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Mulching as a mitigation agricultural technology against land degradation in the wake of climate change

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Abstract

The sloping topography of the island of Rodrigues (an outer island dependency of the Republic of Mauritius) makes it very prone to soil erosion, and loss of fertile topsoil. Climate variability and climate change in the form of increasing temperatures, long periods of drought followed by short periods of torrential rains are exacerbating this situation. Mulching is a cheap, affordable, sustainable agricultural technology for sustainable soil and land management and reducing soil erosion, which can be adopted by small as well as large farmers. The present work on mulching was carried out in Rodrigues in farmers' fields that were prone to severe soil erosion (8% slope) Banana (*Musa sp*) leaves, coconut (*Cocos nucifera*) leaves, and vetiver (*Vetiveria zizanoides*) grass, at 0 t ha^{-1}, 10 t ha^{-1}, 20 t ha^{-1} and 40 t ha^{-1}, were used as natural organic mulches after seeding the plots with maize in a randomised block design with four replicates. Runoff and sediment were collected from the treated and control plots, and analysed for total sediments, total runoff, and nutrient content (N, P, K). Results showed that all the mulches tested contributed to lowering of soil and nutrient losses, albeit in varying amounts. Coconut leaves mulch was found to be the most efficient, followed by vetiver and then banana leaves. Percentage mitigation in soil and nutrient erosion was found to be 28.9% for banana leaves at 10 t ha^{-1}, and 57.3% for coconut leaves at 40 t ha^{-1}. The reduction of soil and nutrient losses was attributed to the mechanical barrier provided by the mulches, and also to the reduction in the momentum of raindrops acting on the soil aggregates. Mulching also contributed to increasing infiltration rate, lowering temperature and therefore lowering evaporation.

Key Words: Erosion, Mulch, Runoff, Sediment, Nutrient losses

1 Introduction

Mulching, which consists of covering the soil surface with organic material (and sometimes inorganic materials), is an age-old practice (Jacks et al., 1955) and was used to control soil moisture, soil temperature, nutrient loss, salinity, erosion soil structure, etc. However, with modern agriculture, this practice dwindled largely, but is now gaining importance once again in the context of sustainable agriculture. In the wake of climate change, high temperature, land slides, flashfloods, etc., mulching has regained its importance. Various types of mulches have been demonstrated to reduce soil erosion by more than 90% compared to bare agricultural soil (Mostaghini et al., 1994).

The need for increasing food security, while at the same time improving the quality of the environment, has prompted the search for materials that can protect the soil and maintain soil health (Armbrust & Jackson, 1977).

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Mulches such as straw have been shown to increase plant growth (Badia & Marti, 2000; Peterson et al., 2009). Similarly mulch cover has been positively correlated with plant cover and plant species richness (Dodson & Peterson, 2010). According to one report, soil erosion is second only to population growth as the biggest environmental problem that threatens agriculture in Africa and, to a lesser degree, in other parts of the world (Eswaran et al., 2001).

Similar to the present study, a report from Ethiopia demonstrated, that under low input agriculture, nutrients associated with sediments in the runoff were beyond tolerable limit (Girmay et al., 2009). The soil resilience, that is the soil's ability to restore its quality following a stress or perturbation, also depends on its inherent properties (endogenous factors) as well as climate and management (exogenous factors) (Lal, 1994). Crop residue mulch which applied as a layer at the soil-air interface protects the soil against raindrop impacts, decreases runoff velocity and shearing strength, and reduces runoff amounts and rate. Consequently, residue mulch decreases the risk of accelerated erosion (Wishmeir, 1973). Because mulch has favourable effects on soil quality and resilience, and also moderate soil temperature and moisture regimes, mulching has beneficial effects on crop growth and yield (Geiger et al., 1992). Crop residue requirements for erosion control depend on a multitude of soil factors, including texture, structure, and slope (Unger, 1985).

The objective of the study was to evaluate the effects of three mulches, namely coconut leaves, banana leaves and vetiver plants, at three different rates, on soil erosion control, runoff control, soil nutrient retention, and particle size distribution. All the three plant species studied as mulches are available readily and in large quantities in the study region, and are easily identifiable by the local people. No scientific studies have been carried out in Rodrigues on the use and effects of mulching, and this paper reports the first study of its kind. The importance of mulching is particularly relevant in the island of Rodrigues, given the observed impacts of climate variability and climate change, such as increasing temperatures, long periods of drought, short periods of torrential rains (MMS, 2010, Pers. Comm), which are exacerbating the soil erosion and loss of fertile topsoil that are consequences of the sloping terrain of the island.

