

Full Length Research Paper

Effects of artificial soil surface management on changes of aggregate stability and other soil properties

Jerry A. Ngailo^{1*} and Sonia F. C. Dechen²

¹Ministry of Agriculture, Food Security and Cooperatives, Uyole Agricultural Research Institute, P. O. Box 400, Mbeya, Tanzania.

²Instituto Agronomico de Campinas (IAC), Centro de Solo de Recursos Agroambientais, Av. Barao de Itapura, 1481, CP28, 13020-902, Campinas SP-Brazil.

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Studies of size distribution, stability of the aggregates, and other soil properties are very important due to their influence on tilth, water infiltration, and nutrient dynamics and more importantly on accelerated erosion but are affected by soil surface management. Both chemical e.g. pH, organic carbon, (OC), exchangeable cations e.g. calcium (Ca), magnesium (Mg) and physical properties such as aggregate size and stability are dynamic properties, which vary in response to forces affecting soil environment. This study was carried out to have a long and detailed understanding of how artificial surface soil covering materials can protect the soil physical and chemical properties from the ravages of soil erosion. Such endeavor would allow us to make suitable modification to soil conservation practices to enhance soil stability and importantly soil productivity. Data measured for eight years on induced erosion experiments on a Ferralsol covered by artificial soil netting locally called sombrite at Campinas, Brazil, were used to examine the effects of accelerated soil erosion on soil chemical and physical properties. Each erosion plot had an area of 25 x 4 m. Four soil treatments were chosen: bare (control) and three artificially covered soils. Changes of soil properties observed in relation to aggregation were bulk density, total and aeration porosity, available water capacity and changes in soil chemical properties. From pooled data stepwise multiple regressions were done to find out the relationship of aggregate stability with pH, calcium, and organic matter. There were no significant differences ($P=0.05$) in mean weight diameters (MWD) and size distribution irrespective of whether samples were collected from the upper middle or lower parts of the erosion plots. There were very gradual decline in mean weight diameters (MWD) and size distribution of water-stable aggregates during the study period. Bulk density increased appreciably on bare soils but remained almost constant in artificially covered soils. However, using Duncan tests, the treatment differences were not significant ($P=0.05$). Non-significant correlation ($P=0.05$) between MWD and the soil chemical properties were observed. Coefficients of determination for pH, OC, MWD and Ca could not sufficiently assist in explaining changes in aggregate stability as a result of surface cover.

Key words: artificial soil covers, soil surface management, soil properties, accelerated erosion, aggregate stability.

INTRODUCTION

Synthetic soil surface covers have the potential to advance soil conservation technologies and to safeguard soil productivity. Some are manufactured by weaving or

bonding fibers made from synthetic materials such as polypropylene and others in the same group. Field studies using such materials as complete soil surface cover in reducing rates of soil erosion have been carried out by various workers in various areas and conditions. The utilization of these materials as a potential soil conservation technique has yielded different results (Windell and Haywood, 1996). Realizing their good use in soil erosion, various new types of plastics and fibers

*Corresponding author. E-mail: jerryngailo@yahoo.com, jjerryn@hotmail.com. Tel: 255-0784-906-728, 255 2510363, 2510062. Fax: 255 2510065.

appear frequently on the market and are continually being evaluated.

Adequate natural or artificial surface covers are major factors in controlling erosion because they reduce the erosive effect of raindrops falling on bare soils and the ability of winds to remove soil particles. Besides, reducing erosion, other benefits of such materials can include conserving soil moisture and nutrient leaching (Truax and Gagnon, 1993). Various new types of plastics and fibers appearing frequently in the market have continually been evaluated (Windell and Haywood, 1996). In studies with forest tree seedlings, a number of researchers (Ashby et al., 1992; Huetteman et al., 1992; Van Sambeek et al., 1995) reported successful establishment of silver maple and white ash with synthetic soil surface covers. Black polyethylene and black-woven polypropylene were shown to improve growth of green ash in a semi-arid environment (Stepanek et al., 2002).

In South America particularly in Brazil sombrite is made up of non-organic materials are often used. However, the nature and effectiveness of synthetic materials are varied for instance; Bhattacharyya et al. (2009) used organic materials called borassus mats constructed from *Borassus aethiopum* (Borassus palm of West Africa) and *Mauritia flexuosa* (Buriti palm of South America) for the same purpose to prevent the degradation of a sandy loam soil. Results indicated that such a geotextile on bare soil significantly ($P < 0.05$) reduced total soil splash erosion by nearly 90% compared with bare plots (24.81 kgm^{-2}).

Attempts to measure changes of aggregate stability in relation to artificial soil surface management in the field are still few in many areas because such measurements on plot scale are difficult to conduct. In some cases more predictive tools based on easily measured soil properties have frequently been found necessary.

Any soil surface covering is meant to protect the destruction of aggregates and in erosion work measured aggregates are characterized by their size, shape and surface roughness. More information on the effects of soil surface management on erosion and physical and chemical soil properties is required due to their effect on productivity of various soils. In addition to providing information on soil productivity, measurement of aggregate stability and related properties have a good prospect of providing suitable parameters for infiltration, runoff and soil erosion models.

With the above in mind, the objectives of our study were two folds firstly, to determine effectiveness of artificial soil surface covers on size distribution and stability of aggregates as affected by accelerated erosion, secondly, to gain more insights on long-term field scale soil physical and chemical property changes as a result of using artificial soil surface covers.

