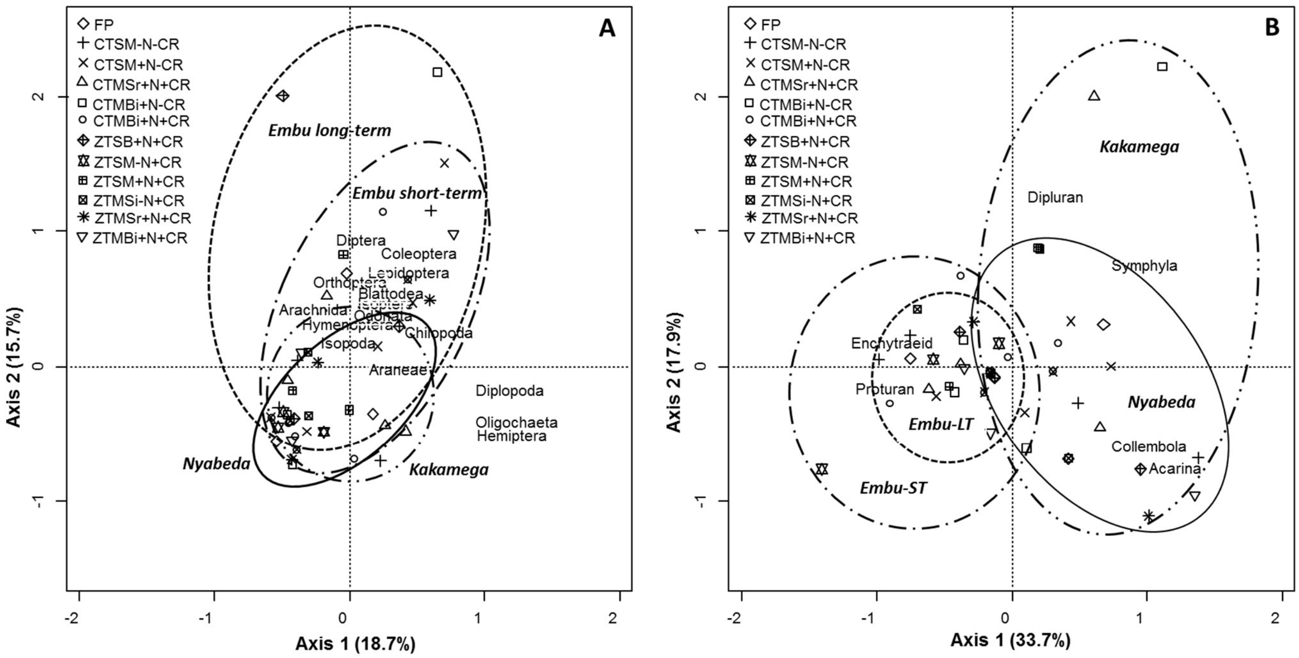


Figure 5. Projection of soil fauna: (A) Macrofauna and (B) Mesofauna along the two principal component (PCA/RDA) axes across different treatments and sites. LT: long-term, ST: short-term.

CIAT is in close contact with CIMMYT colleagues in Kenya who have also undertaken similar soil macrofauna assessments in other SIMLESA trials in Kiboko and Kakamega, together providing a rich data on this aspect.

<u>Soil microbial diversity:</u> During the reporting period, a detailed assessment of the effects of CA system on soil microbial diversity has been conducted using illumina technology in both the 6-year and 13-year trials. This generally focused on bacterial diversity in the soil. We are currently undertaking a similar assessment with the main aim of evaluating if there is any temporal effect in bacterial diversity and population and at the same time including fungi diversity, an aspect not captured in the previous work. From the available data, practicing zero-tillage without residues is clearly detrimental to most of the soil microbial phyla (Table 6). Removal of residues after harvesting significantly reduced the diversity of a number microbial species involved in atmospheric nitrogen fixation, phosphorus solubilization and carbon fixation, like *Cyanobacteria* and *Firmicutes* (Zhan and Sun, 2012); carbon and nitrogen turnover (*Actinobacteria*) (Kielak *et al.,* 2016); as well as methanol degradation and consumption (*Verrucomicrobia*). Nitrite oxidizing *Nitrospirae* and *Nitrospinae* populations also reduced with respect to residue removal in the reduced tillage systems. Differences in microbial diversity between CA and CT, with both practices applied with residues, are rare in our study sites. But quite often, there is no residue application under the conventional system practiced by many farmers where effects on microbial groups maybe pronounced.

