VARIABILITY OF SOIL ERODIBILITY FACTOR WITH SOME SOIL MANAGEMENT PRACTICES IN A SEMI-ARID AGROECOLOGICAL CONDITION, NIGERIA

Jibrin M. Dibal[1], Ali U. Bashir[1], B. G. Umara[1] and Bakari Baraya[2]
[1]Department of Agricultural and Environmental Resources Engineering, Faculty of Engineering, University of Maiduguri, Maiduguri. Borno State, Nigeria
[2]Department of Agricultural and Bio-Environmental Engineering Technology, College of Agriculture, Jalingo, Taraba State, Nigeria
E-Mail: jdibal@yahoo.com

ABSTRACT

An assessment of soil erosion and all factors tangential to it is essential in soil conservation and environmental management. Soil erodibility, or the K-factor, is crucial in predicting the effects of land use and management on soil loss and thus affects every land user. The K-factor is based on permeability class, soil structure, modified silt content, and organic matter percent. Various physical and biological measures are often employed to stabilize the soils against erosion. Information of the effectiveness of the common soil management in soil erosion control is scarce in Maiduguri and environs. The effects of the common soil management practices (bare soil, conservation tillage, mulching, and compaction) on soil erodibility were studied under a simulated rainfall. The universal soil loss equation (USLE) nomogram-based K-factors for each plot were also estimated. The Soil erodibility values varied from 0.014 in mulched soils to 0.022 measured for the bare soils. The erodibility values measured from bare soil were above the nomogram-based values. Mulching and compaction demonstrated high potentials of controlling soil erosion, but due soil densification, compaction resulted into largest runoff volume, and could effect crop growth by wearing away of nutrients. The effectiveness of conservation tillage was found to rely on extent of ground cover. Mulching is thus the most recommended means of soil erosion control in the area.

Keywords: soil erodibility factor, soil management practices, semi-arid agroecological region, Nigeria.

INTRODUCTION

Soil is one of the most essential abundant natural resources that sustain biological life. It plays a crucial role in agricultural production. A variety of farming practices often lead to some forms of soil degradation such as soil erosion **(**Ritter and Eng, 2012). Soil erosion impacts negatively on crop productivity and environmental quality, and depresses the socio-economic status of farmers; it is therefore a threat to the landowners' livelihoods as well as the overall health of an ecosystem (Egbai *et al*., 2012). Soils could either be water- or wind- eroded depending on the external dynamic agent that generates detachment, transportation and deposition of soil particles (Junge *et al*., 2007). Erosion manifests with higher intensity particularly on sloping lands with slope exceeds 5%. It is also influenced by the covering degree of the soils with vegetation amongst others, but most importantly by anthropogenic factor, through actions such as land cultivation. (Kirchhof and Salako, 2000). A number of soil erosion problems originating from natural and/or anthropogenic factor have been reported in Nigeria (Jimoh, 2006; Junge *et al*., 2007 Egbai *et al*., 2012). Jimoh (2006) also reported damages of crops amounting to N30, 000, 000. Destruction of farmlands and crops by soil erosion creates problems for the population, as the farmers are robbed of suitable lands on which to cultivate their crops. Various aspects of accelerated erosion have been studied all over Nigeria (Jeje and Agu, 1990, Egbai *et al*., 2012) and particularly around Maiduguri in the Sahel bioclimatic zone of Nigeria (Nyanganji, 1994; Mala *et al*., 2012). Odihi (1996) reported high incidence of flood in Maiduguri and environs with soil erosion as one of the major problems emanating there from. The soils in the Sahel semi-arid regions of Nigeria are sand-dominated and nutrient-deficient making them exceptionally susceptible to erosion. Heavy rains reaching their peak between June and September also promote severe soil erosion. Understanding and addressing issues of soil erosion therefore deserves a priority attention to mitigate its adverse consequences on socio-economic status of farmers and environmental quality. A very important factor that is known to systematically influence soil erosion is soil erodibility factor (K).