This study also attempted to determine quantitative relationships between artificial soil surface management materials of different intensities for reducing the impact of

accelerated erosion and some selected soil properties. Such generated information may be important in selecting erosion prevention measures in absence of organic covers and for selecting appropriate types of artificial soil covering materials.

MATERIALS AND METHODS

Description of the study area

The soil erosion experiments were established at the Instituto Agronomico de Campinas (IAC) in Sao Paulo State of Brazil located at latitude $22^{\circ}15'$ South and longitude $47^{\circ}04'$ West. The experiments were conducted on erosion plots that have been in place for nearly 66 years since 1943. According to available records these might be the longest continuously run erosion experiments in the world though much of its information is not known outside South America (Tengberg et al., 1997). All twenty four plots were located on a uniform slope of 11%.

The climate is sub-tropical with the mean annual temperature of about 23°C and the mean annual rainfall of about 1410 mm (Ortolani et al., 1995). The altitude around the site ranges from 600 -700 m above sea level. Long-term averages rainfall amount indicate that much of this rainfall is concentrated in the months of October through March in summer. After working with long term erosivity data Lombardi Neto and Moldenhauer (1992) observed that, most of the 62% annual erosion potential erosivity of $6738 \text{ MJmm ha}^{-1} \text{ y}^{-1}$ is concentrated in the months of December to February. In most years a dry season may occur in the months of April through to September and during this time the annual total precipitation is about 325 mm. According to the Brazilian soil classification system, the soils at the site are described as dusky red Latosols (EMBRAPA, 1981) equivalent to Oxisols (Soil Survey Staff, 1994) or Rhodic Ferralsols (FAO-UNESCO, 1998). Generally, these are soils with low activity clays and with inherently low base saturation.

Field methods

The twenty-four plots and four treatments were established for this work in a randomized design on a uniform slope of 11%. The applied treatments are described as follows:

T1 - control (bare soil)

T2 - covered by mixture of artificial green house shade netting material (sombrite) to provide about 11% cover on soil surface,

T3 - covered by sombrite to provide about 18% cover on soil surface and

T4 - covered by sombrite to provide about 30% cover on soil surface.

Each of the treatments above was replicated six times.

From each erosion plot, soil samples were collected each year for eight years. These samples were used for analysis of aggregate stability and for other physical and chemical data determinations in the laboratory.

Laboratory methods

Determination of aggregate stability and related properties

Aggregate stability was determined on 0-20 cm depth from triplicate samples taken from the upper, middle and lower positions of

Table 1. Mean physico-chemical properties of surface horizons at the start of experiment

Treatment	Sand (%)		Silt (%)	Clay (%)	Texture	Chemical properties								
	0.02-2.0 mm					pH CaCl ₂	O.M (%)	P (mgkg ⁻¹)	K	Ca	Mg	H+Al	CEC	B.S (%)
	fine	coarse												
T1	17	16	7	60	clay	5.4	2.7	11	0.26	4.1	1.6	3.0	8.6	65
T2	18	18	10	54	clay	5.3	4.0	6	0.24	4.0	1.7	3.2	9.4	65
T3	16	15	10	59	clay	5.4	3.8	5	0.22	3.8	1.8	2.7	8.5	67
T4	17	21	8	54	clay	5.2	3.9	10	0.29	4.2	1.7	2.9	9.2	68
Mean	17	16.8	8.7	58		5.3	3.7	7.5	0.25	3.8	1.6	3.2	8.9	65
s.d	0.75	2.8	2	2.7		0.12	0.27	2.5	0.04	0.38	0.1	0.35	0.3	2.8
Cv (%)	4	17	23	5		2.3	7.5	35	25	0.10	6	11	3.9	4

T1- control (bare soil), T2-soil surface covered by mixture of 'sombrite' (green house shade netting material) to provide 11% cover on soil surface, T3-soil surface covered by 'sombrite' to provide 18% surface cover on soil surface and T4-soil surface covered by "sombrite" to provide 30% surface cover. Sd- standard deviation. C.v- coefficient of variation.

erosion plots. In the method used for determination, a known amount of soil of some size fraction of aggregates was obtained from the field. Disintegrating forces designed to simulate field phenomenon were subjected to the aggregates. The amount of disintegration was measured by determining the portion (by weight) of the aggregates, which were broken down into aggregates and primary particles smaller than some selected size by sieving or sedimentation. Details of the methodology followed are given by Camargo et al. (1986).

Determination of bulk density, available water capacity (AWC), air filled porosity (PA) or pore space were recorded after equilibrium on tension tables. A particle density of 2.65 kgm⁻³ for mineral soils was used to calculate total porosity, whereas aeration porosity (PA) was calculated using the expression $PA=PT-(V \times 0.03 \text{ MPa})$ where PT= total porosity and V = volumetric water content at 0.03MPa.

Chemical properties

Details of analytical procedures used in the IAC's soil laboratories are found in Boletim Tecnico no.106 prepared by Camargo et al. (1986). From the eroded soil samples, analyses were done each year for eight years on the fine earth fraction to determine chemical parameters. pH was measured in 0.1M CaCl₂, soil organic matter (OM) content was determined calorimetrically and results were obtained from a standard curve under which organic matter was

determined by Walkley-Black method. Potassium (K), calcium (Ca) and magnesium (Mg) were determined by an ion- exchange procedure with resin. After 16 h of shaking, the resin was separated from the soil and extracted with an acid solution of sodium chloride. In this solution P was determined calorimetrically, K was determined by flame photometry whereas Ca and Mg by atomic absorption spectrophotometer (AAS), exchangeable acidity (EA) by SMP buffer. The pipette method was used to determine particle size distribution in the soils.