Table 6. effects of treatments on different phyla at the SIMLESA trials (CT1 and KALRO-Kakamega) in western Kenya

Treatments	Cyanobacteria	Actinobacteria	Acidobacteria	Firmicutes	Verrucomicrobia	Planctomycetes	Bacteroidetes	Nitrospirae	Fusobacteria	Thaumarchaeota	Armatimonadetes	Nitrospinae	Crenarchaeota	Bacillariophyta
CT+CR (CT1)	18.4a	228ab	234a	155ab	96ab	77a	53ab	54ab	22a	15ab	22a	7.3ab	1.1b	2.3b
RT+CR (CT1)	18.6a	270a	225ab	209a	109a	72ab	54ab	58a	19ab	20ab	18ab	6.4ab	3.6a	5.1a
RT-CR (CT1)	3.9b	115b	83b	89b	41b	31b	17b	22b	5b	8b	6b	1.6b	2.1ab	0.7b
CT+CR (KALRO)	14.6ab	173ab	171ab	118ab	62ab	56ab	50ab	36ab	24a	25a	9ab	10.0ab	0.3b	0.7b
RT+CR (KALRO)	14.9ab	169ab	200ab	125ab	91ab	59ab	56a	37ab	34a	27a	10ab	12.6a	0.3b	0.5b

Soil Physical properties: Effects of CA on soil moisture accompanied by soil temperature measurements continue to be assessed. This was done for a whole season in Embu (Kenya) and now being undertaken for a second season in Western Kenya. Besides, soil aggregation analyses have been recently completed to understand effects of CA on soil structure both in Eastern and western Kenya. We will undertake statistical analyses of these data within the next reporting period. Preliminary analyses indicate a clear improvement in aggregate mean weight diameter (MWD) following the practice of CA in KALRO-Kakamega. Further, intercropping of maize and soybean is leading to elevated MWD relative to maize and soybean grown in succession (rotation system) in a 13-yr long-term trial in Siaya County of western Kenya, both on top and subsoils. As expected, aggregate MWD increase with soil depth.

***Long-term trends in organic carbon*:** Soil organic carbon for a long-term trial (16 years since establishment in western Kenya) where over 500 samples were analyzed, was reported in the last period. Here, we report on active total carbon for short-term (3 yr) CA trial in Embu, eastern Kenya. Here, Active carbon is affected by depth ($p \leq 0.001$; Table 7) but not by treatments. Both active and total carbon decrease with depth. Active carbon below 30 cm depth is lower than at higher depths. On the other hand, total C for the very top soil (0-10 cm) is higher than at below 30 cm depths while also 30-60 cm depth has more carbon than 60-90 cm depth. During the period when the trial was in place, maize monoculture was grown. Maize plants have characteristic long fibrous roots which have the potential to reach deep horizons particularly in the loose nitisols.

Table 7: Effect of depth on Active and Total carbon

DEPTH (cm)	ACTIVE C (%)	TOTAL C (%)
0-10	0.07	2.02
10-30	0.07	1.9
30-60	0.05	1.69

60-90	0.03	1.22

Soil Carbon sequestration assessments in long-term trials of Western Kenya: Top soil organic C was only significantly influenced by time factor but not the CA practice in CT1 long-term trial. SOC was also seen to linearly reduce across the treatments from 20.2 g kg^{-1} in 2006 to 18.8 g kg^{-1} in 2015. In 2009, SOC levels in ZT+R+MS and ZT+R+S-M was significantly higher than in the rest of the years. CA did not show any potential to sequester C, with SOC contents in the two management systems decreasing within 0-15 cm depth over time. Application of 2 t ha^{-1} of residues proved too low to raise SOC content in the soil. Macro- and meso- faunal foraging (especially termites) might have acted as the main hindrance to SOC improvement. Secondly, limited SOC protection in the soil aggregates is related to the predominant 1:1 kaolinite clays in the region. Thus, not only are macro-fauna role in residue disappearance important considerations but also the clay type in intervention sites. Increased carbon input e.g. derive also from green manures may confer an advantage under these circumstances. Although not specifically tested under CA, application of 4 t ha-1 of animal manure in another CIAT-managed long-term trial in western Kenya slowed down SOC losses. Mineral fertilizer (N and P) application on the other hand did not show any potential to avert SOC losses. Though the results from these trials do not show potential of CA to sequester SOC under our conditions, they are however important in avoiding SOC losses thus contributing to climate change mitigation. From this work, an article on carbon sequestrations titled- *Reducing losses but failing to sequester carbon in soils- the case of Conservation Agriculture and Integrated Soil Fertility Management in the humid tropical agro-ecosystem of Western Kenya* was submitted to Agriculture, Ecosystem and Environment journal.