Soil erodibility factor (K) is an estimate of the ability of soils to resist erosion based on the physical characteristics of each soil. It is a quantitative description of the susceptibility of soil particles to detachment and transport by rainfall and runoff. For a particular soil, the soil erodibility factor is the rate of erosion per unit erosion index from a standard plot. Texture is the principal factor affecting K, but structure, organic matter, and permeability also contribute significantly (Goldman *et al*. 1986)

It was shown that the value of erodibility factor vary widely with space (Wall *et al*., 1988, Idah *et al*., 2008, Veizi *et al*., 2010, and Vigiak *et al*., 2011) and with different soil conservation and farming practices (Wall *et al*., 1988, Ritter and Eng, 2012). It is therefore impracticable to recommend single K factor for various locations and/or management practices. Common farming practices such as tillage, mulching, composting, and

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compaction, amongst others are widely observed in the semi-arid region of Nigeria. Dauda and samari (2002) showed that considerable research has been conducted to gain an understanding and to quantify the effects of soil compaction on crop growth and supported that it can be a good means of stabilizing soils against erosion. Many studies such as Mamkagh (2009), Nu *et al*. (1996), Bjorneberg *et al*. (2007) uphold the potential of mulching in increasing the hydraulic roughness, retarding runoff flow velocity, intercepting moving soil particles in runoff, and thereby depressing soil erosion. Lack of residue cover and exposure of soil to high intensity rainfall results into poor soil structure, reduced plant-water availability, erosion and significantly undermines agricultural production (Egbai *et al*., 2012) Conservation tillage management with surface residue accumulation has been shown to reduce soil erosion by buffering the soil surface against rainfall impact (Franzluebbers, 2002)

Despite the foregoing, basic information regarding the potentials of some farming practices as a soil erosion measure in the semi-arid region of Nigeria have not been fully explored. The information is needed in order to ascertain common farming practices that are prone to severe erosion or to identify the practices that have optimum potential of conservation soil. The information could also to form data bank for the design of conservation structures and management decisions. The study hypothesis was that soil erodibility cannot be influenced by soil management practices while the objective of the study is to determine the soil erodibility indices of sandy loam soil under various soil management practices.

MATERIALS AND METHODS

Study site

The research was conducted during the dry seasons of 2011 and 2012 near the Department of Agricultural and Environmental Resources Engineering Workshop, University of Maiduguri, in the northeastern region of Nigeria. The area lies between 11.5^{o}N and 13.5^{o}E with mean elevation of 345 m above mean sea level. No rainfall was recorded during the study period. The climate of the environment is semi arid and is characterized by distinct wet and dry seasons. The land cover is an open grass Sahel savanna, with scattered trees and bushes. The soil type is sandy loam. The soil is poorly structured and susceptible to surface sealing and crust formation. Annual rainfall of the region is about 300-500 mm and average daily temperature ranging from 22-35^{o}C, with mean of the daily maximum temperature often exceeding 40^{o}C (Dauda and Samari, 2002). There is a spatial and temporal variation of rainfall in the area, both in duration and intensity (Francis, 2012). Some Physical and Chemical Characteristics of the Soils in the Study Area is presented in Table-1.

Table-1. Some physical and chemical characteristics of the soils in the study area.

Characteristics	Measured values
Textural Composition (%)	
Sand	62.0
Silt	20.0
Clay	18.0
Infiltration rate (mmhr^{-1})	123
Available moisture capacity (%)	12.1
Bulk density (gcm^{-1})	1.38
*p*H	6.4
Electrical conductivity of saturation extract, ECe (msm^{-1})	3.8

Experimental procedure

Data collected essentially comprised of water-sediment samples under a simulated rainfall from four (4) soil conservation practices, namely: bare soil, conservation tillage, mulching, and compaction. Soil erosion pans (3 m long, 1 m wide, and 0.4 m deep) were constructed using a 1 mm thick metal with a pipe (0.25 m internal diameter) welded midway at the brim of each pan, through which the sediment-laden runoff were collected. Soil samples were collected from the farm that was previously seeded to maize intercropped with cowpea and were used to prepare a 150 mm soil layer into each of the erosion pans. Four pans each were thus prepared and treated with either mulch or compaction. The mulches was earlier prepared by burying green grasses (cut approximately 0.3 m long) in to a 1.5 m deep pit for 17 days and was then worked into the soil samples at the rate of 1.5 t/ha. Soil compaction was achieved by manually applying 25 hammer blows to the samples using the standard proctor hammer.