Data analyses

Stepwise regression for the averages of data obtained was carried out to find out quantitative relationships between aggregate stability with some chemical parameters. Mean weight diameter was considered as an independent variable whereas measured soil properties e.g. pH, organic matter and Ca as predictor variables.

RESULTS AND DISCUSSION

Chemical properties and particle size distribution at the start of the experiments.

Table 1 presents the mean particle size

distribution and chemical properties of the surface horizons (0-25 cm) of the plots during the commencement of the experiment. It is striking that there are almost equal quantities of fine and coarse sands in all experimental plots.

The very minor variations of both clay and silt particles are acceptable based on the history of the plots, soil type, and the effects of past erosion under which the soils were subjected to prior to the start of these experiments. Investigators found this to be an added advantage whereby a common starting point in terms of particle size distribution was possible. It is also not unusual to find soils with an oxic horizon as this one with very uniform texture.

In general, the data indicate that there is a pronounced proportion (>50%) of fine clay in soils of all treatments. The dominance of clays imparts a tendency of changing the characteristics of soil matrix by dominating its mineralogy and the exchangeable cations of aggregates. It is also obvious that this does affect the quantities and nature of cementing materials and the composition of the pore fluids in both eroded and un-eroded aggregates. Besides the presence of considerable

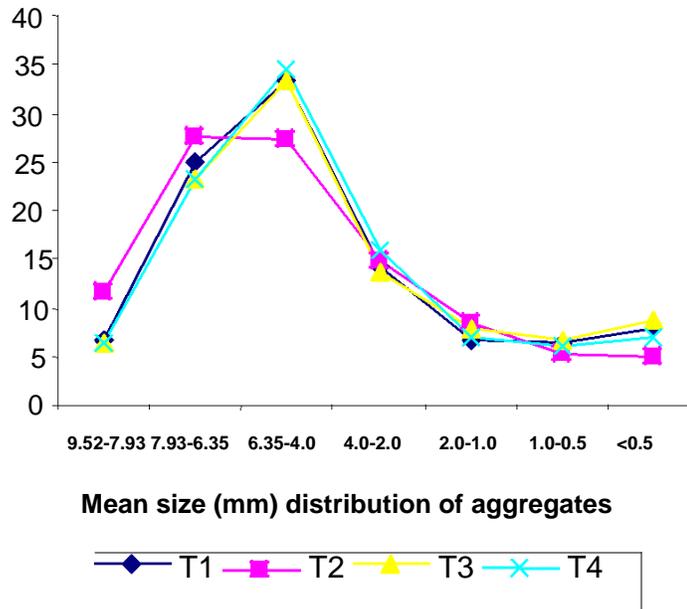


Figure 1a. Size distribution and composition of water stable aggregates at start of experiment.

clay content in soils of all plots, generally there were low nutrient reserves in the soil. Data indicated low levels of pH, phosphorus, organic matter (o.m), cat ion exchange capacity (C.E.C), magnesium, calcium, and potassium. The base saturation levels were also low. These levels of cations are indicative of a highly weathered soil such as Ferralsols.

Exchangeable acidity levels are low in soils of all plots and may be indicative of an impending danger of increased hydrogen and aluminum ion toxicity that is contributory to soil infertility.

Size distribution of aggregates during the start and end of experimental period

Figures 1a and 1b show the size distribution and composition of water stable aggregates for the first year and during the eighth year of experiment. Clearly, there was a dominance of large aggregates (>4 mm) than smaller ones in all treatments at the beginning of the experiment (Figure1a) . The beginning of the experiment is the time when the effects of accelerated erosion on aggregate stability began to be monitored. The proportions of the largest (9.52 - 7.90 mm) aggregates were almost equal in all treatments at the start of the experiments. More obvious is the persistence of proportion of smaller size (<4.00 mm) aggregates at the end of the experiment for treatments T1 and T2 than others. Indicating how the intensity of artificial cover protected the aggregates.

At the end of the experiment the large and dominant

sizes were generally observed in treatments T3 and T4 respectively, in which size ranging between 4.0 and 9.0 mm were dominant. This can be explained by the fact that, in presence of artificial soil surface cover a possibility exists of maintaining aggregate stability because of the lessening impact of the biting action of the rain drops on the aggregates the contrary is also true. The results imply that it was not an easy task to maintain aggregates of same sizes throughout the experimental period despite the artificial protective covers on some of the treatments. The tendency with time was for aggregates in all treatments to become smaller sizes (>4.00 mm). This shows also that the maintenance of suitable aggregates in eroding soils is a daunting task in absence of an effective and efficient protective. Artificial soil surface covers such as sombrite which was used in this experiment is artificial and do not supply any material that enhances soil aggregation.

Effects of artificial soil covers on changes in mean weight diameters (MWD) and bulk density of aggregates within plots.