Activity 2.2.3: Non responsive soils / micronutrients

A review article by the title 'Application of secondary nutrients and micronutrients increases crop yields in sub-Saharan Africa' is published in Agronomy for sustainable Development journal[2]. During its revision, further review was conducted resulting in expansion of the micronutrient-crop response database (this database is also published; its CGspace record that is linked to the dataset is http://hdl.handle.net/10568/82689). Publications included and response ratios observed in each are shown in **Figure** 6 below. In general, the study shows response to micronutrients in most of the encountered studies, sites and soils.

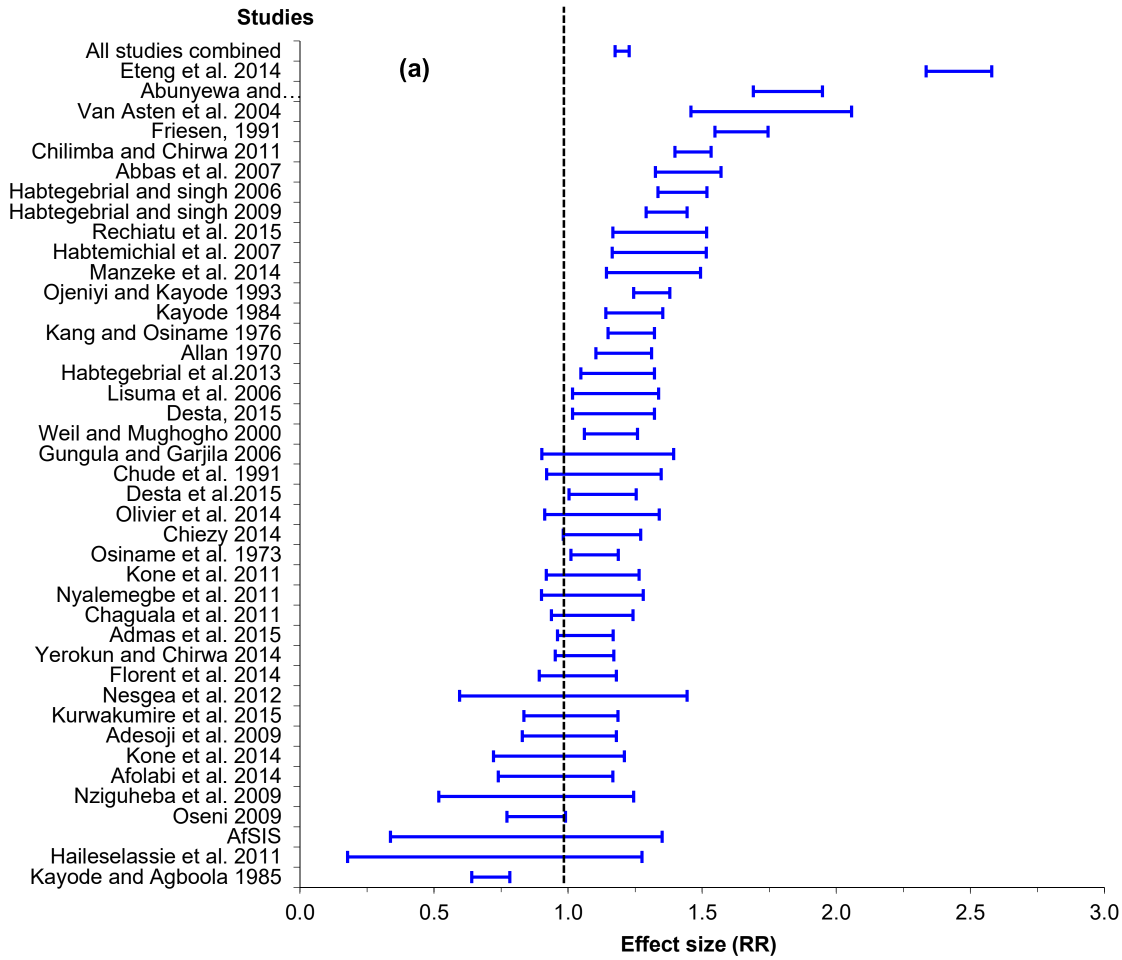


Figure 6. Forest plot of response ratios to micronutrient applications observed under different studies in SSA.

