Assessment of Biomass Transfer from Green Manure to Soil Macrofauna in Agroecosystem-*Soil Macrofauna Biomass*

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Abstract

During 1997 short rains (Oct 1997-Feb 1998), a study was undertaken to assess how biomass transfer within agroecosystem influence soil biodiversity (soil macrofauna biomass).

This was part of a larger experiment conducted to test the hypothesis that diversity, abundance and function of soil invertebrate fauna are related to the quality of organic residues used. Leaf biomass of tithonia (*Tithonia diversifolia* [Hemseley) A. Grey) biomass and senna (*Senna spectabilis* D.C. & H.S. Irwin) biomass at 5 t ha^{-1} dry weight were incorporated into the soil and these were compared with the control without any input and fertilizer at 120 kg N, 150 kg P and 100 kg K ha^{-1} from urea and triple super phosphate (TSP). Macrofauna biomass (fresh weight), was monitored in soil monoliths (25cm x 25cm x 30cm) at the beginning of the season, six weeks after sowing maize and at maize harvest.

Addition of organic residues increased faunal biomass substantially over the fertilized and unfertilized controls. Whereas senna increased total biomass by 45% and tithonia by 49%, the two organic residues did not differ significantly between them. Addition of either senna or tithonia significantly increased earthworm biomass by 390% over no input control. Even though termite biomass increased by 160% in senna and 120% in tithonia over no input control, F test was not significant because of high variability between replications of the same treatment. Fertilizer use did not change biomass of termites and earthworms.

This study shows that:

(1) addition of organic residues significantly increase faunal biomass indicating a likelihood that soil invertebrate functions can be manipulated by external inputs of organic residues

(2) under arable land use system characterized by low amount, range and diversity of food resources, quality of organic residues do not play a significant role in influencing foraging behaviour of soil invertebrates. It therefore remains to be demonstrated whether mixing litter of organic residues of different quality may change this foraging behaviour and consequently the invertebrate functions in agroecosystem.

Key words: Biomass transfer, macrofauna, biomass, earthworms, termites

Introduction

Soil fauna comprises a large variety of organisms with contrasted sizes and adaptive strategies. Their abundance, and composition, hence impact on soil processes vary greatly depending on vegetation and land use practices (Lavelle *et al.*, 1994a). Management practices such as continuous tillage can cause alterations in the population structure, elimination or reduction of key species and in some cases extremely low abundance or biomass (Dangerfield, 1993; Beare *et al.*, 1997). These negative effects created by management practices may last for years.

House and Parmelee (1985), found that soil arthropods and earthworm densities were higher under no tillage than in conventional tillage practices, an expanded and beneficial involvement for this fauna in crop residue decomposition processes. Studies conducted by Brown *et al.* (1996) showed that under agro-ecosystem, earthworms were the most dominant organism in terms of biomass, while in terms of numbers, ants and termites predominated. The faunal biomass was however low, compared with other tropical sites. In terms of diversity of faunal groups, they found that natural sites were richer than cultivated sites. Dangerfield (1993) found similar results and asserted that change of natural forest, for instance, to arable agriculture resulted in a dramatic decrease in faunal biomass, and diversity and a shift in dominance from millipedes to beetle larvae and earthworms. The change in habitat structure (removal of vegetation), the reduced range and abundance of food resources and the more extreme climatic conditions at the soil surface, combine to create an environment beyond the tolerance limits of most soil animals (Dangerfield, 1993). Only those species that are buffered from climatic extremes by building nests (e.g. termites) or living in deeper soil layers (e.g. beetle larvae), are not immediately affected, but may eventually suffer from the reduction in food resources (House and Parmelee, 1985; Dangerfield, 1993; Tian *et al.*, 1997). This explains why a severe depletion of soil fauna has been observed in highly degraded soils (Lavelle *et al.*, 1994b).

Mafongoya *et al.* (1996), found that changes in microbial community could be manipulated by applying prunings of different quality such that processes of litter decomposition and nutrient dynamics are enhanced. The major aim of the study was therefore to find out whether through inputs of locally available organic residues of different quality one could manipulate diversity, populations and 'biomass' of soil invertebrate fauna in order to enhance nutrient cycling, improve soil physical properties and also regulate decomposition processes.

