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Tree Diversity Effects on Litter Decomposition in an Agroforestry System in a Semi Arid Zone in Juja, Kenya

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Abstract
Plant litter decomposition is an important ecosystem function that aid nutrient cycling in agroforestry system, however it is not clear if the diversity of agroforestry tree species affects rate of decomposition of their resultant litters within the early stage of decomposition. This study was conducted in an agroforestry experimental farm that was established in 2011 in Jomo Kenyatta university of Agriculture and Technology, Juja, Kenya. The site contains four treatments involving seven agroforestry tree species from which eleven combinations was grouped for decomposition process. The decomposition process was studied using the standard litter bag technique and the soil moisture content on each treatment plot was measured to determine its confounding effect on litter decomposition. The percentage mass loss of litter after 90 days of decomposition was highest in *Acacia seyal* (48.75%) and lowest in *Cordia africana* (21.65%). The composite litter decomposes faster than the low decomposing monocultures suggesting synergistic interaction but when the observed and predicted litter mass loss was compared a 100% additive effect was observed. The treatment plots with *Faidherbia albida* had the highest soil moisture content (42.97%) while the treatment plots with *C. africana* had the lowest (28.96%). However, effect of soil moisture was not significant on the rate of decomposition (r^2=0.046). These findings suggest that litter combination increases rate of decomposition in low decomposing litters and soil moisture effect was insignificant on rate of decomposition, suggesting other factors are contribution to decomposition. Farmers should therefore use different agroforestry species to benefit from the synergy of the different ecosystem function of different tree species such as enhanced decomposition rate from the low decomposing species.
Keywords: Agroforestry; Decomposition; Nutrients; Soil moisture; Synergistic.

Introduction

Agroforestry is practiced in arid and semi arid lands (ASAL) to improve soil fertility (Jama and Zeila, 2005) among other tree benefits. Previous research by Belsky et al., (1989); Burgess and Adams (1998); Ludwig et al., (2003) shows that agroforestry could improved crop productivity through micro climate improvement and water redistribution from wet to drier soil. Trees on farm could also take nutrients deep down the soil beyond where crop root can reach and bring the nutrient to the reach of crops through litter drops and decomposition(Smith, 2010).

Decomposition of agroforestry tree residues releases nutrients into the soil which is an important ecosystem function (Aerts and De Caluwe, 1997) and regulates nutrient recycling (Hobbie and Vitousek, 2000). The litter decomposition and nutrient release pattern are known to be controlled by biotic and abiotic factors (Aber et al., 1990; Aerts, 1997; Hättenschwiler and Jørgensen, 2010; Mungai and Motavalli, 2006; Silver and Miya, 2001) such as litter quality, temperature and moisture. Initial litter quality and moisture contents are known to be the dominant factor that influences decomposition rate (Melillo et al., 1984).

Agroforestry practices contain a mixture of plant species such as trees and crops that have different growth forms and residue qualities, their mixed residues therefore may not decompose in a similar pattern to their individual components (Zeng et al., 2010). In the combination of trees on farm there could be interactive effects of litter mixtures on decomposition rate (Hoorens et al., 2002; Wardle et al., 1997) which could be additive or non additive (antagonistic or synergistic) (Dijkstra et al., 2009). Deciduous tree leaf litters decompose faster than the ever green leaf litters and comparing the effect of the tree diversity on a long term may underestimate or over estimate the short term dynamics of interaction (Gartner and Cardon, 2004). Therefore this study present a short term decomposition rate of some suitable agroforestry trees in a semi arid eco zone.

In temperate regions, several studies have already been conducted on the effects of litter diversity on litter decomposition (Hoorens et al., 2002; Hattenschwiler et al., 2005; Jabiol and Chauvet, 2012; Osono and Takeda, 2005; Pérez Harguindeguy et al., 2008; Wu et al., 2013) but limited attention has been given to semi arid region. Semi arid regions are known to be faced with soil infertility that is caused by low rainfall, high rate of evaporation to low rate of precipitation (Hasanuzzaman and Hossain, 2014). Tree on farm can be used to improve the quality of the soil among other benefits if properly planned. Proper evaluation of trees are needed to be done prior to introduction of trees in agricultural land because wrong choice of agroforestry trees could bring failure in the agroforestry practices (Nair, 1993). Therefore, it is important to select agroforestry trees with limited competition with crops (Muthuri et al., 2005) especially for soil water in arid and semi arid region and also trees with better decomposition capability to bring about a productive agroforestry practices.