Besides the presence of different degrees of soil covers, the results have consistently shown that the aggregate MWD during the term of the experiment slightly decreased from the upper part of the positions to the lower parts of the experimental plots (Table 2). However, using simple statistical proof, results showed that the MWD results were not significantly different in samples taken from different positions in the experimental plots. A

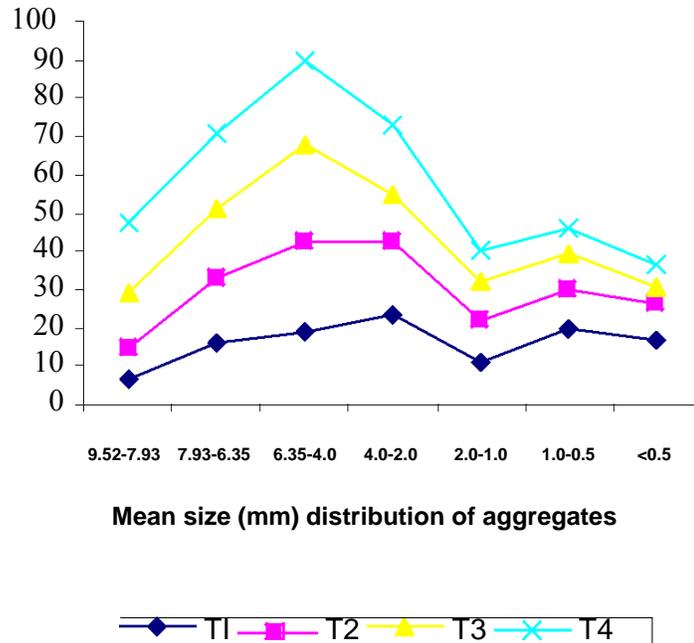


Figure 1b. Size distribution and composition of water stable aggregates in the seventh year.

Table 2. Mean weight diameters (MWD) and average bulk density (Mgm^{-3}) of aggregates for treatments on upper middle and lower positions of the plots.

Treatment	Mean weight diameters			Bulk density		
	Upper	Middle	Lower	Upper	Middle	Lower
T1	4.1	3.0	3.9	1.33	1.23	1.30
T2	3.9	3.8	3.2	1.10	1.19	1.19
T3	3.7	3.7	2.8	1.17	1.19	1.17
T4	3.6	3.6	2.9	1.20	1.23	1.19
LSD (0.05)	ns	ns	ns	ns	ns	ns

Ns=not significantly different between positions on plots within the same treatments, T1- control (bare soil), T2-covered by mixture of 'sombrite' (green house shade netting material) to provide 11% cover on soil surface, T3-covered to provide 18% surface cover on soil surface and T4-covered to provide 30% surface cover on soil surface
Table 2 also depicts the mean bulk density values during the period of the experiment.

coefficient of variation (CV=20%) was slightly high but not unusual for such a soil property.

Aggregation in this case was not only linked to the organic matter because higher MWD were not only found in lower parts of the plots where the clay and organic matter was assumed to be high because of deposition by runoff. It shows that for plots of this sizes there is no difference in the final results whether samples for MWD analyses are collected from any part (upper, middle or lower) of the plots. It implies also that whether triplicate samples for MWD and aggregate stability analyses are collected from any part (upper, middle or lower) of plots of such size (25 x 4 m) the results will show little difference.

Table 2 also depicts the mean bulk density values during the period of the experiment. The study of bulky density was undertaken to investigate the changes in compactness of the soil in not in relation different tillage effects as most studies have done, but different degrees of artificial soil surface covers and to associate it with total porosity. Total porosity is one of the most important characteristics that can be related to aggregate stability and distribution. Moreover, generally there was very gradual change of bulk density following induced-erosion in the 8 years of the experiments. Bulky density increased with time among treatments. The results have been obtained by measuring the aggregates after the treatment application. The differences between the

Table 3. Proportion (%) of large (> 4.00 mm) and small aggregates (< 4.0 mm) during the study period.

Treatment	Aggregate size >4.00 mm		Aggregate size <4.00 mm	
	Start	End	Start	End
T1	65	39	35	60
T2	67	34	33	66
T3	71	32	29	71
T4	69	64	31	36
mean	ns	ns	ns	12

T1- control (bare soil), T2-covered by mixture of 'sombrite' (green house shade netting material) to provide 11% cover on soil surface, T3-covered to provide 18% surface cover on soil surface and T4-covered to provide 30% surface cover on soil surface.

treatments are clear though not significant.

The most important finding from these results however is the high bulk density for T1 treatments than the rest of the treatments. This same trend was observed for upper, middle and lower parts of the plots, followed by the T3 treatments, which for a long time before the experiment was an untilled and therefore bare plot. The change in T1 is largely attributed to the effects of erosion on increasing bulk density. In treatment T4 effects are the same but are also related to the gradual decrease in soil organic matter.

The role played by artificial soil covers on reducing organic matter loss, runoff and subsequently erosion cannot be over-emphasized. Studying the level of soil deterioration, it is obvious that, the different degrees of covers have offered a certain degree of protection to the aggregates and other soil properties throughout the experiment period. Their use in farmers' fields needs a critical look due to their inability to supply organic constituents that are very important in the formation and enhancement of aggregation in soils.

Effects on sombrite on size distribution of large and small aggregates

Table 3 gives results for proportions of aggregate size distribution for the different artificial soil cover in the study period. An arbitrary boundary was set whereby aggregates of >4.00 mm size diameter were considered to be large and those below to be small. Generally, there has been a declining trend in the proportions of large aggregates in comparison to the smaller ones. At the beginning of the experiments all the treatments contained over 50% of large (>4 mm) aggregates.

The compositions of large aggregates though are not entirely consistent with the artificial soil covers on the surface of the soils. This being also due to variations in inherent soil factors as pH, soil organic matter and probably microbial populations. We observe also that at the end of the experimental period more than 50% of the aggregates in most treatments became smaller (<4.00 mm) in size. T4 performed above others by maintaining almost the same composition of larger aggregates

throughout the study period.