Activity 2.2.4: Nitrogen management

We indicated in the previous report on focus and preliminary results regarding to (i) assessing the status of inorganic nitrogen in different treatments at specific sampling periods in conservation agriculture relative to the conventional tillage and (ii) examining the extent of nitrogen leaching under the different amounts of residue and nitrogen management in Embu County. Further analysis has been done in this reporting period. Leached nitrate is affected ($p \leq 0.05$) by treatment but not by growth stage or the interaction between these factors. Application of nitrogen increased leached nitrate by 3 to 6 times that in control (unfertilized) treatment (Table 8). Treatments with nitrogen application had similar amounts of leached nitrate. Only leached nitrate under zero tillage (3R+80N) was higher ($p \leq 0.05$) than in the control treatment (conventional tillage with no N). Elevated leached nitrates in fertilizer treatments is expected following applied nitrates in fertilizer. Unlike expectation, residue application in this young conservation agriculture systems does did not reduce nitrate leaching.

Table 8: Effect of treatments on nitrate concentration in leachate

TREATMENTS	NITRATE LEACHED (mg/l)
CT0R+0N (Control)	8.7^{c}
CT0R+80N	27.7^{abc}

CT3R+80N	36.5[abc]
ZT3R+80N	49.9[a]
ZT3R+120N	27.0[abc]
ZT5R+80N	37.1[abc]

Further, within the SIMLESA trial at KALRO-Kakamega, lysimeters were installed and leachate samples taken at four different crop growth stages. These are accompanied by depth-wise mineral N sampling. Laboratory analysis is on-going and the results will be shown in the subsequent reporting.

Effects on soil mineral N content

As expected, soil mineral N varied by growth stage ($P<0.05$) and was in the order V0>V8>V10=R4 (Table 9). It also reduced with depth ($p \le 0.05$; 0 to 10 cm> 10 to 30 cm> 30 to 60 cm = 60 to 90 cm) for all growth stages except V8 when increase by depth was observed (i.e., significant ($p \le 0.05$) interaction between depth and growth stage). Higher top-soil mineral N is attributed to mineralization of crop residues and other organic matter (like weeds) deposited and/or applied on or near the soil surface, applied fertilizers etc. A birch effect may be responsible for the higher mineral N at the topsoil during V0 growth stage while increased mineral N movement down the soil depth with soil water is likely responsible for elevated mineral N at lower depth in V8 growth stage. There was consistent rains during the period preceding the soil sampling at V8 (top dressing had been done at V6). Highly reduced mineral N at V10 and R4 is explained by high uptake of N by crops and reduced moisture to facilitate mineralization at a time when no more topdressing was occurring. Though N levels in R4 are low, the crops requirement of N supply from the soil is negligible.

Table 9: Effect of depth and growth stage interaction on soil mineral N in Embu

DEPTH	GROWTH STAGE			
	V0	V8	V10	R4
0-10	21.9[a]	9.4[b]	6.2[a]	7.9[a]
10-30	13.8[b]	8.3[b]	5.5[ab]	6.7[ab]
30-60	6.7[c]	10.7[ab]	4.4[b]	4.6[b]
60-90	3.7[d]	12.3[a]	4.3[b]	4.0[b]

Column of means with the same letter are not significantly different ($p \le 0.05$)

Besides depth and growth stage, soil mineral N amount was affected ($p \le 0.05$) by treatments and its interaction with growth stages (Table 9). Overall (i.e., aggregated over sampling times), greater ($P<0.05$) mineral N was observed in conventional tillage (with N added) than in control and the zero tillage treatments. At individual growth stages, there were no differences in mineral N at later growth stages (V10 and R4) but only in earlier ones (R0 and V8). At V0, both conventional treatments with fertilizer had higher mineral N than all zero tillage treatments. There were no differences among the zero tillage treatments. Also, among conventional tillage treatments, application of N without residues resulted in higher mineral N than control, an observation not made when residues were also applied. Similar trends were observed for mineral N at V8 with the exception that here, mineral N was higher than the control even for the conventional tillage treatment where application of nitrogen was accompanied by chemical nitrogen application. Therefore, surface application of residues (zero tillage) locked available mineral N and increasing N application (from 80 to 120 kg N/ha) did not further increase soil mineral N except for insignificant increases at V10. Secondly, that conventional tillage treatments results in elevated mineral N even for unfertilized control at planting indicates elevated birch effect under CT than under zero-tillage (i.e., effects of first rains following land cultivation). Third, elevated mineral N at planting may result to increased inefficiencies. Lastly, application of residues in conservation agriculture causes short-term N immobilization in the system (i.e., at the very early growth stages) but not later. In the Embu case, incorporation of residues has insignificant effect on mineral N under conventional tillage system.