Previous studies have discussed trees with potential benefits to agricultural crops (Gindaba et al., 2005;

Nair, 1993) such as nutrient release, moisture retention, protection against erosion and so on but the influence of introducing diverse trees on litter decomposition and moisture content have not been well studied in semi arid part of Kenya. This research focused on the influence of diverse tree introduced to farmland on soil moisture content, how the tree diversity affect their rate of decomposition and the relationship between the decomposition rate and moisture content. The aim is to shed more light and give information that could help farmers to optimally benefit from ecosystem services that could be rendered by tree diversity. It was hypothesized that tree diversity will improve the rate of litter decomposition and that moisture content will have a high relationship with the rate of decomposition.

2.0 Materials and Methods

2.1. Study Site

The research site is located in Jomo Kenyatta university of Agriculture and Technology (JKUAT), Juja, Kiambu County, Central, Kenya. JKUAT is in Thika District, 35 km from Nairobi, latitude 1°06´S, longitude 37°01´E and 1520m altitude (Muthuri et al., 2005) and classified as warm and temperate. The study site is believed to be part of the mapping unit LPD by Wanjogu and Kamoni, (1986) which has a flat topography, Soil characterized as chromic vertisols, poorly drained, dark grey and extremely firm cracking clay. The pH ranges from 5.2 to 5.8 in the top soil and from 4.8 to 7.0 in the sub soil. The temperature averages 19.7 °C (Wanjogu and Kamoni, 1986) and mean annual rainfall is 856 mm and is bimodal, with primary and secondary peaks in April and November (Muthuri et al., 2005). The least amount of rainfall occurs in July with average of 12 mm, the highest precipitation occurs in April with an average of 175 mm. The month of March is the hottest with 21.3°C and July the coldest with 18.4°C (Wanjogu and Kamoni, 1986). It has low fertility shallow soils which are sandy or clay and can support drought resistance crops like soya beans, sunflowers and ranching (Kiambu, 2013).

2.2. Experimental design

The experimental site is on eight acres land of length and width of 355m by 100m which is sub divided into 16plots of 50m by 40m and each plot is separated by a pathway of 5m. It comprise of three treatments and a control; each with four replicates. The treatments are allocated through randomized completely block experimental design; with blocking associated with soil characteristics. Each treatment plot has seven rows, four of the rows have tree species inter plant with two legumes (*Calliandra calothyrsus* and *Grilicidia sepium*) and the remaining three rows have the tree species alone. The treatment include seven agroforestry tree species which are set up as *Cordia Africana* treatment*, Faidherbia albida* treatment*,* mixed tree treatment containing *F. albida*, *C. africana*, *Grevillea robusta*, *Acacia xanthophloea* and *Acacia seyal.* The control treatment has two legumes on four rows and the remaining three rows are left without trees.

Leaf litter and mature senescence leaves of the seven agroforestry tree species were collected from the study site and dried to constant weight at 65°C. Using litter bags of (20×13cm) with 1mm mesh size, eleven different litter composition were prepared which include the seven agroforestry species (*C. africana*, *F. albida*, *G. robusta*, *A. seyal*, *A xanthophloea*, *C. calothyrsus* and *G. sepium*), *C. africana* mixed with the two legumes, *F. albida* mixed with the two legumes, Mixture of the five tree species and mixture of the five tree species with the two legumes. Five grams of each was put in twenty litter bags and mixed litter contain each species in equal grams and the litter bags installed in the field according to the plots treatment. A total of 11 composition bags (5 sampling period including before installation × 4 replicates) of each litter type were prepared. Overall, 220 litter bags were prepared, 140 monocultures, 40 bags contain mixture of 3 species, 20 bags contained mixtures of five species and 20 bags contained mixtures of seven species. Each species in any of the mixtures was equally represented in mass. Forty four litter bags (four replicate and 11 compositions) were retained for initial dry mass and nutrient elements while the remaining bags were installed in the plots based on the experimental treatment on each plots. Four in each combination was evacuated on the 15th, 30th, 55th and 90th day. The evacuated bags were brushed to remove soil attached to it and oven dried at 65°C until constant mass and weight recorded.