2 Research methodology

2.1 *Site description*

This work was conducted in the island of Rodrigues (lat. 19°43′ and lon. 63°25′), spreading over two seasons in the valley of Nassola. The site is 335 metres above sea level, on a slope of about 8% towards the north. The soil is located on basaltic bedrock and is of the Low Humic Latosol (USDA-Tropeptic Haplostox and FAO- Humic Nitosol). The soil is slightly acidic. Crop production is usually of low external input; maize and beans are grown predominantly. The experimental plots belonged to one of the farmers in the village of Nassola and the plots were used as a demonstration plot for other farmers of the Nassola valley. Although the plot was under fallow for two seasons, there was clear evidence of serious erosion, as a rainwater harvesting reservoir located down the slope showed heavy siltation.

The meteorological data for the period of the two-year study was as follows: annual precipitation −157.2 mm; mean temperature −25.6℃ with a max temperature of 33℃; relative humidity −78%; (Mauritius Meteorological Service, Pers. Comm., 2010). The trial was conducted for two consecutive seasons in 2009/2010. Results discussed in this paper are mean values of the two seasons.

2.2 *Field experimentation and data collection*

The experiments investigated the effect of three different mulches, namely banana (*Musa sp*) leaves, coconut (*Cocos nucifera*) leaves, and vetiver (*Vetiveria zizanoides*) grass, at 0 t ha^{-1}, 10 t ha^{-1}, 20 t ha^{-1} and 40 t ha^{-1}, dry weight. These organic mulches were chosen because they are available in large amounts in the study region and no economic use of these resources was evident.

The experiment was laid in farmers fields' in a randomized complete block design with four replications. Before the experiment the site was cleared of vegetation and the existing terraces were reinstated. Each plot was 5 m ×5 m, and the net plot size from which growth and yield attributes was measured was 4 m×4 m. Plots were separated by a path of 1 m, while blocks were at a distance of 2 m. Soil samples were collected from the plots at depths of 0 – 20 cm during land preparation and at the end of the experiment, and analyzed for physical, chemical, and biological properties using standard procedures (Anderson & Ingram, 1993; Rowell, 1994). Maize seeds were planted in furrows lined with homemade compost at the rate of 20 t ha^{-1}. No chemical fertilizer was applied as the area was under fallow for more than three years. Three seeds were sown per stand with a spacing of 25 cm and the seedlings were thinned to two per stand two weeks after sowing (WAS). Manual weeding was done by hand pulling at 4 and 9 WAS and their dry weight at 70℃ were taken from each plots. Plots were watered on alternate days during the morning and evening with 20 litres of water/plot. Sheet metal was embedded to a depth of 15 cm and protruding 15 cm above the soil surface and the boundaries facing along the slope. The design adopted was that described by FAO (1993). Runoff from each plot was measure daily or after every rainfall event. Runoff depth was calculated by dividing total runoff volume collected in the tanks by the plot area. Sediments were calculated after stirring the runoff and taking a known volume (100 ml) and drying it at 105℃. Compost (20 t ha^{-1}) was applied evenly in all the plots and ploughed into a depth of 15 cm.

Soil moisture was measured every two days by tensiometers (pre-calibrated for this soil type) placed in the field. Similarly, soil temperature was measured every alternate day using stainless steel Fisher brand bi-metal dial thermometers, having a stem length of 20.3 cm, gauge diameter of 4.5 cm, and accuracy of 1.0% of dial range at any point of dial.

2.3 *Soil and mulch analysis*

Percentage of C and N and C/N of the three mulch materials were estimated prior to adding to the soil.

Soil pH, total N, available P, exchangeable K, Ca, Mg, and organic matter were estimated before the start of the experiment. The pH of the soil was determined in situ on a 1 : 2.5 soil: water ratio with a portable pH meter. Total nitrogen was determined by the Kjeldahl method. Available phosphorus was determined by the Bray method with HCl / NH_4F. Exchangeable K, Ca, and Mg was extracted by 1M ammonium acetate at pH 7 and estimated by flame photometry (Anderson & Ingram, 1993; Rowell, 1994).

Grain yield of maize was measured at maturity at 12 weeks after sowing. Data for each year were subjected to analysis of variance and treatment means were compared using Fisher's Least Significant Difference (LSD) at 5% level of probability.