Materials and Methods

Study site description

The study was conducted at Maseno (0°6' N, 34°35' E, and 1560 m above sea level), in Vihiga District of western Kenya (Jaetzold and Smith, 1982). The area receives an average annual rainfall of 1800 mm in two rainy seasons; 'long rains' (March to July) and 'short rains' (September to January). However during 1997 a total rainfall of 2037 mm was received, with 1200 mm in the short rains because of *El nino* phenomenon. Mean monthly temperature ranges between 14.6°C and 30.7°C. The soil at the experimental site was classified as Kandiudalfic Eutrodox (USDA, 1992). At the start of the study, the field had the following soil physical and chemical characteristics at 0-15cm and 15-30 cm depths respectively: pH (1:2.5 soil water) 5.5, 5.5; organic carbon (g kg^{-1} soil) 15.5, 14.5; extractable soil inorganic P (mg kg^{-1}) 1.3, 0.9; exchangeable calcium (cmolc kg^{-1}) 4.03, 3.85; exchangeable potassium (cmolc kg^{-1}) 0.15, 0.13; clay (%) 41, 42; sand (%) 33, 33; silt (%) 26, 25; porosity ranged between 50% and 60%. The soil is considered to be moderately P fixing with a soil P concentration corresponding to 310 mg P kg^{-1} adsorbed by the soil (Nziguheba *et al.*, 1998).

Experimental set up and management

The present study was superimposed on an on-going larger experiment that was initiated in 1995 during the short rains season to evaluate six organic tree and shrub residues (*Tithonia diversifolia, Lantana camara, Calliandra calothyrsus, Senna spectabilis, Sesbania sesban* and *Croton megalocarpus*), as sources of nutrients in comparison with inorganic nutrients at six different N and P levels. The treatments were replicated four times in a randomized complete block design in plots of 7.5 m wide and 7 m long.

The study was conducted during the 1997 short rains in the following treatments using maize as the test crop:

(1) Control: maize with no external inputs (Farmers' practice),
(2) Maize + fertilizer input at: 120 kg N, 150 kg P and 100 kg K ha^{-1},
(3) Maize + fresh biomass of *Tithonia diversifolia* at 5 tonnes (dry weight) ha^{-1} and
(4) Maize + fresh biomass of *Senna spectabilis* at 5 tonnes (dry weight) ha^{-1}.

The trial initially did not include "absolute control" (no N and P), so a farmers' no input control was randomly assigned to one of the unutilized blank plots in each replication. The site was relatively flat and there was no particular problem of runoff from plot to plot.

The amount of N and P added by the organic residues depends on the chemical composition. Chemical composition was determined every season at the time of application. All the selected material contained fairly high N and P, but differed with respect to tannin, lignin, polyphenol levels (Table 29.1). In the fertilized plots, 120 kg N ha^{-1} rate was chosen as it is close to the total N applied for the different materials ranging

between 136 Kg N ha^{-1} to 183 Kg N ha^{-1}. The rate is also sufficient to overcome N limitation to maize growth in these soils. The choice of the two residues (tithonia and senna) was based on:
1) the nutrient (N and P) concentration,
2) plant residue quality index (PRQI) (Tian *et al.*, 1995) and
3) availability in the region for potential use by farmers.

The difference between the two test materials as measured by PRQI has turned out to be much smaller than initially thought. However, the experience of many researchers indicates that tithonia decomposes faster than senna and represents high quality residues (Gachengo, 1999; Palm *et al.*, 2001). In western Kenya, particularly around Maseno area, farmers grow tithonia as part of live fence around their farms to mark boundaries or as hedges on contour. *Senna spectabilis* trees are also common. The two residues were therefore readily available.