Soil moisture was measured on each treatment plots using a soil moisture probe (ML3 Theta Probe). On each plot 5 trees were randomly selected and soil moisture was measured at 50cm and 100cm from the base of the tree at 10cm and 20cm below top soil. On the control plots soil moisture was measured at four points on the edge and a point in the middle of the plot, on rows with legumes the measurement was taking from 5 randomly selected trees.

2.3. Data Analysis

The loss in dry mass of litter samples was calculated as difference between the initial dry mass and remaining mass at each sampling time. The rate of decomposition was calculated using the percentage of mass loss divided by respective days of sample collection (Hasanuzzaman and Hossain, 2014). Decay constant for leaf litter was calculated using the negative exponential decay model of (Olson, 1963) as sited by (Liu et al., 2009) as follows:

$$Xt / Xo = e^{(-kt)} \quad (1)$$

Where Xo is the initial weight and Xt is the remaining weight at time exponential function. Half-life calculated using equation 2 (Daldoum et al., 2010)

$$(t_{50}) = 0.693/k \quad (2)$$

Predicted mass loss was calculated as

$$PML= (S1\times\%S1) + (S2\times\%S2).....+ (S_n\times\%S_n) \quad (3)$$

where PML is the predicted mass loss, S is the observed mass loss in pure species and % S the proportion of the pure specie in the mixture (Salamanca et al., 1998). Calculation was done on data collected on each sampling day. To test for additive or non additive effect, the predicted and observed (mass loss in combination) mass loss was compared by independent sample t-tests (Gao et al., 2015). Decomposition rates between the compositions and soil moisture between the treatments was compared by analysis of variance. The relationship between soil moisture content and rate of decomposition was analyzed using correlation (scattered box). All statistical analysis was carried out using Excel 2007 and IBM SPSS version 21 with accepted significance level of $p<0.05$.

3.0 Results

3.1 Litter decomposition

The litter mass loss of all our samples followed a biphasic mode of decay (Dhanya et al., 2013) with initial rapid mass loss in the first 15days followed by a slow mass loss in the remaining sampling period (figure 1A and B). When decomposition rate for 90 days was observed, 44% of the material has decomposed before 15days, 29% between the 15th and 30days, 15% between 30 and 56days and 12% between the 56 and 90 days (Table 1). The highest percentage average mass loss was found in *A. seyal* 48.75% while *C. africana* had the lowest average percentage mass loss of 21.65%. The amount of days for 50% of the specie to decompose was highest in *C. africana* (288 days) and lowest in *A. seyal* and *F. albida* (106 days) see table 2. Though on the 90th day, *F. albida* and *A. xathophloea* lost 56% of its mass while *C. africana* lost 29.6% as shown in figure 1a. The percentage rate of decomposition was higher in all mixtures containing *C. africana* than *C. africana* alone while *F. albida* had a higher rate of decomposition than all the mixture containing *F. albida*. *A. seyal* and *A. xanthophloea* rate of decomposition was higher than all combination they were present while *G. robusta* had a lesser rate of decomposition than all mixture in which it was present see table 2.

From the observation of all the mixtures, mixture of *F. albida* with the two legumes had the lowest percentage mass loss. The mixture of the five tree species had a higher percentage mass loss than the mixture of the five tree species with the two legumes. Anova show no significant difference (f=0.900, p=0.541) when the average mass loss in the eleven compositions were compared.