Table 9: Effect of treatment and growth stage interaction on soil mineral N in Embu

TREATMENT	**GROWTH STAGE**			
	V0	**V8**	**V10**	**R4**
CT0R+0N	11.5^{bc}	8.9^{c}	4.5^{a}	5.3^{a}
CT 0R+80N	13.2^{a}	12.4^{a}	4.9^{a}	5.6^{a}
CT 3R+80N	12.2^{ab}	11.7^{ab}	5.6^{a}	5.8^{a}
ZT3R+80N	10.8^{bc}	8.7^{c}	4.8^{a}	6.2^{a}
ZT 3R+120N	10.3^{c}	9.4^{c}	6.0^{a}	5.9^{a}
ZT 5R+80N	9.8^{c}	10.1^{bc}	4.6^{a}	5.7^{a}

Columns with the same letters are not significantly different (p≤0.05)

Effects of tillage on soil mineral N in Western Kenya

Soil mineral N under residue and inorganic N application in CA and CT systems in short-term trials of Embu, eastern Kenya were presented in the previous reporting. Here, we present soil mineral N over 5 different sampling periods in Long-term trials of Western Kenya where sampling was at four depths (0-10, 10-30, 30-60 and 60-90 cm). At KALRO site in Kakamega, sample analysis was done to assess treatments effect on soil mineral N concentration after application of varying rates of residues and inorganic N in CA relative to 75 kg N ha^{-1} in CT. Results based on repeated measure analysis show that treatments, depth, time and the interaction between these factors were strongly affected ($p \leq 0.01$) by crop residue and inorganic N application. All through the sampling period, CT system with 75 kg N ha^{-1} (0R+75N) had a higher soil mineral N ($P \leq 0.05$) content than that of CA treatments (it had 68, 67, 72, 73 and 58% more N than that of CA (0R+75N) treatment receiving similar rates of inorganic inputs; Table 10). Effects of residue application were observed in the 2nd and 5th samplings where CA treatment with 2 tons of residues + 75N (2R+75N) had more soil mineral N content than that of 4R+75N. However, no significant differences in soil mineral N were observed when residue application rates were raised to at least 4 tons ha^{-1}.

Contrary to CA, CT systems without residue retention present large levels of mineral N in the soil which are prone to losses especially if high rainfall is experienced as is often in this site. CA systems prove to have higher potential to control soil mineral N availability by causing a subsequent release that matches crop nutrient demand thus averting leaching losses. Given the set of treatments, application of 4 tons of residue in this site seems a better recommendation although more investigations are needed. This rate would provide crops with sufficient N supply, higher soil cover essential in reducing surface crusting and ensuring long-term C mineralization and macroaggregation which would enhance sustainable nutrient management for improved crop yields. The moderate Mineral N amounts in the 0N treatment are interesting and could indicate a system that has moderate SOC content that is being mineralized.

Table 10: Effects of residue and inorganic N application on soil mineral N concentration in KALRO site in 2016 cropping season.

TREATMENTS	1st Sampling	2nd Sampling	3rd Sampling	4th Sampling	5th Sampling
Conservation0R 0N	8.25^{a}	3.84^{a}	11.13^{ab}	8.44^{a}	13.86^{ab}
Conservation0R 75N	6.14^{a}	3.82^{a}	13.00^{ab}	8.21^{a}	18.94^{b}
Conservation2R 75N	6.13^{a}	4.86^{a}	13.94^{b}	8.76^{a}	17.09^{b}
Conservation4R 75N	5.68^{a}	4.58^{a}	10.27^{a}	6.28^{a}	12.47^{a}
Conservation8R 75N	5.18^{a}	3.91^{a}	12.92^{ab}	7.87^{a}	13.48^{a}

Conventional0R 75N	15.39[b]	8.20[b]	26.86[c]	22.35[b]	26.07[c]

Contrary to KALRO site, mineral N in on-farm trials on CA and CT systems at Bungoma site in Western Kenya was affected only by depth and time ($P \leq 0.01$). The lowest depth (25-50 cm) had significantly lower mineral N than the higher depths (0-10 and 10-25 cm) as expected. The CA treatment had similar mineral N as the conventional tillage treatment throughout the sampling period despite that conservation tillage systems are known to cause N immobilization when residues are applied on the soil surface.