Table 29.1: Chemical composition and plant residue quality index (PRQI) of tithonia and senna foliage

Plant residue	%N	%P	%Lignin	% Poly-phenols	C/N ratio	PRQI(%)
Senna spectabilis	3.3	0.21	9.0	1.03	10.89	10.26
Tithonia diversifolia	3.5	0.28	9.0	3.20	10.10	10.59

Crop management

The entire field was tilled manually at the beginning of the season. Tithonia and senna biomass were incorporated into the topsoil during land preparation. The materials were collected a day before land preparation. The required quantity of the fresh materials at 5 t ha^{-1}, was weighed (based on predetermined fresh weight to dry weight ratio; 16:1), and distributed uniformly on the ground before working into the soil. Maize (hybrid 511), was sown on October 9, 1997 (a day after incorporating treatments), at a spacing of 0.75m between rows and 0.25m between plants. Two seeds were placed into each hole, but the crop was thinned to one plant per hole 14 days after emergence, during first weeding. In the fertilizer treatment, the entire quantity of P as triple super phosphate and K as muriate of potash and half quantity of N as urea required for the plot were weighed and incorporated into the soil during land preparation. The balance of N was top dressed one and half months (42 days), after crop emergence during second weeding. In the field, no plant protection for both pests and diseases was applied as the study involved faunal observations.

Macrofauna biomass assessment

Using a monolith unit of size 25 cm x 25 cm x 30 cm, samples were taken at three periods during the season (Anderson and Ingram, 1993):

1) at the start of the experiment before the treatments were applied (October 6, 1997),
2). six weeks after treatments were applied (November 19, 1997) and
3) at the end of the season (February 18, 1998).

At each observation, two samples were taken randomly from each plot. The monolith was placed over a randomly selected spot and using a metallic mallet, it was driven into the soil until it was level with the ground. The soil from the monolith was removed by hand depthwise (0-10, 10-20 and 20-30 cm) into plastic buckets. The soil from each depth was placed in different plastic trays (20 cm by 30 cm) and gently sorted out to locate the animals. The animals were separated into major taxonomic groups, recorded and then collected in glass and plastic bottles using a pooter. In the laboratory, counting and weighing (for biomass), were done. The fresh weight (in grams) determination took place within 12 hours from the time of sampling. Biomass of different category of animals was expressed per metre square (Anderson and Ingram, 1993).

Data analyses

The data collected were subjected to analyses of variance (ANOVA), to compare treatment effects on diversity, populations and biomass of soil invertebrate fauna ANOVA was conducted using the GENSTAT 5 Committee (1993) statistical package. Where sampling was conducted at different periods, the data were analyzed in a split-plot design with the applied treatments as the main plot factor and sampling period as the sub-plot factor. Treatment differences were evaluated using the least significance difference (LSD) at $P<0.05$. Standard error of difference of means (SED) was given.

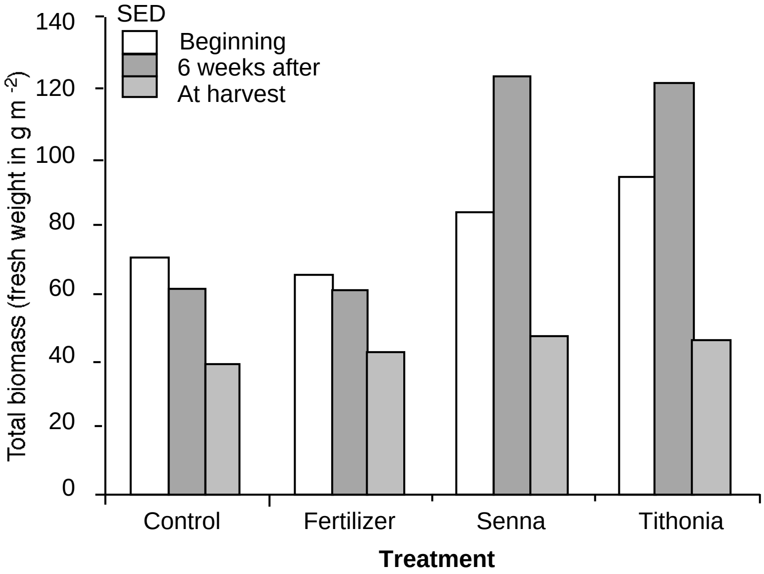
Results

Total faunal biomass

Addition of organic residues increased faunal biomass substantially over the fertilized and no input controls. Whereas senna treatment increased total biomass by 45% and tithonia by 49%, the two organic residues did not differ significantly.

