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Watershed management for controlling field erosion using some adopted developmental processes

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Abstract

Preventive and curative measures to reduce land desertification were investigated in four communities in Osun State. Watershed management was adopted for four farms where such adopted processes like agri-silvipasture, agri-horti-silviculture and agroforestry were practiced. Each of the existing farms that were researched into where these practices were available was an hectare. Agri-silvipasture was adopted in two communities, each as agri-silviculture and silvi-pastoral system. Surface water from the lands were drained into a well-designed triangular waterway, each for a plot of an adopted practice. Cocoa trees, maize, palm trees and teak farm plots were used. Among the parameters measured/calculated were the velocities of flow, v; discharge, Q and maize yield. One-way analysis of variance was used for statistical analysis with means separation by Duncan multiple range tests. It was found out that scouring of the soil particles in the channel occurred from the upper course to the middle and then extended to the lower portion of the waterway with highest flow velocity of 0.945m/s and the lowest of 0.574m/s. The mean were 0.846±0.122 for the flow velocity and 7.428±0.588 for the discharge in the agric-silvipasture system (SPC) treatment. Watershed land had ability to support the use of various adopted development to reduce their erosivity indices, manage the environmental watershed to provide more water for agriculture.

1. Introduction

The integrated effort on land development for effective soil and water conservation with a view to 'in situ' utilisation of rain water for crop production and animal is watershed management. Utilisation of natural local resources for improving agriculture and allied occupation/industries (small and cottage) so as to improve socio-economic conditions of the local residents is one objective of watershed management (Balasubramaniyan and Palaniappan, 2005, [1]). It is used to conserve the soil moisture by combating soil erosion and land loss. Soil erosion is a widespread devastating problem in many parts of the world. It is the deterioration of soil by the physical movement of soil particles from a given site. It is as a result of many interacting factors like weather, vegetation, soil, relief, geology and human beings. The level of urbanisation and industrialisation processes and the rapid increase in the population, the degree of destruction to natural ecosystems is far greater than maintenance by humans (Tingting et al., 2008, [2]).

The on-site and off-site costs of soil erosion reach about 44 billion dollars in the US (Pimentel et al., 1995, [3] as referenced by Roberto et al., 2013, [4]), 4.2 billion dollars in Brazil (Hernani et al., 2002, [5]) and 45.5 billion dollars in the European Union

(Telles et al., 2011,[6]). Adopting some soil management practices that are naturally strategic to combating or protecting soil from ruin agriculturally and watershed best management practices are highly essential in Nigeria. Soil losses have also been on high in Nigeria especially of recent. Mathematical models are used to predict/quantify soil losses. The universal soil loss equation (USLE) (Wischmeier and Smith, 1978, [7]) and the revised soil loss equation (RUSLE) (Renard et al., 1991, [8]) have been most and widely used models in predicting soil erosion losses (Baskan et al., 2010, [9]).

Rainfall is the major climatic characteristics that influence soil erosion, given the extraordinary importance of soil detachment processes due to drop impact and runoff shear (Roberto et al., 2013, [4]). Others are rainfall pattern, topography/relief, soil and land use type. Though rainfall is the main factor that induced soil erosion, not all rainfall can, only those showers of high intensity (Tingting et al., 2008, [2]). So the erositivity of the soil is highly determined by the intensity of the rainfall events. Establishing various indexes use in solving soil erosion complexities to fully reflect the regional characteristics of the research area must include its causal factors mentioned above. These indexes include rainfall erosivity index, soil erodibility index, relief index and land cover index. Among these, relief is the most stable.