Mixtures including *C. africana* and *G. robusta* had higher average percentage mass loss than *C. africana* and *G. robusta* alone (between 17-29% and 19-28% higher than when alone respectively), *F. albida*, *A. seyal*, *A. xanthophloea*, *C. calothyrus* and *G. sepium* mass loss was higher in monoculture than in mixture where they were present (10-21, 10-20, 4-14, 15-18, 11-14% higher than in mixed respectively). From the overall mass loss when we compared the single species alone with the combination in which they occur, both antagonistic and synergistic effect was observed but when predicted and observed mass loss where compare, a 100% non additive effect was observed from all our tested mixture.

The 100% additive effect observed gave room to extent tentacle towards calculating the interaction strength between the observed and expected. To calculate the strength of interaction, a formula was coined from Hoorens et al., (2009). The interaction strength was calculated using 1-(expected/observed mass loss), when observed mass loss is greater than expected mass loss a positive interaction occur but when the expected mass loss is greater than the observed mass loss a negative interaction occurred. The strength is measured based on the result deviation from zero. The observed strength of the reaction only deviate slightly from zero which show a slight difference between the observed and the expected. 25% of the mixture had a positive interaction while 75% had a negative interaction.

3.2. Moisture content

The average moisture content was highest in *F. albida* treatment plots 42.97 and lowest in *C. africana* treatment plots 28.96. Average percentage moisture content in rows with legumes was higher 39.67 than the rows with tree species alone 35.99 (Figure 2) but the differences was insignificant (t-test= 1.54, p=0.13). Average moisture content between treatment was highly significant (f=24.659, p<0.001) with plot with *C. africana* significantly different from other treatment plots. Treatment plots with *F. albida* had the highest percentage moisture content 28.40 while plots with *C. africana* had the lowest percentage moisture content 19.14. The order follow *F.albida* > control > mixed > *C.africana.* Moisture content was insignificantly different from 50cm and 100cm away from the tree and also between the 10cm and 20cm depth.

3.3. Relationship between litter decomposition rate and soil moisture content

Relationship between average moisture contents in all treatments and rate of decomposition of litters shows a weak correlation (r^2= 0.046) (Figure 3). There was no significant difference between the rate of litter decomposition between all the three treatment plots (f-test= 0.045, p=0.956).

4.0. Discussion

4.1. Litter decomposition

There was a rapid mass loss in the first 15 days for all the compositions which could be attributed to breakdown of non lignified carbohydrates (Corbeels, 2001; Parsons et al., 1990; Prescott, 2005). The slower rate of mass loss after the 15th day may be attributed to decomposition of lignified carbohydrates (Corbeels, 2001; Liu et al., 2007; Melillo et al., 1982).

The mass loss was lower in some compositions in monoculture than in their corresponding mixture while some compositions were higher in monoculture than in their corresponding mixture as stated in our result above. When the calculated predicted from single species composition litter mass loss was compared with the observed in mixture, the result was insignificant in all tested compositions. Information by (Gartner and Cardon., 2004) explain critically that when mass loss in the mixed litter matches calculated mass loss from the individual specie then the dynamics in the mixture can be predicted from the monoculture and this is known as additive effect. The additive effect observed in this research could be attributed to our experimental time frame (e.g time duration, size of our mesh (1mm) which is believed to exclude meso and macro decomposer organism from entering), location or the quality of our individual species. This showed that our monoculture litter mass loss composition could be used to predict the mass loss in the mixture they are present. Gartner and Cardon (2004) Postulated that methods, location and differences in litter chemistry of species used to test mixing effect can bring about an additive effect in the mixture. Handa et al., (2014) reported that large fauna has a significant effect on decomposition, C and N loss in litter mixture.

The fact that our predicted litter mass loss was not significantly different from the expected did not suggest that there was no mixing effect, but the effect of low decomposing litters has been balanced up by the effect of the high decomposing litter. Gartner and Cardon, (2004) also make a similar suggestion. This finding conforms with the finding of (Hoorens et al., 2009) that found no significant interaction at the plant functional type (PFT) level on mixture due to balancing up of interaction between the negative values and the positive values. The result of our present study suggested that ecosystem dynamic of short time litter decomposition of the species used for this present study can be predicted by the individual specie litter decomposition parameters. This did not conform to some previous studies that found mixing effect on litter decomposition when predicted and observed were compared (Gartner and Cardon, 2004; Salamanca et al., 1998) this might be attributed to our short time frame, the quality of our experimental species or experimental zone. The implication of this result can also be explained with the fact that individual specie in the mixture drove the pattern of decomposition and not the specie richness (Ball et al., 2008; Hattenschwiler et al., 2005; Hoorens et al., 2009).