Faunal biomass varied significantly over time between green manure, fertilizer and no input control. At the beginning of the season, senna and tithonia green manure treatments recorded 17% and 32% higher faunal biomass than the no input control and 28% and 43% than fertilized control, respectively. At six weeks after applying the materials, senna treatment recorded 100% higher biomass than the fertilizer and no input control treatments. Tithonia treatment recorded 96% higher biomass than both fertilizer and no input control treatments (Figure 29.1). While the biomass in the fertilized and no input treatments decreased continuously as the season progressed, it increased in the green manure treatments by 48% for senna and 29% for tithonia at six weeks stage and then declined to about 50% of the initial values at crop harvest in both treatments (Figure 29.1).

Figure 29.1: Total biomass (fresh weight) of soil fauna in maize green manured with organic residues compared with fertilized and unfertilized control at different periods during 1997 short rains at Maseno, Western Kenya



Earthworm biomass

ANOVA of earthworm biomass indicated significant differences due to treatments, sampling period and interaction between them.

The average earthworm biomass across treatments was low at 2.1 g m^{-2} for both fertilizer and no input control, but addition of both senna and tithonia green manures, significantly increased the biomass by five times. The two organic materials did not differ in their effect on earthworm biomass. For no input control and fertilizer treatments, the earthworm biomass was highest at the beginning of the season and it decreased considerably in course of the season. Green manuring with senna and tithonia increased the earthworm biomass by 100% and 72% respectively, at six weeks after applying the material, but the biomass at final crop harvest was low similar to that in other treatments (Table 29.2).

Table 29.2: Fresh weight of earthworms in maize green-manured with organic residues compared with fertilized and unfertilized control at different periods during 1997 short rains at Maseno, western Kenya

Treatment	Sampling time			Mean
	Before sowing	6 weeks after sowing	At harvest	
		(weight g m^{-2})		
Control	9.8 (3.6)	0.5 (1.2)	0.3 (1.0)	2.1 (1.9)^{b}
Fertilizer	8.5 (3.4)	0.4 (1.1)	0.7 (1.3)	2.1 (2.0)^{b}
Senna spectabilis	21.6 (5.2)	10.7 (3.8)	3.0 (2.2)	10.3 (3.7)^{a}
Tithonia diversifolia	8.0 (3.3)	13.8 (4.2)	1.7 (1.8)	10.3 (3.7)^{a}
Mean	11.4 (3.9)	4.3 (2.6)	1.2 (1.6)	
SED (treatment)		(0.4)		
SED (sampling time)		(0.3)		
SED (interaction)$_1$		(0.6)		
SED (interaction)$_2$		(0.6)		

F test: Treatment = p<0.001; Sampling time = p<0.001; Treatment sampling time = p<0.001.

Means followed by the same letter within a column are not significantly different at 5% level of probability. Values in parentheses are square-root $\{\sqrt{(x+0.5)}\}$ transformed.
SED (interaction)$_1$ = Standard error of difference of means for sampling time in any treatment.
SED (interaction)$_2$ = Standard error of difference of treatment means at a given sampling time.

Termite biomass

Addition of either fertilizer or organic materials, increased the biomass of termites significantly compared with the no input control.

Table 29.3: Fresh weight of termites in maize green-manured with organic residues compared with fertilized and unfertilized control at different periods during 1997 short rains at Maseno, western Kenya.

Treatment	Sampling time			Mean
	Before sowing	6 weeks after sowing	At harvest	
		(weight g m^{-2})		
Control	2.1 (1.9)	0.1 (0.8)	0.1 (0.8)	0.5 (1.2)
Fertilizer	2.0 (1.9)	0.1 (0.8)	0.2 (0.9)	0.5 (1.2)
Senna spectabilis	1.4 (1.7)	2.5 (2.1)	0.3 (1.1)	1.3 (1.6)
Tithonia diversifolia	0.7 (1.3)	2.8 (2.2)	0.5 (1.2)	1.1 (1.6)
Mean	1.5 (1.7)	0.9 (1.5)	0.2 (1.0)	
SED (treatment)		(0.3)		
SED (sampling time)		(0.3)		
SED (interaction)$_1$		(0.6)		
SED (interaction)$_2$		(0.6)		

F test: Treatment = NS; Sampling time = NS; Treatment sampling time = NS.