Soil erosion management brings good agricultural sustainability; sustainable agricultural productions were as a result of farmers' readiness to adopt improved agricultural productions from scholars through various soil management practices. One of the goals of the effective soil management practices is to create farming systems that mitigate environmental harms associated with unhealthy or artificial activities from man (Sustainable Agriculture, 2001,[10]). Sustainable agriculture is part of a larger movement toward sustainable developmental processes, which recognizes that natural resources are finite, it acknowledges limits on economic growth, and encourages equity in resource allocation (Horrigan et al., 2002,[11]). If some largely yieldable developmental processes are adopted in Agriculture, it is ecologically sound, economically viable, socially just, culturally appropriate, especially when based on a holistic scientific approach (Madden and Chaplowe, 1997,[12]). Among various soil management practices that are adopted are, contouring, strip cropping, mulch tillage, stuble mulch, terracing, crop rotation, cover crops farming, no-till and low-till farming, rotational grazing, polyculture and monoculture, advanced biological farming, silvi-pasture and agro-forestry to mention a few (Sustainable Agriculture, 2001,[10]).

The soil development processes that were used in this study include agri-silvipasture, agri-horti-silviculture, alley-cropping and agroforestry. Agri-silvipasture is the combination of agri-silviculture and silvi-pastoral system. Agri-silviculture is when farmers in dryland grow field crops and forest trees together up to a particular stage, in silvi-pastoral farming, the grasses are raised in place of field crops in the vacant space between the forest trees (Balasubramaniyan and Palaniappan, 2005,[1]). Agri-horti-silviculture is a system where fruit trees are grown along with crops and multipurpose tree species, it is highly diverse in vegetation with highest productivity. In this case, crops like rice, mustard, soybeans or vegetables may be grown in between banana or guava (Balasubramaniyan and Palaniappan, 2005,[1]). It is said that in all these, the ecosystems are restored and balanced naturally (Ifeanyi-obi *et al.*, 2013,[13]).

But, how could each of the aforementioned soil development processes contribute to reduced flow velocities of water and thereby reduce soil erosion on the farm? Would Nigerian farmers adopt these practices? When watershed management is practiced, how far could it be effective? How it be understood by farmers to adopt? How would agricultural soils with these adopted processes fair and could crop yield increase? Do soil erosion indexes' management help to alleviate the effects of the soil erosion causing factors? Could it be said that soil erosion risk is lower in the forest area than in the agriculture and plantation area? Could certain agronomical crops resist the soil detachment processes due to drop impact and runoff shear? It was hypothesized, therefore, that farmers' adoption of various developmental processes on soil management in the grassroots through watershed agriculture will protect, conserve and improve the land resources for efficient and sustained production. Hence, the objective of the study was to investigate the effects of different adoptable development processes through watershed management in agriculture on the flow velocities of water, discharge and crop yield.

2. Materials and Methods

The study was carried out in some villages/towns, Mokore, Ago-Owu Farm settlements in Ayedaade LGA in Osun State of Nigeria. The state covers 14,875 km^2 and lies within longitude 4.536' N and 7.815' E latitude (Osun State Diary, 2011,[14]). It has sandy loam soil, well drained and had 300 mm-350 mm rainfall annually. The area was vast, opened to sun and like many other places in south west Nigeria is prone to erosion. Four adopted development processes were used namely, agri-silviculture, silvi-pastoral system, agri-horti-silviculture and agroforestry. Four different plots were selected for the research with each process in each. Farmers were found to have been practicing these sustainable practices unknowingly, however, there little modifications to suit the procedures in the research. Cocoa trees, coco-yam, guinea grass, plantain, maize, cassava and palm trees were planted.

For the agri-silviculture, cocoa trees planted three years earlier was chosen as the forest tree crop while maize was planted in-between the rows two times consecutively for three months-period each, it was tagged SCM. The maize was planted in a single row so as not to be shaded by cocoa trees and to be able to have yield. In the silvi-pastoral system plot, cocoa trees planted three year also was used, therein planted were maize in a single row in between the rows of cocoa, it was tagged SPC. Palm trees, cocoa and maize in between were used as horticultural crops in agri-horti-silvicultured, it was tagged AHS. Here cocoa served as fruit tree, palm tree was used as multipurpose tree species and maize as field crops. Matured teak forest trees were used as agro-forestry crop, (with maize planted in between as well), also tagged AFT.

The maize was planted without any herbicides/insecticides like APRON that can prevent any diseases like downy mildew. This was purposefully done to provide the same environment for the maize and to erase influence of external agents. Each of the SCM, SPC, AHS and AFT plots had substantial land mass of not less than 1ha used for the study simultaneously together. The research was done at no-till for all the plots (treatments).

