Influence of conservation tillage on soil microbial diversity, structure and crop yields in sub-humid and semi-arid environments in Kenya

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Introduction

Conservation tillage approaches affect soil microbial populations, soil structure and crop performance but the effects within African climate and soil conditions are not well understood. Tillage is known to affect soil aggregation through disruption of macro-aggregates and increased turnover rate of organic resources. In many small-holder farming systems in Africa, crop residue after harvest is either left on the farm as a strategy for soil fertility management or removed to serve varied uses: fodder, fuel etc. We investigated how maize stover retained within the cropping systems affects soil aggregation under conventional and reduced tillage systems. The stover is usually of lower quality than legume residues and their interaction could lead to aggregation differences between cropping systems where legume is included, and those planted with cereal only. In most sub-Saharan Africa, intercropping is the most predominant cropping system within small holder farming systems. However, works reported in literature focus mainly on pure crop stands either in rotation or continuous monocropping with a one-time per season application of some external organic resource. By affecting composition and structure of organic matter (Agnelli et al. 2004), cropping systems could in-turn affect microbial diversity through variability in nutrient and energy sources. In this study therefore we investigated the effect of conservation tillage practices, organic resource application and cropping systems on soil microbial diversity, soil structure and crop yields.

Materials and Methods

This study was conducted in two agro-ecological zones; a semi-arid zone (Machang'a in eastern Kenya) and sub-humid zone (Matayos and Nyabeda in western Kenya). The experiment in the semi-arid site was a randomized complete block design with 3 tillage systems (conventional tillage, no-till and tied-ridging) each with two organic applications (2 t ha^{-1} manure applied alone and, 1 t ha^{-1} manure plus 1 t ha^{-1} crop residue). The experiments in the two sub-humid sites were designed as split-split plots with tillage (conventional and reduced tillage), crop residue (0 and 2 t ha^{-1} maize stover) and cropping systems (continuous maize, maize soybean intercropping and rotation) as the main, split and split-split plots respectively. Conventional tillage involved hand hoeing to about 10-15cm depth as done by small-scale farmers, 3 times per season. Tied-ridges were prepared during trial initiation and maintained throughout the experiment, with tillage restricted to refreshment of the ridges. In the no-tillage system, land preparation was done using hand hoes and only hand pulling of weeds in between the season. Under reduced tillage, hoeing was restricted to surface scratching to 3cm depth to remove weeds. Average crop yield data for the first 3, 4 and 8 seasons in Matayos, Machang'a and Nyabeda, respectively, is reported.

Soil sampling for microbial analysis and aggregation determination was done during 4th, 5th and 10th seasons in Machang'a, Matayos and Nyabeda, respectively. Aggregation sampling depths were 0-15cm for Machang'a and 0-20cm for Nyabeda and aggregate separation was by wet sieving using a series of 3 sieves (2mm, 250µm and 53µm). Isolation of POM, silt-clay and micro-aggregates within macro-aggregates was done according to the procedure of (Six et al. 2000). Bacteria and fungal diversity were determined from dry-incubated soils for Matayos and Machang'a and fresh soil for Nyabeda, using PCR-DGGE techniques.

Results and discussions

Conservation tillage systems could have similar or lower yields compared to conventional tillage systems. We observed similar yields between Tied-ridge and conventional tillage over 4 cropping seasons in Machang'a, but significantly lower yields in reduced and no-tillage systems (Table 1). In the dryland site also, although no-till yields were lower than conventional system for the initial seasons, they increased progressively and were significantly higher by the fourth season (data not shown). Application of crop residue increased yields by 13% in Matayos and 15% Nyabeda while combination of manure and CR in Machang'a increased yields by 24% over manure only treatments (Table 2). CR is important also in soil water conservation and regulation of soil temperature especially when applied as surface mulch, as often done in reduced tillage. Recently, in order to improve water relations and crop performance in no-till and reduced tillage systems, modifications have emerged including ripping and sub-soiling and the results are promising (Motavalli et al. 2003), but also depending on the rainfall regime. We also observed the effect of crop residue on yield to vary with tillage and application of inorganic N; application of CR suppressed yields in conventional tillage especially when N was not applied indicating soil inorganic N immobilization, but upto 30% yield increases attributable to crop residue were observed under reduced tillage (data not shown).