4.2. Soil moisture content

There was a higher soil moisture content on rows mixed with legumes on each treatment plots than on rows with tree species alone, which align with the study of Kalinda et al., (2015) and Spevacek, (2011) which observed that leguminous trees can increase soil moisture retention. Soil moisture content in *C. africana* treatment plots was significantly different from other treatment plots which might be attributed to higher water usage by *C. africana* during the growing season for its re flushing. Gindaba et al., (2005) find fine roots of *C. africana* extending three times more than their crown radius in his research on *C. africana* in Ethiopia, this reduces the soil water content around the tree. Observation of Akpo et al., (2005) also found soil moisture content in the open land higher than under tree shade of *Acacia tortilis* and *Balanites aegyptiaca* doing second half of growing season (June-September) in North Senegal due to the same reason as above.

4.3. Relationship between litter decomposition and Soil Moisture

The weak correlation between the rate of decomposition and soil moisture content showed there are other factors contributing to the rate of decomposition of litter in this study. It support studies by Aerts (1997); Bothwell et al., (2014); Kirschbaum, (2004); Lellei-kovács et al., (2011); Xiao et al., (2014). The study by Xiao et al., (2014) showed result on soil moisture and litter decomposition was marginally significant (r^2=0.043, p=0.051) and study by Bothwell et al., (2014) report (r^2 = 0.03, p = 0.67) which show that soil moisture content was not the only predictor of leaf litter decay rates in an experiment conducted in a tropical montane wet forests in Hawaii.

There was no significant difference when rate of decomposition between the treatment plots were compared. The age of the tree on our study site could be a factor because the trees on our study site were only four years old at the period this research was conducted. The tree age might also have impact on the potential of the trees to have significant effect on its immediate environment. Spevacek, (2011) speculated that *F. albida* reach its maturity at above seven years old.

5.0 Conclusions

These findings suggest that litter combination increases rate of mass in low decomposing litters but the additive effect observed in mixed litter suggest individual litter of the monoculture was driving the litter decay dynamics. Soil moisture effect was not significant on rate of decomposition suggesting that other factors are also contributing to decomposition rate in semi arid regions. Hence farmers are encouraged to use different agroforestry species in order to benefit from the synergy of the different ecosystem function from different tree species such as enhanced decomposition rate on low decomposing tree species. Research using the actual litter fall percentage like the natural settings in the field (Gartner and Cardon, 2004) and also long term is suggested to actually know the main reason behind the additive effect found in litter mixtures.

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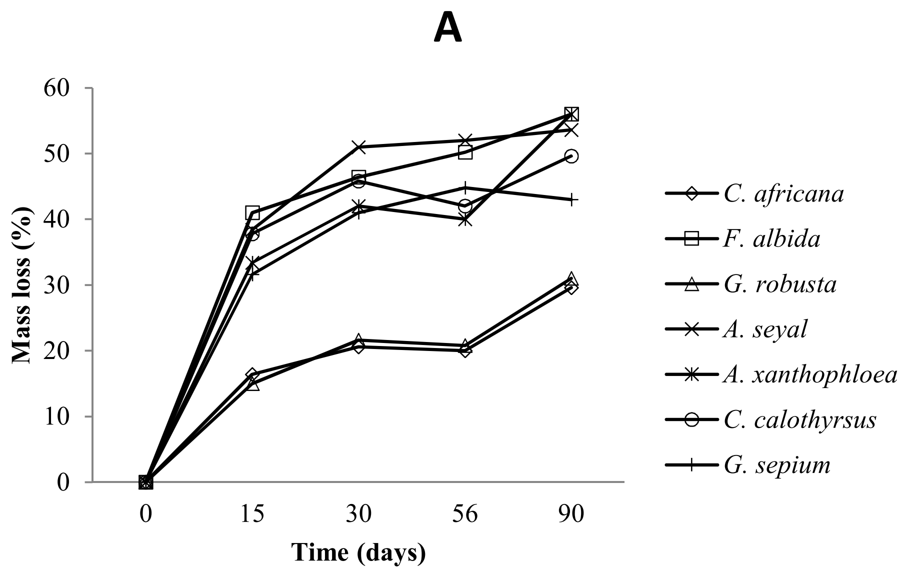
Table 1. Percentage of litter decomposed on each sampling day

