Soil fertility erosion and the associated cost of NPK removed under different soil and residue management in Ghana

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ABSTRACT

Two experiments were carried out at the University of Science and Technology, Kumasi, Ghana, to study the effect of different tillage practices and mulching rates on fertility erosion and its associated cost. In Experiment 1, tillage treatments studied were hand tillage by hoe, plough-plant, plough-harrow-plant, and excessive-tillage (double ploughing + 3 times harrowing + 3 times spike-tooth harrowing and planting). In Experiment 2, the mulching treatments, using dry *Panicum maximum*, were bare plot (T_0), no mulch + maize (T_1), 2 t/ha maize (T_2), 4 t/ha mulch + maize (T_3), and 6 t/ha mulch + maize (T_4). The test crop in both experiments was maize (*Zea mays* L.). Both studies were carried out on runoff plots on a slope of 3.5 per cent. The eroded sediments were analyzed for NPK and organic matter. Enrichment ratios were calculated to give indices of fertility erosion. The cost of NPK removed by erosion was calculated by the Replacement Cost method. In Experiment 1, hand tillage and all tillage in excess of plough-plant caused significant losses of soil, water, NPK and organic matter. In all cases, the excessive tillage recorded the highest losses whilst plough-plant had the least. In most cases, the eroded sediments were richer in NPK and organic matter than the parent soil. The NPK removed by erosion represents a hidden cost to agricultural production. The seasonal cost in cedis per hectare of NPK losses due to erosion in a maize production enterprise, expressed as a 15-15-15 NPK fertilizer, were 15528, 7354, 2163 and 805 for excessive, hand, plough-harrow-plant and plough-plant tillage, respectively (1 US Dollar = ¢2,200). In Experiment 2, mulching significantly reduced soil, water, NPK and organic matter losses, with the magnitude of reduction being greater as mulch rate increased at 2 t/ha intervals from 0 to 6 t/ha. Enrichment ratios ranged from 0.9 to 2.3 for organic matter, 0.9 to 1.8 for N, 1.5

RÉSUMÉ

QUANSAH, C., SAFO, E. Y., AMPONTUAH, E. O. & AMANKWAH, A. S.: *Erosion de la fertilité de sol et le coût assôcié à NPK enlevés sous les différentes gestions de sol et de résidu au Ghana.* Deux expériences se sont déroulées à l'Université de Science et de Technologie, à Kumasi au Ghana pour étudier l'effet de différentes pratiques de labourage et la proportion de paillage sur l'érosion de la fertilité et son coût associé. En Expérience 1, les traitements de labourage étudiés étaient le labourage manuel avec la houe, labourer - planter, labourer - herser - planter et labourage-excessif (double labourage + 3 fois de hersage + 3 fois de hersage avec les dents à pointes et plantation). En Expérience 2, les traitements de paillis en se servant de *Panicum maximum* sèche, étaient, le terrain-nu (T_0), paillis nul + maïs (T_1), 2 t/ha de maïs (T_2), 4 t/ha de paillis + maïs (T_3), 6 t/ha de paillis + maïs (T_4). La culture d'essai dans les deux expériences étaient le maïs (*Zea mays* L.). Les deux études se sont déroulées sur les terrains descents avec une pente de 3.5 pour cent. Les sédiments érodés étaient analysés pour NPK et la matière organique. Les proportions d'enrichissement étaient calculées pour avoir les indices de fertilité d'érosion. Le coût de NPK enlevés par l'érosion était calculé par la méthode de Coût de Remplacement. En Expérience 1, le labourage manuel et tout labourage en excès de labourer - planter provoquaient des pertes considérables de sol, eau, NPK et la matière organique. Dans tous les cas, le labourage excessif enregistrait les plus hautes pertes alors que labourer-planter avait les moindres. Dans la plupart des cas les sédiments étaient plus riches en NPK et matière organique que le sol mère. Les NPK enlevés par l'érosion représentent un coût déguisé à la production agricole. Le coût saisonnier en cedis par hectare de pertes de NPK provoquées par l'érosion dans une entreprise de production de maïs, exprimées comme l'engrais 15-15-15 NPK étaient: 15,528, 7,354, 2,163 et 805 respectivement

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to 1.3 for P, and 1.5 to 2.9 for K. The cost in cedis per hectare of NPK removed were 14416, 8908, 5712, 4692 and 2584 for T_0, T_1,T_2, T_3 and T_4, respectively. The results for both experiments showed that although losses of soil may be small, the concentration of nutrients in the eroded sediment could be high.