Reduced and no-till farming can be effective in enhancing soil macro-aggregation. In both sites where aggregate separation was done (Machang'a and Nyabeda), higher aggregation was observed in conserved plots compared to conventionally tilled ones. This demonstrates that avoiding soil disturbance is necessary to improve aggregation of both clay and sandy soils. Although no significant effect of organic resource application on aggregation was observed over the overall soil depths, there was positive effect with combination of manure and crop residue in Machang'a increasing aggregation index by 17% over manure only treatments. And we also observed significant crop residue effect on soil aggregation at the surface 0-5cm soil layer, the zone where much of the CR was located (data not shown) showing that managing soil organic matter remains of great importance for the structural stability of the very surface soil. Among the cropping systems, intercropping had higher aggregation indices compared to the rotation system, but similar with continuous cereal system (data not shown). Continuous presence of a legume in the intercropping system could favour stability or re-formation of macro-aggregates via its root residues and legume organic exudates, its associated microbial community or simply the effect of its higher plant density (maize plus soybean) relative to the other systems. However, under rotation, the macro-aggregates formed during the legume phase likely break up after the legume crop is removed, leading to increased micro-aggregates and silt and clay fractions and hence lower aggregate mean diameter.

Diversity of bacteria is affected by tillage and organic substrates of different sources (Øvreås and Torsvik 1998). Diversity of bacteria in Machang'a and Nyabeda were not affected by tillage but in Matayos, reduced tillage showed higher bacteria diversity over conventional tillage system. Fungi diversity was higher in CT than in RT but nevertheless, we found no difference in the numbers of identified bands. Higher band volume under reduced tillage indicated that few fungal communities dominated this system, leading to the lower Shannon diversity index observed. Also there was significantly low diversity of fungal where crop residue was applied compared to treatments without crop residue, again due to domination by fewer species. Shannon diversity is high only when species numbers are high and evenness fulfilled. It could also be that domination by few species of fungi pushes other existing species to the <1% of microbial cells, usually too few to be detected by PCR-DGGE technique. As observed with soil aggregation, both bacteria and fungi diversity (Shannon index) were higher in intercropping compared to continuous maize system as observed in Nyabeda (data not shown). In Machang'a despite low carbon content, bacteria diversity was higher than in Matayos perhaps due to the towards neutral pH compared to more acidic soils in Matayos. In a continental-scale research involving different sites in North and South America, diversity of soil bacteria communities increased as soil pH increased from acidic to near neutral (Fierer and Jackson 2006).

Table 1. Effect of tillage on maize grain yield, aggregate mean weight diameter and microbial diversity

Site	Tillage	Maize grain yield (t ha-1)	Aggregate MWD	Bacteria diversity (H')	Fungi
Matayos	RT	1.44^{a}	-	2.05^{b}	-
	CT	2.01^{b}	-	1.79^{a}	-
	SE	*0.186*	-	*0.085*	-
Nyabeda	RT	3.15^{a}	1.81^{b}	2.02^{a}	1.56^{a}
	CT	3.71^{b}	1.47^{a}	2.04^{a}	1.67^{a}
	SE	*0.156*	*0.080*	*0.075*	*0.057*
Machang'a	NT	1.74^{a}	0.80^{b}	2.11^{a}	-
	TR	2.08^{ab}	0.74^{ab}	2.10^{a}	-
	CT	2.30^{b}	0.60^{a}	2.11^{a}	-
	SE	*0.124*	*0.053*	*0.090*	-

RT=reduced tillage; CT=conventional tillage; SE= standard error; values in the same site and column, followed by the same letter are not significantly different at P=0.05

Conclusions

Conservation tillage systems are important for improvement of soil structure in both clay and sandy soils. Application of crop residue as surface mulch is a good strategy both to improve soil structure and crop yields. In sandy dryland environments where nutrient leaching is prevalent, combinations of the modest crop residue and goat manure affordable by smallholder farmers is a superior strategy to sole application of equal tonnage of organics in form of manure. Both conservation tillage and application of organic resources in farming enhance bacterial populations but domination by few fungal species is expected. In the light of the improvements in soil structure and microbial populations, conservation approaches could be superior strategies, but the lower crop yields should be overcome. Integration of a legume used as an intercrop with cereal could offer a unique opportunity for increased microbial diversity and soil structure improvement.

Table 2. Effect of crop residue on maize grain yield, aggregate mean weight diameter and microbial diversity

Site	Tillage	Maize grain yield (t ha-1)	Aggregate MWD	Bacteria diversity (H')	Fungi
Matayos	-CR	1.62[a]	-	1.93[a]	-
	+CR	1.83[a]	-	1.91[a]	-
	SE	*0.12*	-	*0.085*	-
Nyabeda	-CR	3.20[a]	1.62[a]	2.04[a]	1.77[b]
	+CR	3.68[a]	1.67[a]	2.02[a]	1.46[a]
	SE	*0.21*	*0.073*	*0.073*	*0.057*
Machang'a	Manure only	1.82[a]	0.66[a]	2.07[a]	-
	Manure+CR	2.26[b]	0.77[a]	2.15[a]	-
	SE	*0.101*	*0.043*	*0.073*	-

CR=crop residue; H'=Shannon index of diversity; SE= standard error; values in the same site and column, followed by the same letter are not significantly different at P=0.05

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