3 Results and discussions

3.1 *Soil Characteristics*

Results of analysis of the soil prior to the experiment are shown in Table 1. The soil is slightly acidic, pH 6.4, probably due to the low rainfall and soil moisture in the area and also because the soil has received no chemical fertilizer and was under fallow. The texture is silty; there were previous signs of erosion as deposition of large amounts of clay was very noticeable down the slope in the water harvesting reservoir. However the fallow seemed to have slowed down the erosion because of the vegetative cover. Nearby cultivated fields showed extensive signs of soil erosion with exposed plant roots and visible bedrock.

The organic matter was 4.15% in the fallow plots which is quite satisfactory. Nearby fields that were under cultivation had a lower organic matter content of 3.75%. This could well be due to the loss of organic matter by decomposition and soil erosion as no soil conservation method was used. C/N was 89.5, which is quite normal for a soil which is not undergoing lot of disturbance.

Table 1 **Physical and chemical characteristics of soil in the experimental plots**

Soil parameter	Values	Soil parameter	Values
Sand (%)	43.1±1.2	Organic matter (%)	4.15±0.8
Silt (%)	32.6±1.2	Total N (%)	0.026±0.002
Clay (%)	24.3±0.8	Av. P ($mg\ kg^{-1}$)	6.23±0.51
Bulk density ($\times 10^3\ kg\ m^{-3}$)	1.45±0.5	Exch. K ($mg\ kg^{-1}$)	96±4.3
EC ($dS\ m^{-1}$)	1.36±0.3	Exch. Ca ($mg\ kg^{-1}$)	150±9.7
pH	6.4±0.5	Exch. Mg ($mg\ kg^{-1}$)	90±5.2

The values of exchangeable K and available P are quite satisfactory, although no chemical fertilizers were applied. The values are due to mineralization of organic matter generally. The soils are quite old and release of nutrients from mineralization of parent materials is expected to be insignificant. The values of Ca and Mg are quite satisfactory and are not expected to adversely influence the results of this experiment. The soil is therefore classified as Low Humic Latosol (LHL), Tropectic Haplustox (USDA), Humic Nitosol (FAO/UNESCO).

3.2 *Soil Loss*

Soil loss was highest in the control (unmulched) plots, equivalent to 8.3 t ha^{-1} yr^{-1} as compared to 3.5 t ha^{-1} yr^{-1} in the coconut mulched plot at 40 t ha^{-1}, representing a decrease of almost 100%. Furthermore, soil loss due to erosion was more or less dependent on the rate of the mulch applied and also the nature of the mulch. Banana mulch at 10 t ha^{-1} provided the least erosion mitigation of 5.9 t ha^{-1} yr^{-1}, whereas coconut mulch at 40 t ha^{-1} provided the highest erosion control (3.55 t ha^{-1} yr^{-1}). The mulches provided a reduction in soil losses due to detachment of raindrop impacts, erosive properties of the runoff, as well as transportation of the sediment by raindrop splash and surface runoff (Watson & Laflen, 1988). Mulch cushions the impacts of the raindrops on soil aggregates and offers a mechanical barrier to the runoff, and thereby increases infiltration of water in the soil profile and also acts as a sediment trap.

The difference in the reduction of soil loss from the various mulches is due primarily to the decomposition rate (half-life) of these mulches in the soil. Mulch has a low C:N ratio [e.g. banana leaves decompose at a much faster rate than those having a high C:N ratio (Table 2)]. Furthermore, it is quite probable that soil placement enhances soil microbial activity and soil organic matter, and these enhance soil aggregate stability (Maqubela et al., 2009).

Table 2 **C : N ratio of the three mulches tested in the present study**

Mulch	Carbon (%)	Nitrogen (%)	C/N
Banana	42.4	2.12	20
Vetiver	41.6	1.36	30.6
Coconut	31.05	0.75	41.4

The data in Table 3 stresses the importance of protective soil cover in reducing soil erosion. This demonstrates that all the three mulches, irrespective of nature and rate of application, reduced soil erosion substantially as compared to the control.

Table 3 **Sediment loss from mulched and unmulched plots**

	0 (t ha^{-1})	10 (t ha^{-1})	20 (t ha^{-1})	40 (t ha^{-1})
Control	8.3 ± 0.52 a*			
Banana		5.90 ± 0.24 b	5.60 ± 0.47 b	5.10 ± 0.37 b
Vetiver		5.25 ± 0.33 b	4.64 ± 0.39 c	4.10 ± 0.28 c
Coconut		4.00 ± 0.28 c	3.80 ± 0.18 cd	3.55 ± 0.14 d

* Means ± sd followed by the same letter are not significant at $P = 5\%$ with LSD.