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pour le labourage excessif, manuel, labourer-herser-planter et labourer-planter (1Dollar E-UA = ¢2,200). En Expérience 2, le paillis reduisait considérablement les pertes de sol, eau, NPK et matière organique avec l'ampleur de la réduction étant plus grande lorsque la proportion de paillage augmentait à intervalle de 2 t/ha de 0 à 6 t/ha. Les proportions d'enrichissement varient de 0.9 à 2.3 pour la matière organique, de 0.9 à 1.8 pour N, de 1.5 à 1.3 pour P et de 1.5 à 2.9 pour K. Le coût en cedis par hectare de NPK enlevés était 14,416, 8,908, 5,712, 4,692 et 2,584 respectivement pour T_0, T_1, T_2, T_3 et T_4. Les résultats pour les deux expériences montraient que malgré le fait que les pertes de sol soient petites, la concentration de substances nutritives dans les sédiments érodés pourrait être élevé.

Introduction

The loss of soil and water through erosion by water is almost always accompanied by losses of plant nutrients. The process, termed fertility erosion (Ellison, 1950), is selective in that finer soil particles relatively high in plant nutrients and organic matter are the most susceptible to erosion. Consequently, the eroded sediment is usually the most fertile, containing higher concentrations of organic matter and plant nutrients in available form than the soil from which it was eroded and any fertilizers the farmer has applied (Massey & Jackson, 1952; Ellison, 1950).

While it is useful to know the magnitude of soil nutrient losses, their on-site costs are equally important. Unfortunately, these aspects have received very little research attention because nutrient depletion is invisible (FAO, 1990; Van der Pol, 1992; Gachene, Jarvis & Mbuvi, 1997). In Ghana, apart from the preliminary work of Convery & Tutu (1990), there is no explicit study on the cost of fertility erosion. Yet, the quantification of fertility erosion and the associated costs can significantly contribute to the economic assessment of soil degradation due to erosion, and enhance the creation of awareness of erosion problems and the need to seriously do something about them at the policy, institutional, and farmer levels.

In examining these issues, Bonsu & Quansah (1992) observed that for countries whose economies depend heavily on the agricultural sector, the loss of agricultural productivity implies a loss of revenue for the socio-economic development of the country. A reversal of this trend requires the development and adoption of landuse systems that are capable of replenishing or maintaining the nutrient status of the soil in addition to controlling erosion (Sanchez *et al.*, 1997; Ofori & Fianu, 1996; Quansah, Drechsel & Lefroy, 1997).

This study used data from two earlier studies on NPK losses due to erosion (Quansah *et al.*, 1997; Quansah & Baffoe-Bonnie, 1981) to assess the cost of fertility erosion. The study allows the demonstration of a method for calculating the cost of fertility erosion and the assessment of the impact of tillage and residue management of fertility erosion and its associated cost.

Materials and methods

Location

Two experiments were carried out at the Experimental Fields of the Department of Crop Science, University of Science and Technology, Kumasi, Ghana.

Characteristics of the experimental sites

The experimental sites fall within the semi-deciduous forest zone with a mean annual rainfall of 1302 mm/h. Rainfall intensities of 25-75 mm/h sustained for 15 min are common. The soils at the sites belong to the Akroso series (Haplic Acrisol) and Bomso series (Ferric Acrisol) for Experiments 1 and 2, respectively. The Akroso series consists of loamy sand and Bomso series is a sandy loam. The soils are generally low in nutrients (Table 1).

TABLE 1

Characteristics of the Soil at the Experimental Sites (0-15 cm of soil profile)

Parameter	Haplic Acrisol (Experiment 1)	Ferric Acrisol (Experiment 2)
*p*H 1:2.5 (H_2O)	6.00	5.30
Total N (%)	0.09	0.15
Available P (mg/kg)	3.50	2.50
Exchangeable K (cmol/kg)	0.08	0.14
Carbon (%)	0.62	1.46
Organic matter (%)	1.07	2.52
Sand (%)	72.6	57.6
Silt (%)	17.2	18.2
Clay (%)	10.2	24.2

Experimental design

In Experiment 1, a completely randomized design (CRD) with four replications was used in studying the effect of the following tillage treatments on erosion:

1. Hand tillage consisted of cultivating the land with a hoe and cutlass as practised by local farmers.
2. Plough-plant (a reduced tillage) comprised ploughing with a disk plough followed by planting.
3. Plough-harrow-plant (conventional tillage) consisted of ploughing with a disk plough, harrowing and planting.
4. Excessive tillage consisted of double ploughing + 3 times harrowing + 3 times spike-tooth harrowing and planting.