The stability of these aggregates seems to decline with decline in organic matter (Table 1) content probably as any dying plant roots were not replaced. This seems to be the main reason because during the study period there was a continuously declining trend in levels of organic matter. Another important observation as regards these findings is that, for this type of soil probably a 30% surface cover ensures protection of the soil surface and the most appropriate for protecting the large aggregates. Any other degree of cover might not probably ensure long term solution to the impact of rain drop on breaking down the aggregates into minute units which eventually suffer from the effects of runoff. Relating to erosion, the above findings also underscores the fact that the dominance of smaller aggregates provides better substrates for erosive agents to act upon better, but accurate transport estimation by runoff would require knowledge of aggregate sizes and distribution for the eroded aggregates.

Artificial soil covers and their influence on aggregation and water at saturation (WAS) and available water capacity (AWC). Regardless of the aggregate sizes and MWD, there were no significant differences in the results of WAS and AWC in the long period of the experiment of artificial covers (Table 4).

On the other hand, high organic matter was probably well protected from runoff in the T2-T3 which are artificially covered soils. The covered and uncovered plots had no major differences in water at saturation (WAS), field capacity (FC), and permanent wilting point (PWP) but slightly on AWC. The variations in WAS, FC, and PWP between treatment were minimal. But AWC was the lowest in T1 most probably due to the decline in the organic matter content which greatly determines water holding capacity of the soils. Availability of water from the soil depends among other factors on organic matter and texture but in this experiment soil organic matter and texture variations in the treatments are very minimal due to lack of annual incorporation of plant matter. This also relates very well to the fact that there has been continued decline in aggregation due to lack of incorporation and mixing plant of matter. The artificial soil surface cover though effective in controlling erosion does not add organic matter. This should be a special

Table 4. Mean aggregates sizes, aggregate stability (MWD), water at Saturation (m m³), and available water capacity in plots.

Treatment	Mean agg. size (mm)	MWD	Water at saturation (WAS) (mm ⁻³),	Field capacity (FC) (mm ⁻³),	Permanent wilting point (PWP) (mm ⁻³),	Available water capacity (AWC) (mm ⁻³),
T1	4.1	4.01	0.54	0.30	0.21	0.09
T2	4.1	3.92	0.54	0.30	0.16	0.14
T3	4.1	3.73	0.56	0.26	0.16	0.11
T4	4.0	3.73	0.54	0.31	0.20	0.11
LSD(0.05)	ns	ns	ns	ns	ns	ns

ns - Not significant at 0.05 probability level, T1- control (bare soil), T2-covered by mixture of 'sombrite" (green house shade netting material) to provide 11% cover on soil surface, T3-covered to provide 18% surface cover on soil surface and T4- covered to provide 30% surface cover on soil surface.

Table 5. Changes in aggregate sizes in relation to dry bulk density total porosity and air-filled porosity during the experiment.

Treatments	Start of the experiment				End of experiment			
	%large aggregates (>4 mm)	BD Mgm ⁻³	TP %	PA %	%large aggregates (>4 mm)	BD Mgm ⁻³	TP (%)	PA (%)
T1	65	1.25	53	17	39	1.26	51	17
T2	67	1.22	54	14	34	1.17	52	22
T3	71	1.21	54	20	32	1.19	53	22
T4	69	1.21	54	20	64	1.20	52	22

T1- control (bare soil), T2- covered by mixture of 'sombrite" (green house shade netting material) to provide 11% cover on soil surface, T3- covered to provide 18% surface cover on soil surface and T4- covered to provide 30% surface cover on soil surface, BD- Bulk density. PA-air filled porosity. PT- total porosity.

consideration when applying them.

Changes in proportions of large aggregates, dry bulk density, total porosity and air-filled porosity during the experiment

From Table 5 there were observable changes that have occurred during the study period. However, the changes do not show any significant differences between soils covered in various degrees of an artificial material. The initial conditions were compared to conditions that took place during the study period. It is observed that, the decrease in the sizes of aggregates has affected bulk density, total porosity, and air -filled porosity. This was observed in the results. Total porosity estimates pore distribution.

The decrease in the sizes of aggregates imply that, there has been a loss of organic matter which encourage aggregation at this juncture other chemical elements e.g. have a significant role in aggregation can also be implied. These results also signify that in absence of other external stress, erosion has impact on total and air-filled porosity. Pore sizes (porosity) influence the strength property of the soil. A more porous soil has in most cases weaker aggregates. Probably the uniformity of soils in

terms of organic matter and particle sizes has made the soil invariably sensitive to changes in total porosity, air filled porosity and bulk density.

In absence of compaction by traffic or any other force the other force considered was the impact of the raindrop. It was observed that there was largely a change of proportions of large aggregates in all treatments. At the end of the experimental period the remaining proportions of large aggregates decreased, BD and slightly changed TP and PA for all treatments except in T1. The differences between treatments weren't significant (P=0.05).