In the CIAT long-term CA trial, the treatments, depths and time of sampling significantly influenced mineral N. Among the treatments, intercropping system had lowest mineral N which is expected due to competition between the maize and soybean crops (Table 11). Under the maize-soybean rotation system, practicing CA with residue application resulted in higher mineral N relative to common conventional tillage without residues. It seems, as expected, that nitrogen immobilization is no longer an issue after the long-term application of organic resources under CA in this environment, unlike the observations at the KALRO-Kakamega site.

Table 11. Total Nitrogen at different depths and time intervals across treatments in CT1 Trial

Treatment	Urea type	TN1	TN2	TN3	TN4	TN5	TN6
0-10 cm Depth							
RT, +R, M/S Intcrop, 0N+60P		8.78d	9.09c	14.14c	7.79b	3.6b	11.25bc
RT, +R, M-S rot, 60N+60P	N	24.49a	12.71bc	16.51c	15.99a	10.15ab	16.04ab
RT, +R, M-S rot, 60N+60P	S	20.16ab	15.44ab	18.45bc	11.35ab	11.46a	17.12ab
CT, -R, M-S rot, 60N+60P	S	12.48cd	8.84c	15.24c	8.64b	6.93ab	12.94bc
CT, -R, M-S rot, 60N+60P	N	10.7cd	11.77bc	14.86c	10.63ab	4.5b	11.21bc
RT, +R, cont. Maize, 60N+60P	N	15.8bc	18.23a	27.5a	15.89a	6.25ab	16.47ab
RT, +R, cont. Maize, 60N+60P	S	17.01bc	16.53ab	18.79bc	12.26ab	5.99b	21.23a
CT, -R, cont. Maize rot, 60N+60P	S	12.91bcd	13.27abc	22.4ab	11.39ab	7.58ab	12.72bc
CT, -R, cont. Maize rot, 60N+60P	N	9.19d	15.46ab	18.57bc	9.45b	3.47b	9.39c
10-25 cm Depth							
RT, +R, M/S Intcrop, 0N+60P		11.82bc	9.57cd	12.38b	8.3bc	4.09cd	9.41a
RT, +R, M-S rot, 60N+60P	N	16.29ab	10.99bcd	11.94b	12.89ab	10.99a	10.64a
RT, +R, M-S rot, 60N+60P	S	16.01ab	15.05ab	12.35b	12.62ab	9.85ab	9.35a
CT, -R, M-S rot, 60N+60P	S	9.2c	9.53cd	12.46b	6.72c	7.52abcd	8.45a
CT, -R, M-S rot, 60N+60P	N	10.07c	9.32d	11.96b	6.46c	3.58d	7.86a
RT, +R, cont. Maize, 60N+60P	N	16.71ab	16.31a	17.83a	15.47a	9.73abc	10.57a
RT, +R, cont. Maize, 60N+60P	S	18.08a	17.21a	15.87ab	16.23a	7.22abcd	12.07a
CT, -R, cont. Maize rot, 60N+60P	S	12.84abc	12.3abcd	14.87ab	14.56a	5.59bcd	9.62a
CT, -R, cont. Maize rot, 60N+60P	N	9.45c	14.73abc	13.63ab	11.87ab c	3.5d	9.48a
25-50 cm Depth							
RT, +R, M/S Intcrop, 0N+60P		10.53abc	7.34bc	7.67a	5.28c	3.29b	9.78c
RT, +R, M-S rot, 60N+60P	N	11.72abc	7.7bc	7.77a	8.53abc	6.51ab	26.34a
RT, +R, M-S rot, 60N+60P	S	13.41ab	9abc	8.59a	7.84abc	9.03a	11.99c
CT, -R, M-S rot, 60N+60P	S	7.64c	6.49c	7.15a	6.93bc	5.2ab	9.61c
CT, -R, M-S rot, 60N+60P	N	8.06c	7.36bc	7.42a	5.22c	3.84ab	18.11b
RT, +R, cont. Maize, 60N+60P	N	14.11ab	12.07ab	9.32a	12.04ab	8.14ab	26.84a
RT, +R, cont. Maize, 60N+60P	S	15.62a	13.24a	10.43a	8.33abc	8.71a	10.09c
CT, -R, cont. Maize rot, 60N+60P	S	10.7abc	8.7abc	8.39a	12.93a	4.33ab	9.53c
CT, -R, cont. Maize rot, 60N+60P	N	9.37bc	8.73abc	7.62a	9.56abc	4.46ab	25.34a