Triangular shape waterway of good cross-section was constructed in each of the treatments. The selection of channel cross sectional shape was influenced by a number of factors including required capacity, Q; slope or gradient of the channel, s and maximum velocity permissible without danger of scouring for the kind of soil, v. This velocity may be design velocity (v), in such case, ability of the vegetation to resist erosion is limited. It may be permissible velocity (flow velocity) in the channel, in this case, it is dependent upon the type, condition and density of the vegetation and the erosion characteristics of the soil. The research assumed to maintaining a uniform velocity throughout the reach of the waterway, principally to control sedimentation.

In this research, flow velocity, calculated using Manning's formular for open channel was used, v = $\frac{R^{2/3}}{n}\left(S^{0.5}\right)$ where v is the flow velocity; R is hydraulic radius of the channel = $\frac{a}{p}$; where a = cross-sectional area and p = wetted perimeter (m); S = Slope of channel (m/m) and n - roughness coefficient (2.1 is used for non-vegetated waterways); n may be difficult to evaluate because it varies tremendously with the depth of flow (Schwab et al., 1981). The research chose the same depth of flow, same wetted perimeter and hydraulic radius for the watershed ways throughout the length of the channel. This was to remove error that may be due to discrepancies in the channel design parameters. The research also assumed that velocity calculated is the mean velocity of the moving water in the channel and is usually greater than the velocity of water in contact with the soil. Crop yields were evaluated using simple weight measurements.

The data obtained regarding the velocity and crop yield in kg were subjected to One-way Analysis of Variance (ANOVA), the treatment means of the data were separated using Duncan Multiple Range Tests.

3. Results

Table 1 reveals the results of the flow velocities calculated from the data obtained from hydraulic radius R, wetted perimeter P and the area of the waterway, a, for three equidistant points, (Upper, Middle and Lower courses) in each of the ways in the treatments. The reason behind the three spots readings were to be sure if there will be differences in velocities down the waterway despite no other entering stream or rill erosions (they have been controlled through mini-collectors and directed down waterways). Another reason was if the same depth, same wetted perimeter and hydraulic radius chosen for the watershed ways may have influenced the velocities of the moving water. Noteworthy to know that the depth of flow changes from 0.7 in the middle to upper courses and they ranges from 0.7 to 1.2 m; they affected it as the results show in Table 1. The highest flow velocity for SPC with value 0.983 m/s, slope 10% and the lowest for AFT with value 0.574 m/s, slope 6%, it reveals the higher the slope, the more the flow velocity and the depth changes due to scouring of the soil along the waterway.

Table 1. *Flow velocities, m/s, of flow for the treatments at three spots in the waterway*

Treatments	Upper course	Middle course	Lower course
SCM	0.665	0.787	0.844
SPC	0.686	0.870	0.983
AHS	0.745	0.848	0.945
AFT	0.574	0.627	0.776

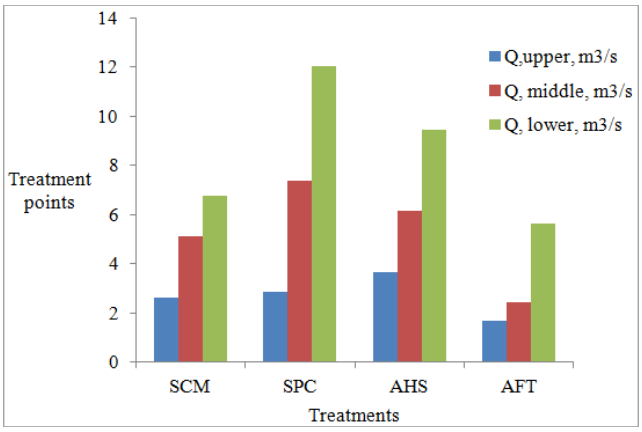

Figure 1. *Expected discharge Q in m³/s, from each of the treatments*

Table 2. *p-values for the velocities, v and expected discharge, Q.*

Treatments					
	Source	SCM	SPC	AHS	AFT
p-values	v, m/s	0.0001	0.001	0.000	0.000
	Q, m^3/s	0.0001	0.0001	0.004	0.005
		S	S	S	S