From the foregoing discussion, it was clearly observed that only in T1, an obvious change in PT and PA could be observed. The changes before and after the experimental period were minimal in artificially covered soils (T2-T4). Aggregate stability declined with time in uncovered soils and the effectiveness of the protection by sombrite was related to the proportion of coverage, the present findings underscores the role of continuous incorporation of organic materials and the need of adequately covering the soils to avoid raindrop impact. Slight changes in B,D, PT and PA are mainly observed in treatments that were not compacted or not greatly affected by erosion. The stress that has been inflicted on these soil properties is not detrimental to the productivity of soils but may become

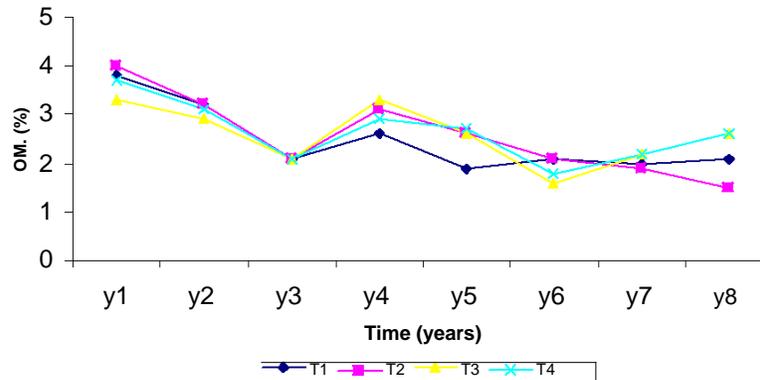


Figure 2a. Changes in organic matter during the study period.

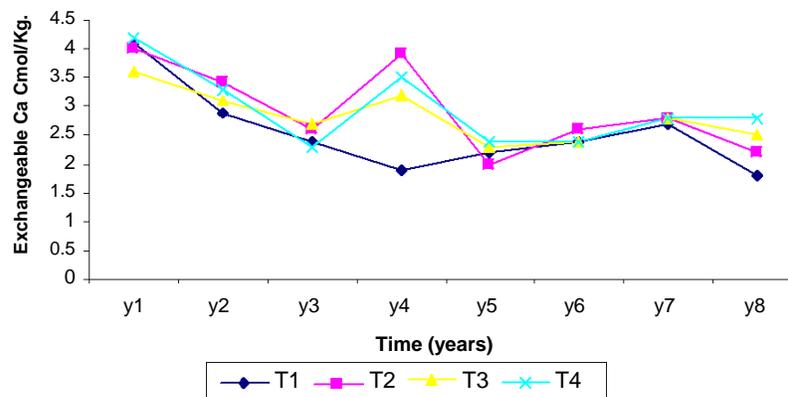


Figure 2b. Changes in exchangeable calcium in soils during the study period.

detrimental with time.

Chemical properties of eroded soil from runoff plots covered with an artificial net

The trend of organic matter and some elements during the study period are given in Figure 2a through 2e. The figures also depict the changes in base saturation and exchangeable acidity in the soil with time.

Changes in organic matter

Organic matter is one of the principal properties that affect aggregation. During the study period there was a declining trend of organic matter in all treatments (Figure 2a). The decline was not smooth but varied depending on climatic factors. Rainfall and temperature have an impact on growth of vegetative cover and subsequently provided the bulk of organic matter thus encouraging aggregation.

The decline in organic matter was clearly manifested in

T1 (bare soil) although there were some variations between years. T1 also showed that much of the organic matter was removed by erosion from the bare as compared to artificially covered soils. The decline did not exceed 60% of the original amount of organic matter in all soils. However, such a decrease clearly emphasize the need to add organic matter to the soil to replace the dwindling reserves and to have the soils well protected to avoid any excessive decline in aggregate stability and other chemical properties.

Artificial soil covers on exchangeable bases

Effects on changes of exchangeable calcium

Figure 2b show the effects of sombrite on exchangeable calcium levels in the soils throughout the experimental period. The initial level of exchangeable calcium was in T4 (30% covered). In other treatments the decline was more than 50% of the initial levels. This indicates that there is a certain level at which such artificial covers are

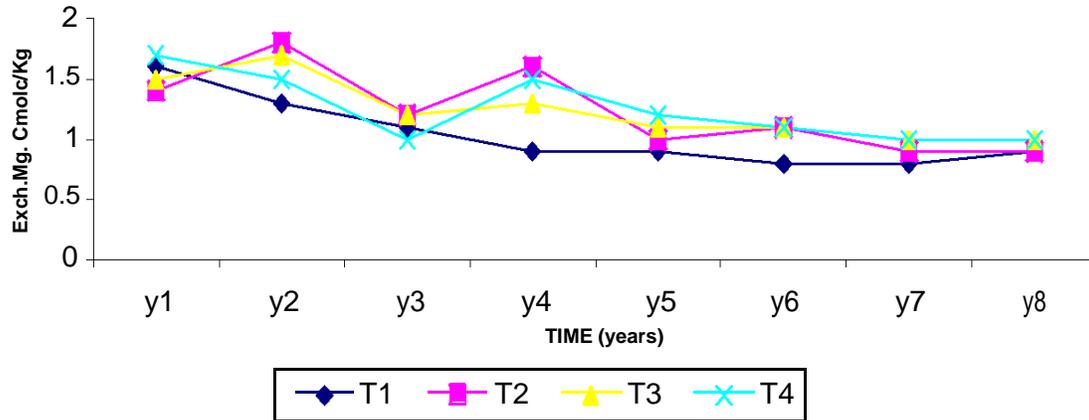


Figure 2c. Changes in exchangeable magnesium during the study period.