Values in parentheses are square-root $\{\sqrt{(x+0.5)}\}$ transformed.

SED (interaction)$_1$ = Standard error of difference of means for sampling time in any treatment.

SED (interaction)$_2$ = Standard error of difference of treatment means at a given sampling time.

NS = Not significant at 5% level of probability.

Termite biomass in fertilizer and no input control was highest at the beginning of the season, which decreased to very low levels in course of the season. In contrast to this, there was a 2-4 increase in termite biomass six weeks after applying senna and tithonia green manures, respectively. However, the biomass declined thereafter to similar levels to the other treatments. Treatment differences were not significant because of high variability among replicates.

Discussion

Microclimate, food resources and land use practices (e.g. pesticide application, burning and clearing of land), are major factors affecting the diversity, abundance and biomass of soil fauna communities (Warren *et al.*, 1987). Management practices such as continous tillage can cause alterations in the population structure, elimination/reduction of key groups and species of soil fauna and in some cases, low abundance or biomass (Dangerfield, 1993; Beare *et al.*, 1997). Studies have shown that cultivated sites are usually poorer than natural sites in terms of faunal diversity and biomass (Brown *et al.*, 1996).

Biomass of the soil fauna was low within the agroecosystem. This is similar to results observed elsewhere in arable fields (Dangerfield, 1993; Brown *et al.*, 1996). In arable land use systems, the change in habitat structure where vegetation are removed, reduced range and abundance of food resources and the extreme climatic conditions at the soil surface combine to create an environment beyond tolerance limits of most soil fauna groups. The low diversity, abundance and biomass of the soil invertebrate fauna observed, particularly in the no input control, typically represent the status of soil fauna in the fields of resource poor farmers. Most small-scale farmers clear and burn the land and rarely add external inorganic inputs to the soil for nutrient replenishment. The implication is that a change to continuous cropping decreases plant richness, thereby reducing the diversity of food resources and residue quality. Studies have shown that such changes in the land use systems lead to reduced abundance, biomass and diversity of soil fauna communities (Warren *et al.*, 1987; Dangerfield, 1993).

Application of senna and tithonia residues increased the biomass of the soil fauna groups for example earthworms. Studies have also shown that addition of organic residues such as senna and tithonia increase the faunal population by 100% over no input control (Ayuke, 2000). Organic inputs such as crop residues, tree prunings and manures, provide food to soil organisms. Greater faunal biomass in residue applied treatments may be the result of a greater accumulation of organic matter. Accumulation of organic matter from these residues (senna and tithonia), may provide resource base for the invertebrates. Coleman *et al.* (2000) states that soil organisms are strongly limited by available energy sources and are in a state of starvation much of the time. The increased supply of organic matter may possibly eliminate this state, in turn allowing their consumers, i.e. earthworms and termites, to subsequently increase in numbers hence increase in biomass. Surface applied residues preserve soil water from evaporation, reduce soil temperature and provide conducive niches for certain faunal groups. However, the insignificant differences observed in faunal biomass between senna and tithonia, could be due to reduced structural complexity and low diversity in food brought about by changes in the arable land use system.

Conclusions

In intensively cropped and nutrient depleted soils such as the Kandiudalfic-Eutrodox soil of this experiment, addition of organic residues increase the faunal biomass, for example earthworms within the cropping seasons. However under arable land use system characterized by low amount, range and diversity of food resources and the type and quality of organic residues do not play a significant role in influencing foraging behaviour, hence biomass of soil invertebrates. Even though faunal biomass was high in senna and tithonia treatments than under fertilizer and no input controls, they did not significantly differ in their effect of biomass. It therefore remains to be demonstrated whether mixing litter of organic residues of different quality may change this foraging behaviour resulting in increased biomass and consequently the invertebrate functions in agroecosystem.

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