S- significant at 0.05

The expected discharge, Q showed that silvi-pastoral, SPC had highest value of 12.032 m^3/s recorded in the lower course, Table 3 and was lowest in AFT, agro-forestry, 1.668 m^3/s at the upper course. All the values were not within the same range as recorded; velocities range between 0.574 and 0.983 m/s. The means when separated using Duncan Multiple range tests were statistically different from one another at $p< 0.05$, Table 3.

Table 3. Mean Values (±STD) of v and Q in the treatments

Treatments	v, m/s	Q, m^3/s
SCM	0.765^a ±0.075	4.820^{ab} ±2.087
SPC	0.846^b ±0.122	7.428^b ±0.588
AHS	0.846^b ±0.082	6.409^c ±2.910
AFT	0.659^c ±0.086	3.243^a ±2.101

Mean values with the same superscripts along the column for each of v and Q are not significant at 0.05

The crop yield namely maize in treatments SCM, SPC and AHS had both the good grains and decay ones shown in Figure 2; the maize planted in all the plots had a lot of decayed grains, more in SCM than any other plots.

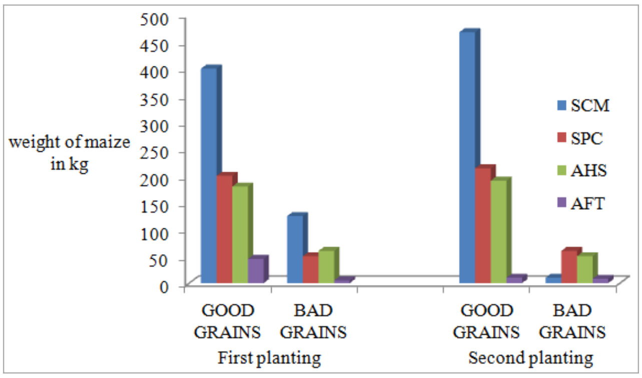

Figure 2. *Maize yield in kg, from each of the treatments*

4. Discussions

The flow velocities obtained from hydraulic radius R, wetted perimeter P and the area of the waterway, a, at three equidistant points, (Upper, Middle and Lower courses) were different. The reason was because the scouring of the soil particles in the channel had occurred from the upper course to the middle and then extended to the lower portion of the waterway. Although, there were initially the same depth, wetted perimeter and hydraulic radius for the whole length as designed in the research, the depth, d of the flow had changed sooner and now ranged between 0.7 and 1.2 m. These depths influenced changes in the wetted perimeter and hydraulic radius for the watershed ways have influenced the velocities of the moving water.

The highest flow velocity for SPC with value 0.983 m/s, slope 10% and the lowest for AFT with value 0.574 m/s, slope 6%, it reveals the higher the slope, the more the flow velocity and the depth changes due to scouring of the soil along the waterway. Though the land topography was relatively stable, but did not remain constant over time, at watershed scale, it influenced the water movement. Just as slope increases the flow velocities, forest interrupts rain splashes and thereby reduces their impacts on the soil, leading to low velocities of flows in AFT plot from the results above affect flow velocities, AHS, Table 1. Tingting et al., (2008),[2] also got the same result as they concluded that soil erosion risk in the forest area is lower than in the agricultural and plantation land. The increase in depths of flow could also be attributed to the particle sizes in the channel, they were silty clay.

The expected discharge, Q showed that silvi-pastoral, SPC had highest value of 12.032 m^3/s recorded in the lower course, Table 3 and was lowest in AFT, agro-forestry, 1.668 m^3/s at the upper course. All the values were not within the same range as recorded; velocities range between 0.574 and 0.983 m/s. The reduced discharge of water from the channels in AFT, SCM when compared to the AFT and SPC may be as a result of the heights of the crops in the plots. Higher trees tend to reduce the rain strikes' intensities on the soil than shorted trees, thereby, serving as a land cover index in the plots (Baoyuan et al., 2000,[15]).