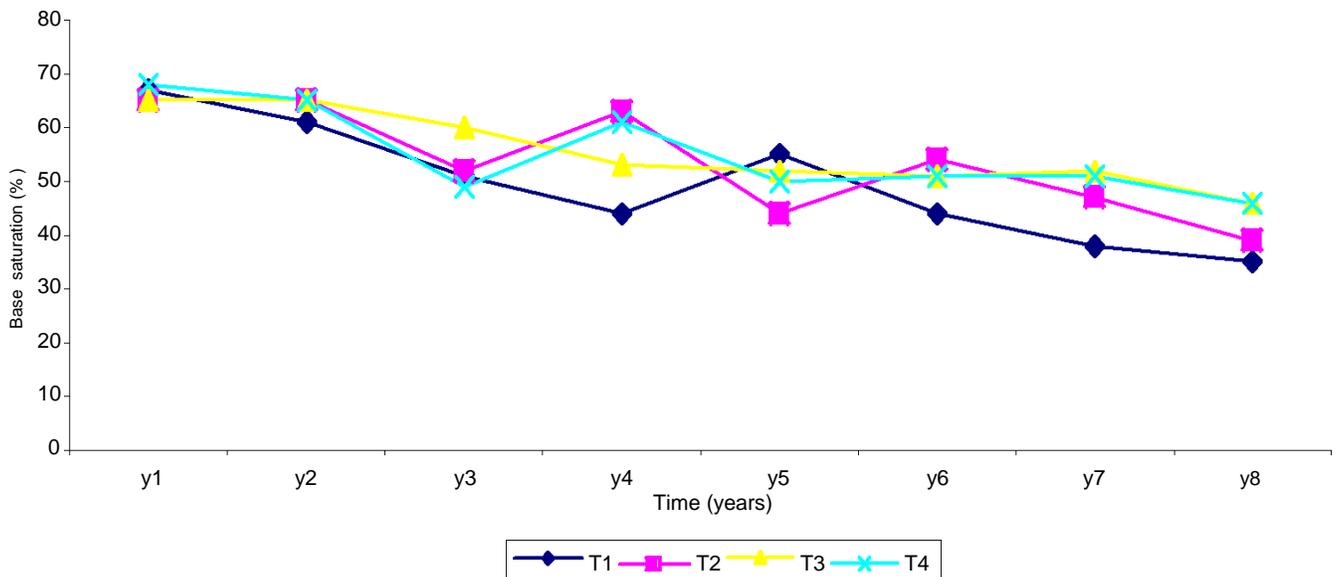


Figure 2d. Changes on percentage base saturation.

effective. Treatment T1 (bare) consistently had low annual exchangeable calcium averages which clearly show that the severity of erosion on depletion soil chemical elements in absence of any form of soil cover can be immense. For all treatments the decline did not exceed 1.5 cmolkg^{-1} and in most cases tended to follow the same trend as that of organic matter.

Effects of artificial covers on changes exchangeable magnesium

Figure 2c depicts the decline in exchangeable magnesium during the experimental period. Of all the elements, magnesium decrease was very gradual. T1 always indicated the lowest magnesium contents than in the rest of treatments.

The slight decline of magnesium is probably related to the low levels of the element initially present in the soils (Table 1). On the other hand the very low decline of Mg in relation to Ca as a result of erosion always lead to an imbalance that is detrimental to crop production.

Generally soil erosion in unprotected soils despite depleting the soil nutrients reserves, it also leads to imbalances. Initially base saturation was over 70% but was less than 50% at the end of the experiment.

Effects on changes in base saturation

Figure 2d depicts the decline in base saturation in the soil with time caused by erosion. Of all the properties studied base saturation showed a dramatic decrease in all treatments cautiously indicating that there was a drastic

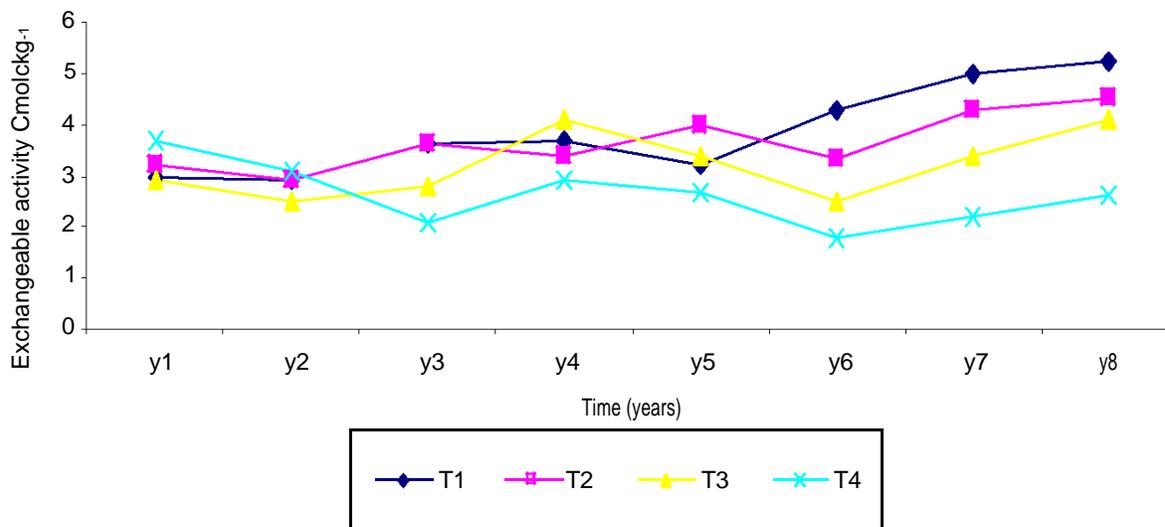


Figure 2e. Changes in exchangeable acidity during the study period.

decline in soil fertility as erosion proceeds. The changes were very well pronounced for T1 (bare). Generally soil erosion in uncovered soils despite depleting the soil nutrients reserves, also leads to imbalances. Initially base saturation was over 70% but was less than 50% at the end of the experiment.