Sampling Days	Decomposition rate	Percentage decomposed
15	20.56	44
30	13.71	29
56	7.06	15
90	5.46	12
Total	46.79	100

Table2. Average mass loss, decomposition rate, decay constant after 90 days and the corresponding days for half of the litters of the eleven samples to decompose.

Species	Average mass loss (%)	Decomposition Rate (per day)	T_{50} (days)
C. africana	21.65	0.62	288
F. albida	48.4	1.45	106
G. sepium	22.1	0.61	279
A.seyal	48.75	1.45	106
A.xanthophloea	42.85	1.25	124
C. calothyrsus	43.8	1.34	126
G. sepium	40.1	1.19	140
C. africana, C. calothyrsus and *G. sepium*	30.3	0.88	195
F. albida, *C. calothyrsus* and *G. sepium*	31.65	0.91	198
C. africana, *F. albida*, *G. sepium*, *A. xanthophloea* and A. seyal	39.65	1.11	136
C. africana, *F. albida*, *G. sepium*, *A. xanthophloea*, *A. seyal*, *C. calothyrsus* and *G. sepium*	32.3	0.92	181



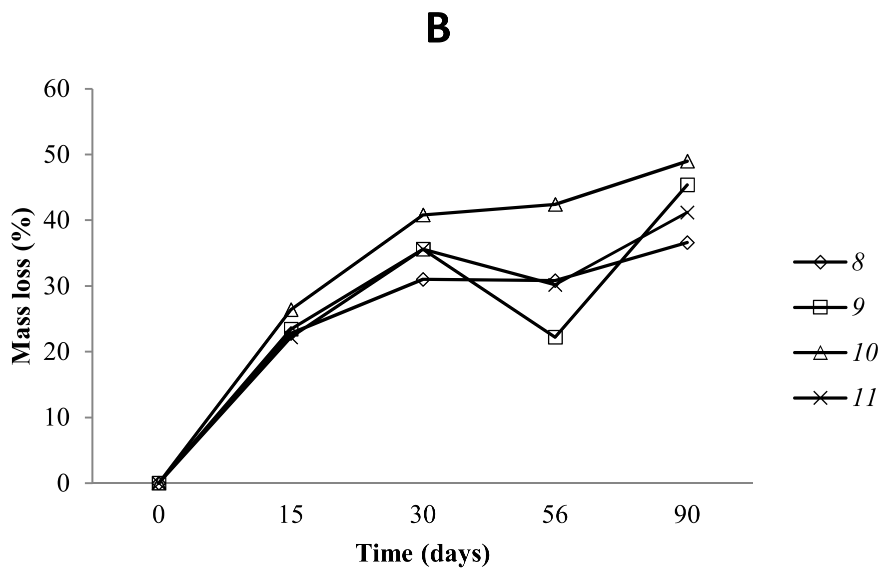


Figure 1 Rate of mass loss across the sampling period of 90days. 1A show mass loss in litters of the seven experimental tree species, 1B show mass loss in litters of all mixture. 8 represent combination of *C. africana*, *C. calothyrsus* and *G. sepium*. 9. *F. albida*, *C. calothyrsus* and *G. sepium*. 10. Mixtures of *C. africana*, *F. albida, G. robusta, A. xanthophloea* and *A. seyal*. 11. mixtures of *C. africana, F. albida, G. robusta, A. xanthophloea , A. seyal, C. calothyrsus* and *G. sepium*.