A 2 x 1 m plot was initially marked out under the simulator to represent the bare soil upon which rainfall was simulated. After sufficient data were collected from the bare soil, the same plot was littered with stubbles and tilled manually to represent conservation tillage. It was also subjected to simulated rainfall and sediment laden water samples were collected. The erosion pans containing the prepared soil sample were then subjected to simulated rainfall in turn for 180 seconds. A wooden wedge-shaped structure was used to create a 1.5 % slope. During each run, samples of sediment-water mixture were collected at the outlet of the erosion pan at 30 seconds interval from the start of each storm. All the sediments-water samples collected were filtered in laboratory and the residues were measured gravimetrically to arrive at sediment concentrations from which soil losses were computed. Soil losses in each plot or erosion pan were calculated as the product of the sediment concentrations and runoff volumes divided by the cross sectional area over which the samples flowed. The soil erodibility factor (K) was calculated from equation (1) (Vanelslande *et al*., 1984).

$$K = \frac{A}{R\,X\,LS} \qquad (1)$$

Where: A is the observed soil loss in t ha-1, R is the rainfall erosivity index and LS is the topographic factor. The rainfall intensity and I_{30} (the maximum 30-minute intensity) of rainfall events were calculated on the basis of the rain gauge data collected prior to commencement of the experiment. A rainfall intensity of 228.6 mmh^{-1} was used in the study. The rainfall erosivity index (EI_{30}) for each rainfall event in was then obtained by multiplying rainfall energy by I_{30} (mm h^{-1}). Equation (2) was used to compute the rainfall energy (Wischmeier and Smith, 1978)

$$KE = 210.3 + 87 \log_{10} I \qquad (2)$$

where

I = rainfall intensity (mm h^{-1})

The kinetic energy per unit area (E) was obtained by multiplying *KE* with the rainfall height (cm). The rainfall erosivity factor *R* was obtained as the sum of the EI_{30} index for the entire storm events of the experiment. The K factors for each plot were also estimated using the universal soil loss equation (USLE) nomograph in order to compare with the measured K factor.

RESULTS AND DISCUSSIONS

The data on soil erodibility factor is presented in Table-2. Variability in the measured values of K for different soil management practices was observed in the Table. Generally a spectrum of K-factors varied from 0.014 in mulched soils to 0.022 measured for the bare soils. Wall *et al*. (1988) reported similar values for sandy loam soils in Ontario, Canada.

These values are generally low relative to the erodibility values of 0-0.55 for some tropical soils (Bryan, 2000), these values, however, border around the nomogram-estimated values (Table-4). Higher value usually denotes higher severity of soil erosion. The cumulative erodibility factors ranged from 0.167 for mulched soils through 0.265 for bare soils. Mulching the soils have translated to a reduction of erodibility by 36.4 % thereby playing a dominant role in reducing soil erodibility. The mulch had depressed erodibility factor below the nomogram-based erodibility factor (Figure-1b) and also has led to least value of cumulative erodibility factor. This decrease can be attributed to less detachment by splash and lower runoff velocity and transport capacity. This observation is consistent to the findings of Nill and Nill (1993).

Table-2. Measure and cumulative K values for the different soil management practices.

	Bare soil		**Compacted soil**		**Mulched**		**Conservation tillage**	
	Measured K values	**Cumulative K values**	**Measured K values**	**Cumulative K values**	**Measured K values**	**Cumulative K values**	**Measured K values**	**Cumulative K values**
	0.016		0.012		0.010		0.014	
	0.037	0.052	0.015	0.027	0.013	0.022	0.020	0.033
	0.033	0.065	0.009	0.036	0.008	0.030	0.011	0.044
	0.015	0.079	0.011	0.047	0.009	0.040	0.013	0.057
	0.025	0.105	0.019	0.066	0.016	0.056	0.022	0.079
	0.028	0.132	0.021	0.087	0.018	0.074	0.024	0.104
	0.024	0.156	0.016	0.102	0.013	0.087	0.019	0.122
	0.027	0.184	0.033	0.136	0.029	0.116	0.037	0.159
	0.032	0.215	0.023	0.159	0.020	0.135	0.027	0.187
	0.027	0.232	0.012	0.172	0.011	0.146	0.015	0.201
	0.017	0.249	0.013	0.185	0.011	0.157	0.015	0.217
	0.016	0.265	0.012	0.196	0.010	0.167	0.014	0.230
Mean	0.025		0.016		0.014		0.019	