Effects on changes in exchangeable acidity

Figure 2e indicates the changes in potential acidity in soil as erosion proceeded. All treatments showed an increase of potential acidity with time. The increase in exchangeable acidity is gradual. However, the increase varied between treatments but was highly noted in T1 and less in T4. The two extremes show that if the soil is well covered (see T4) there is a possibility of reducing the increase of acidity the reverse is true if the soil is left bare (see T1). The implications of increasing exchange acidity in soil show that there is not only the degradation of physical state of the soil in terms of aggregate stability and size but also chemically. Chemical degradation significantly affects the productivity of soil by increasing the soil infertility due to aluminium toxicity more critical to Ferralsols in which this phenomenon was observed. It also increases the need to invest in amendments, which are important to restore the soil to a more productive state.

Effects of artificial covers on relationship between aggregate stability and selected soil chemical properties

The data for soil reaction (pH), organic matter (OM), the levels of calcium (Ca) in the soils and aggregate stability (MWD) for the different treatments were pooled to find any relationships between the soil properties. Equations

1 to 4 are regression equations depicting the likely relationship between aggregate stability to MWD and soil chemical properties as:

$$\text{MWD} = 1.01\text{pH} - 2.79, R^2=30 \text{ ns} \dots \dots \dots 1$$

$$\text{MWD} = 0.362\text{Ca} + 1.41, R^2=28 \text{ ns} \dots \dots \dots 2$$

$$\text{MWD} = 0.223\text{O.M} + 1.64, R^2=12 \text{ ns} \dots \dots \dots 3$$

$$\text{MWD} = 0.942\text{pH} + 0.267 \text{Ca} - 0.041\text{OM} - .45, R^2=40 \text{ ns} \dots \dots \dots 4$$

N.s indicates non-significant correlation.

Equation 1 indicates that any change in pH of the soil is inversely related to the MWD in all treatments. Soil reaction is indirectly involved in aggregate stabilisation through its influence on various microorganisms (microflora and microfauna) which normally play a very crucial role in the soil aggregation process. A range of pH conditions affects either positively or negatively, the different types of fungi particularly actinomycetes and bacteria (Wood, 1995). Despite of the obvious trend, soil reaction in all treatments could not sufficiently explain the variability of the aggregate stability. The equation shows that only about 30% ($R^2=30$) of changes in MWD could be attributed to soil reaction despite the presence of artificial covers on soil.

Equation 2 indicates that, levels of calcium in the soil positively affected the MWD. It also indicates that about 28% ($R^2=28$) of the variability in calcium levels in the soils in the treatments may be involved in MWD. This study however, has not shown clearly how calcium affected aggregation in soils treated in this manner. Equation 3 indicates that there is a positive relationship between OM and MWD such that a unit decrease in organic matter affects aggregate stability in the same direction. This is a

common phenomena observed by many researchers (White, 1993). Nevertheless, the coefficient of determination ($R^2=12$) indicate that organic matter accounted for only 12% of the observed variability in MWD. This is a very poor relationship and in this study it does not strongly underscore the role of organic matter and its influence to aggregate stability.

Multiple regression equation 4 relates MWD to the three-soil properties pH, Ca and OM. The observed coefficient of determination $R^2=40$ does also indicate a weak relationship between MWD and these properties in soils covered with artificial materials like sombrite. This implies that the equation cannot solely be used to predict MWD with the desired confidence in soils treated in this manner. However, the equation still underscores the fact that the selected properties have some influence on other soil properties and MWD. Many other researchers (Sun et al., 1995) working on varied soils and conditions have observed strong relationships between MWD and these properties more particularly with organic matter but most of experiments were conducted under controlled environments and not in the field.

Conclusions

Despite the presence of artificial protective soil covers on soil, aggregate size distribution, mean weight diameter index and other soil chemical properties declined with time in all treatments. Based on these results, the following major conclusions can be made:

1. There was a gradual decline in soil physical and chemical parameters aggregate stability and size distribution despite the presence of different levels of artificial covers on soils. However, the 30% cover decline in T4 gave the largest proportions of large aggregates than the rest of the covers. This underscores the need to find out more effective artificial covers that protects the soil aggregates from the damaging effects of raindrops.
2. The decline of water stable aggregate stability was not only related to the absence of an effective cover but more importantly on the gradual decline of organic matter and associated chemical properties. Exchangeable cations and other soil properties e.g. pH and base saturation affect aggregation. Their effects seem to be variable and tend to vary in the direction of decrease of MWD. Annual decline of levels of Ca, Mg, base saturation, and the increase in pH and potential acidity were also associated with decline in MWD. As a management strategy, it is advisable that for promotion of an effective soil aggregation, seasonal incorporation of fresh organic matter should be considered.
3. In all treatments (bare and covered) a gradual decline of aggregate stability in eroded soils was accompanied by decrease in nutrient levels, base saturation and increase in potential acidity with time. However, the decrease is fast at the beginning and more gradual later. This implies that, other factors remaining constant, the

amount of nutrients removed from soil is related to the quantity in soil at the beginning.

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