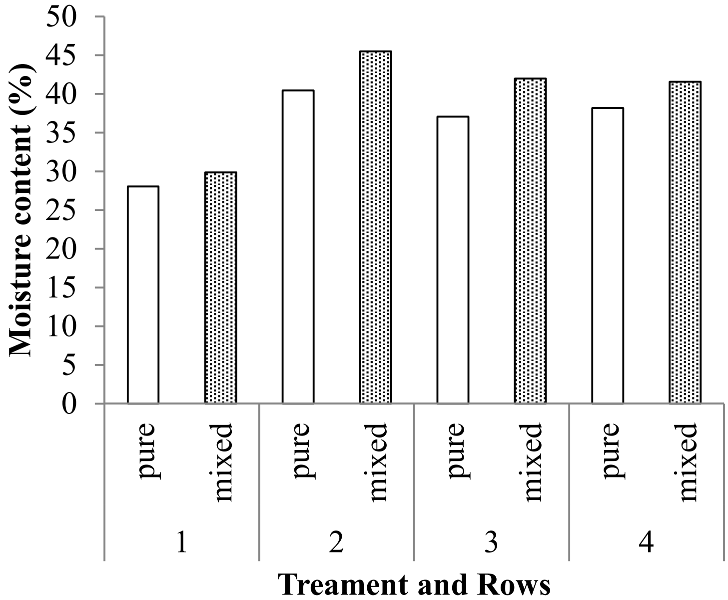


Figure2. Moisture content in each treatment plots and rows (1.Represent *C. africana* plots, 2 represent *F. albida plots*, 3 represent mixed plots and 4 represent Control plots. Pure represent rows with treatment of the tree species alone mixed represent rows with tree species mixed with the two legumes *C. calothyrsus* and *G. sepium*.

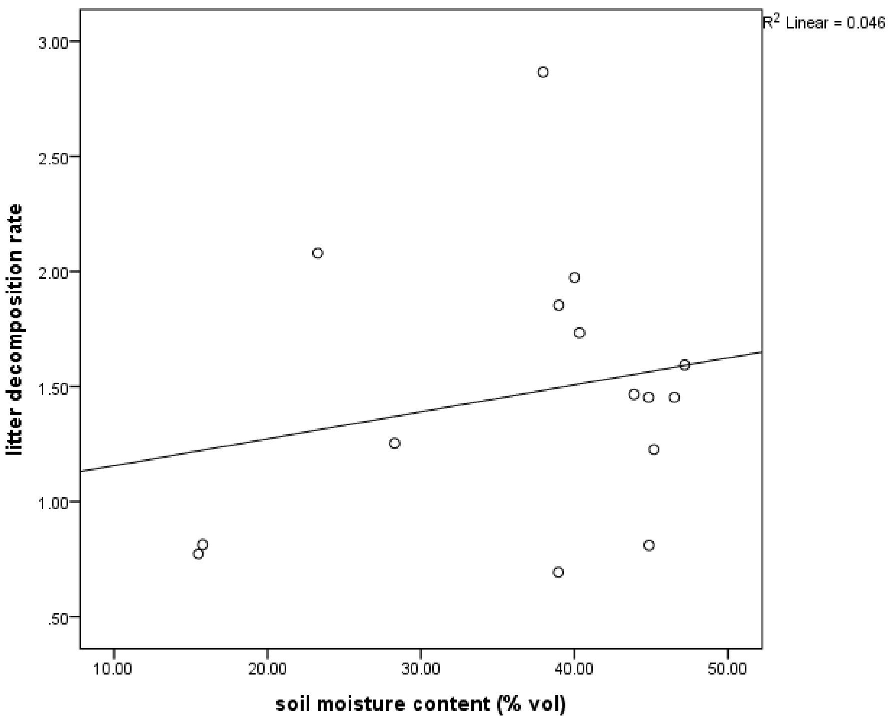


Figure3. Relationship between decomposition rate of litters of all experimental samples and average percentage moisture contents in all treatment plots.