The mulches physically acted as obstacles for the flow of water-sediment mixture out of the erosion pans. The values of erodibility factor measured on bare soils were generally above the nomogram-based erodibility factor (Figure-1a). This is presumably due the large proportion of sand and silt content of the soil (Table-1). The bare soils also yielded the highest cumulative soil erodibility (Figure-1a). Soils that are predominantly sandy lack cohesion and tend to be highly erosive because of ease of detachment and transport of particles (Egbai *et al*., 2012).

The application of compaction and conservation tillage achieved reduction of the erodibility factor by 27.3 and 13 % respectively (Table-2). Soil compaction restricts soil detachment due to densification of the soil, but promotes large volume of overland flow as shown in Table-3, and could increase nutrient losses. Figures 1 c and d shows that the influence of soil compaction and conservation tillage maintained the soil erodibility values around the nomogram-based values. The nomogram usually give the erodibility values based on the natural characteristics of the soil, it is thus not always the desired value.

The performance of conservation tillage in reducing soil erodibility was lowest amongst the practices studied. This could be on the account of the presence of large percentage of loose unprotected soil particles. The plant stubbles can sometimes be moved along with the soil particles when runoff discharge is becomes large. Junge *et al*. (2008) and Kirchhof and Salako (2000) stressed the suitability of conservation tillage as an effective soil erosion control measure through the protective effect of residues on the soil surface. However, this study revealed that the performance of conservation tillage in reduction of soil erosion appeared to be limited by the tonnage and the degree of soil surface coverage by the stubbles.

The result demonstrates the initial high degree of erodibility of the soil and that the influences of the soil management practices on soil erodibility are noteworthy, the effectiveness of any practice in soil erosion control is, however, a function of intensity of the controlling ingredients used.

Table-3. Runoff volumes (ltr) collected from for the different soil management practices.

	Bare soil	Compaction	Mulching	Conservation tillage
	10.650	25.104	7.924	9.287
	11.982	28.244	8.915	10.448
	12.250	28.876	9.114	10.682
	9.653	23.579	8.007	8.417
	11.002	25.934	8.185	9.594
	11.543	27.209	8.588	10.065
	12.000	24.627	5.269	10.464
	9.852	23.223	7.330	8.591
	11.851	27.935	8.817	10.334
	10.004	23.581	7.443	8.723
	12.114	25.792	6.250	10.563
	11.830	27.886	8.802	10.316
Mean	11.228	25.999	7.887	9.790

Table-4. Nomogram-based K values.

Bare	0.017
Mulch	0.015
Conservation tillage	0.02
Compaction	0.021

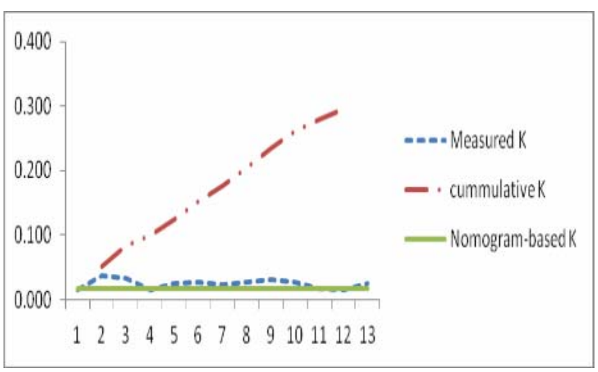

Figure-1(a). comparison of measured, cummulative and Nomogram-based erodibility factors for bare soils.