The crop yield namely maize in treatments SCM, SPC and AHS had both the good grains and decay ones shown in Figure 2; the maize planted in all the plots had a lot of decayed grains, more in SCM than any other plots. The decay came about as a result of the inability of the sun to dry up the grains under steady conditions of low temperature drying (Barre et al., 1988,[16]).

The significant differences at $p< 0.05$ in velocities and discharges for each of the treatments may be attributed to the land cover provided by the crops. The means when separated using Duncan Multiple range tests were statistically different from one another, Table 3. Statistical differences for each of the for each treatment observed may be surmised to mean that the different adoption processes on land for sustainable management of soil have effects on the depth of flow of water, perimeter of the channel and the hydraulic radius as their relative magnitudes continue to change within that small period.

The significant effect ($p < 0.05$) observed between different adopted development processes and crop yields of maize in all could be because none of the plots was converted into monoculture plantations at any point in time during the period of the experiment. All the plots were polyculture. This may resulted in significant deposition and concentration of organic matter stock especially from decay leaves and grasses and crop leaves.

Silvi-pastoral, SPC had highest velocity of 0.983 m/s recorded at lower course, and was lowest in AFT, agro-forestry, 0.574m/s in the upper course with maize yield of 250 kg and 274 kg of good and bad grains in SPC and 50 kg and 18 kg of good and bad grains in AFT. This generally lower values of yield could be attributed to the type of farming been practice on these soils, the AFT had lower yield per 1000 stands of maize compare to others because of the tall nature of the teak, in such case, the few yield were obtained from the spaces where teak were sparsely distributed. All the crops planted in these fields do well in their different treatments except maize mainly due to shades from other crops that prevented sun from reaching them. Moreover, the results also showed that less trampling of pasture during the farming period and the no-till operation employed, these have been found to reduce the rate of erosions in the soils/plots.

Ecological implications of these is that soils that have these adopted development practice on them for soil management will have less susceptibility to erosion and thereby root penetration for plant will not be disturbed, soil micro-organisms and their activities will not be compromised, nutrient availability will be on at each point in time and the soil nutrient will be able to recycle itself, thus less cost for the farmers.

The engineering implications may include the low soil erodability index (soil erodability factor is the average soil loss in tonnes/ ha per unit erosion index for a particular soil when cultivated or at continuous fallow; it is a constant). It accomplishes this as a result of reducing runoff erosivity index which will in turn reduce the tonnes/ha of soil loss per year (Schwab *et al.*, 1981,[17]) and especially here with land cover indices that were high. Another engineering implication is that double cropping becomes possible in most years by utilising water stored in small reservoirs from the watersheds made from the plots. Another engineering application is that with the forest trees and row maize planted being able to have significant effect on soil erosion means agronomical crops can resist the soil detachment processes due to drop impact and runoff shear.

The environmental impacts of all these adopted processes, if assessed, will augur well for the agricultural soils, the living organisms: animal and human and all other biotic lives in their ecosystem and probably, the nature might have been mimic. It can be surmised that watershed land had ability to support the use of various adopted development to reduce their erosivity indices, manage the environmental watershed to provide more water for agriculture, reduce desertification, protect biotic and abiotic lives and naturally restore the ecosystem. Another ecological benefit is that of utilising the natural local resources for improving agriculture and allied occupation/industries (small/cottage) such as to improve socio-economic conditions of the local residents.

5. Conclusions

The following conclusions were arrived at in the study:

Scouring of the soil particles in the channel occurred from the upper course to the middle and then extended to the lower portion of the waterway. Soil erosion risk in the forest area is lower than in the agricultural and plantation land. Heights of trees tend to reduce the rain strikes' intensities on the soil than shorted trees, thereby, serving as a land cover index in the plots.

Different adoption processes on land for sustainable management of soil have effects on the depth of flow of water, perimeter of the channel and the hydraulic radius as their relative magnitudes continue to change within that small period. Watershed land had ability to support the use of various adopted development to reduce their erosivity and manage the environment to provide more water for agriculture.

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