Means followed by the same letter in each column are not significantly different. Separation of means has been done depthwise.

<u>Activity 2.3.2: Recommended domains for soil health management</u>

No activity in this reporting period.

<u>Activity 2.3.3: Monitoring protocol for on farm experiments</u>

No activity during this reporting period.

Capacity building: Two students have been thoroughly trained on soil fertility and agronomy at MSc degree level. The 2 students, both of Kenyatta University, have developed and submitted draft Theses on conservation agriculture to the university supervisors.

Partnerships: In our reported CIAT - KALRO (Dr. George Ayaga) created through SIMLESA, full DNA illumina sequencing has been undertaken for 11 CA/CT practices derived from the KALRO-Kakamega CA trial initiated through SIMLESA and CIATs' long-term CA trial in western Kenya. This is the first full DNA sequencing on CA practices that we are aware of so far in SSA.

Journal Publications

Kihara J., Sileshi W. Gudeta, Nziguheba G., Kinyua M., Zingore S., and R Sommer. Application of secondary nutrients and micronutrients increases crop yields in sub-Saharan Africa. Agronomy for Sustainable Development journal. . 37: 25 DOI 10.1007/s13593-017-0431-0 http://rdcu.be/tUsw

Margenot A. J., Paul B.K., Sommer R, Pulleman M.M., Sanjai J. Parikh, Louise E. Jackson, Steven J. Fonte. 2017. Can conservation agriculture improve phosphorus (P) availability in weathered soils? Effects of tillage and residue management on soil P status after 9 years in a Kenyan Oxisol. Soil & Tillage Research 166 (2017) 157–166. http://dx.doi.org/10.1016/j.still.2016.09.003

Sommer. R., Paul. B. K., Kihara, J., and Mukalama, J. (Unpublished). Reducing losses but failing to sequester carbon in soils- the case of Conservation Agriculture and Integrated Soil Fertility Management in the humid tropical agro-ecosystem of Western Kenya. Submitted to Agriculture, Ecosystems and Environment journal

Ayuke, F.O, Kihara, J, Ayaga, G. and Micheni A. Conservation agriculture enhances soil fauna diversity and abundance in low input systems of Sub-Saharan Africa. Submitted (December 2016) to Soils and Tillage Research journal.

Published Databases

Kihara, Job; Sileshi, Gudeta Weldesemayat; Nziguheba, Generose; Kinyua, Michael; Zingore, Shamie; Sommer, Rolf, 2017, "Replication Data for: Application of secondary nutrients and micronutrients increases crop yields in sub-Saharan Africa", doi:10.7910/DVN/8AJQJJ, Harvard Dataverse, V1

Presentations:

Sommer, R.; Kihara, J.; Mukulama, J.; Karanja, N.; Ayaga, G.; Nyambati, J.; Paul, B. 2016. Impact of soil conservation practices on soil health, climate smartness and performance of smallholder farms in Western Kenya. In: Tropentag 2016: "Solidarity in a competing world fair use of resources" September 18-21, 2016, Vienna, Austria Vienna, AT. 1 p.

Sommer R., Kihara J. and Paul B.K. 2017. The soil carbon dilemma in the humid tropics: cannot hoard it!? A conference presentation made by Job Kihara in Vienna Austria, 24th April 2017 during the European geosciences union conference. Permanent link to this item: http://hdl.handle.net/10568/80911

MSc Theses

Peter Bolo. 2017. Effects of longterm use of organic and inorganic Fertilisers on soil microbes and nutrient availability in Nyabeda, Siaya County, Kenya. Thesis under review by university supervisors

Michael Kinyua. 2017. Effects of tillage, crop residue and inorganic nitrogen on soil carbon and nitrogen dynamics in Embu County, Kenya. Thesis under review by university supervisors