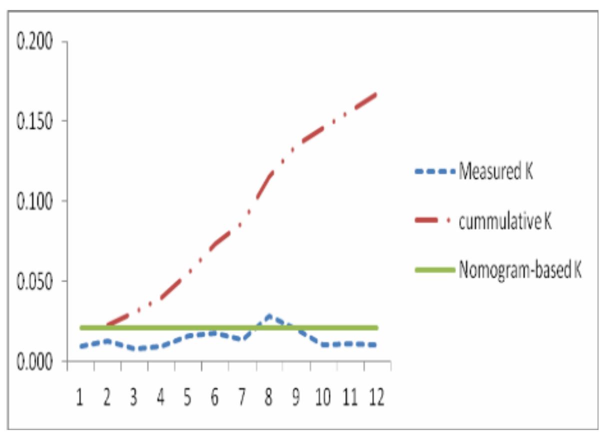

Figure-1(b). comparison of measured, cummulative and Nomogram-based erodibility factors for mulched soils.

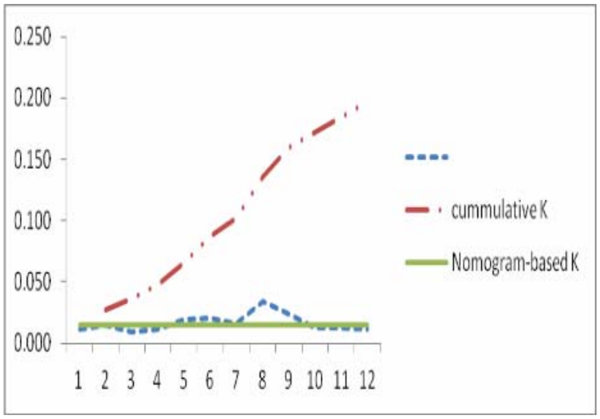

Figure-1(c). comparison of measured, cummulative and Nomogram-based erodibility factors for compacted soils.

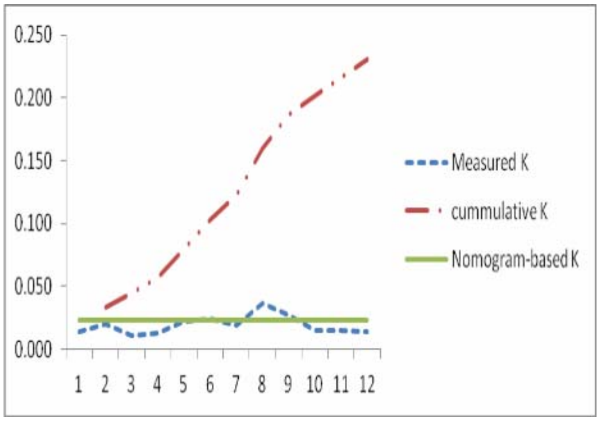

Figure-1(d). comparison of measured, cummulative and Nomogram-based erodibility factors for conservation tillage.

CONCLUSIONS

The variability of soil erodibility factors with common physical and biological measures employed to hold back soil erosion are studied. The results of field studies on four soil conservation practices suggest that soil erodibility varies with conservation practice adopted. Highest K values were from the bare soils under natural situations and the lowest K values recorded from the mulch-treated soils. The erodibility values of soil treated with compaction, mulches and conservation tillage all proved effective in reducing risks of soil erosion, with mulching in the fore front. Runoff volumes collected from compacted soil were largest, signifying higher potential of nutrient losses from farm lands. This could dampen enthusiasm of adopting compaction as soil conservation measure. The 10% ground cover in conservation tillage was found to be insufficient to effectively control soil erosion, and hence the need to improve on ground cover to achieve reliability as a soil conservation measure. 1.5 t/ha of grass mulching appeared to be the best. The study therefore cautions against practices over grazing, forest destruction, and other human related activities in the area that are responsible for the aggressive exposure of the soil natural vagaries. The study recommends a practical approach of soil management that would encourage continuous substantial vegetal cover on the soil toward mitigating the effects of soil erosion, improve on the soil structure, and ensure environmental sustainability. Further studies are needed on variability of K factor with texture, space, and time.

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