3.3 *Particle size distribution of sediments*

Analysis of particle size distribution by Bouyoucous method (Table 4) showed that the sediments from the mulched plots had a higher percentage of the coarse fraction (mixture of coarse and fine sand) rather than the fine fractions (silt and clay). The mulched plots contained less of clay and silt. The clay fraction in the coconut mulch plot was 18% compared to the 25% in the control. This trend was observed in all mulches irrespective of the rate of application. It appears from the result that the mulches have resulted in some degree of sorting by retaining more of the coarse particles than the fine particles. This is partly due to the higher density and higher sedimentation rate of the coarser particles.

Table 4 Particle size distribution of sediments from mulched and unmulched plots

	Control (%)	Banana (%)	Vetiver (%)	Coconut (%)	Before experiment
Sand (2 – 0.02 mm)	35	37	45	52	43.1±1.2
Silt (0.02 – 0.0002 mm)	40	40	35	30	32.6 ± 1.2
Clay (<2 μm)	25	23	20	18	24.3 ± 0.8

3.4 *Nutrient losses*

Table 5 shows the amount of nitrogen (as ammonium and nitrate), phosphorus (as phosphate) and potassium from the mulched and unmulched plots. Mulches were very effective in retaining nutrients as compared to the unmulched plots. Highest retention was in the coconut mulched plots (40 t ha^{-1}) as compared to the control. Furthermore, the data shows that banana leaves were the least effective and coconut leaves were the most effective irrespective of rates in retention of nutrients. Banana leaves, due to its low C:N ration decompose at a much faster rate and therefore the soil cover was reduced quicker than coconut leaves which had a delayed decomposition.

Table 5 Nutrient losses from mulched and unmulched plots

Mulch	Application Rate (t ha^{-1})	Nitrogen (as ammonium+nitrate) (kg ha^{-1})	Phosphorous (as phosphate) (kg ha^{-1})	Potassium (kg ha^{-1})
Control		0.40±0.013a*	0.40±0.017a	2.50±0.17h
Banana	10	0.30±0.020b	0.30±0.015b	1.80±0.13d
	20	0.25±0.011c	0.18±0.017d	1.70±0.14d
	40	0.23±0.012c	0.15±0.013d	1.60±0.18d
Vetiver	10	0.30±0.020b	0.25±0.014c	1.60±0.14d
	20	0.28±0.012bc	0.19±0.016d	1.50±0.17d
	40	0.22±0.010c	0.13±0.05e	1.30±0.12e
Coconut	10	0.20±0.014c	0.18±0.017d	1.30±0.10e
	20	0.17±0.015d	0.10±0.018f	1.20±0.11ef
	40	0.15±0.013d	0.08±0.007g	0.90±0.10g

* Means±sd followed by the same letter are not significant at $P = 5\%$ with LSD.

3.5 *Runoff*

The runoff from control plots as well as mulched plots is shown in Table 6. It is clearly seen that all the mulches drastically reduced runoff. Highest mitigation of 75% was observed in the 40 t ha^{-1} coconut mulch and lowest in the 10 t ha^{-1} banana leaves (25%). All the mulches offered mechanical barriers to the water flow and improved infiltration. Such substantial reduction in runoff is attributable to increased infiltration due to water flow retention, and also dissipation of raindrop energy, and prevention of surface sealing. Similar findings have been reported by other investigators (Bhatt & Khera, 2006). Furthermore, increased organic matter, brought about by the decomposition of the mulches, is another possible explanation for the reduction in runoff. However such high reduction in runoff may not prevail for a long time as the water will slowly cause soil crusting and hence infiltration will reduce with time.

Table 6 **Runoff (mm) from mulched and unmulched plots**

	0 (t ha^{-1})	10 (t ha^{-1})	20 (t ha^{-1})	40 (t ha^{-1})
Control	40±2.4 A *			
Banana		30±3.1aB	26±1.9bB	24±1.6cB
Vetiver		22 ±1.9aC	20±1.6bC	18±1.2cC
Coconut		18±1.3aD	14±1.1bD	10±1.0cD

* Means±sd followed by the same capital letter down a column, and same small letter across a row, are not significantly different at 5% using LSD.

4 Conclusions

The work clearly shows the beneficial effects of the three mulches investigated. Soil loss and nutrient loss with runoff were all drastically reduced; the mechanism by which these reductions are brought about are mainly mechanical barriers to raindrops on soil aggregates, increased water infiltration, activation of soil microbial activity. The experiment conducted on farmers fields acted as a demonstration plot for all farmers in Nassola valley. Since the farmers were involved in the experiment right from its inception, it had wide ownership and the technology was widely adopted by the farmers. A booklet on the beneficial effects of mulching was distributed freely to all farmers.

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