In Experiment 2, the effect of the following five mulching treatments on erosion were studied in a randomized complete block design (RCBD) with three replications:

T_0 - bare plot
T_1 - no mulch + maize
T_2 - 2 t/ha mulch + maize
T_3 - 4 t/ha mulch + maize
T_4 - 6 t/ha mulch + maize

The mulching material consisted of dry Guinea grass (*Panicum maximum*) which is a common weed on most continuously tilled farms in the semi-deciduous forest zone. The percentage carbon, nitrogen, phosphorus, and potassium contents of the mulch were 41.5, 0.47, 0.02, and 0.45, respectively. The C/N ratio was 88.3. Before the application of the mulch, the experimental field was ploughed and harrowed. The test crop in Experiments 1 and 2 was maize (*Zea mays* L.), with the respective varieties being Diacol 153 and Abeleehi.

Soil loss and runoff measurements

The two experiments were carried out on runoff plots with sediment and runoff-measuring devices on a slope of 3.5 per cent. Plot sizes were 27.4 m × 3.1 m and 10 m × 5 m for Experiments 1 and 2, respectively. Plot boundaries consisted of 30-cm wide strips of galvanized iron roofing sheets. These were driven 20 cm into the soil, leaving 10 cm above the soil surface. Each plot was bounded at the upslope end by an earth bund and a diversion channel to protect the plot from off-site runoff. At the lower ends of the plots were the measuring equipment comprising collecting troughs to contain the eroded sediments and sedimentation tanks to collect the runoff.

The overflow sampling device consisted of 11 drainage tubes arranged around the top section of the sedimentation tank. Anytime the tank was full, the tubes drained the excess runoff, and one was tapped through a rubber tubing into an overflow tank. Thus, 1/11th of the runoff was retained. The volume of runoff retained multiplied by 11 gave the total volume of overflow. At the end of each erosive rain, the eroded sediment on the trough was dried and weighed. The runoff was thoroughly stirred and sampled to determine sediment concentration. Total soil loss was the sum of the total dry sediment in the runoff and that on the collecting trough. Total runoff was the sum of the volume of runoff in the sedimentation tank and the total volume of overflow.

Chemical analysis of the eroded sediments

The original soils and eroded sediments from the two experiments were analyzed for the following:

1. Total nitrogen by a modified micro-Kjeldahl method.
2. Available phosphorus by the Bray P1 method with a dilute acid flouride as the extractant.
3. Exchangeable potassium by flame photometry with ammonium acetate used as the extractant.
4. Organic carbon content by the Walkley-Black wet combustion method. Percent organic carbon was multiplied by 1.724, the van Bemmelen factor, to give percent organic matter.
5. *p*H was measured in 1:2.5 soil-water ratio.
6. Particle size distribution was determined by the Bouyoucos hydrometer method.

Enrichment ratio (ER)

The enrichment ratio (ER) for the nutrients were calculated to give indices of fertility erosion.

The ER is given by:

$$ER = \frac{\text{Concentration of nurients in the eroded sediment}}{\text{Concentration of nutrients in the parent soil}}$$

This study reports the results of the major wet season for both experiments.

The cost of NPK removed by erosion

The financial loss incurred by the farmer as a result of soil fertility erosion may be appreciated only when the amounts of nutrients lost are possibly converted to bags of fertilizer and priced. In this study, an effort was made to cost the major nutrients (NPK) lost through erosion to facilitate the estimation of the financial loss associated with their removal. Among the available methods for assessing the costs of soil erosion, the Replacement Cost method was found to be appropriate for the data used (Enters, 1998). The approach calculates the costs that would have been incurred to replace the NPK removed through erosion in the form of fertilizers.

Estimation of cost of nutrients in the eroded sediments

The NPK contents of the eroded soil were converted to the forms in which they exist in fertilizers, i.e. N, P_2O_5 and K_2O (kg), respectively, by multiplying by the following constants:

$$\text{kg N} = \text{kg N}$$
$$\text{kg P} \times 2.29 = \text{kg } P_2O_5$$
$$\text{kg K} \times 1.2 = \text{kg } K_2O$$

One bag of 15-15-15 NPK compound fertilizer (50 kg) costs ¢34,000 (US $1 = ¢2,200). Being one of the commonest fertilizers used in maize production in Ghana, it is assumed that the farmer would replace the lost nutrients in the form of 15-15-15 NPK compound fertilizer. Since a 100-kg bag of 15-15-15 NPK fertilizer contains 15 kg each of N, P and K, a 50-kg bag will contain 7.5 kg each of N, P and K, giving the amount of nutrients as 22.5 kg NPK. Since one bag (50 kg) of 15-15-15 NPK fertilizer contains 22.5 kg NPK, the total amount of NPK in the eroded sediment can be converted to bags of fertilizer. A sample calculation is presented below for excessive tillage (Table 2):

$$N = 6.9900 \text{ kg/ha N}$$
$$P = 0.56 \text{ kg/ha} \times 2.29 = 1.2824 \text{ kg/ha } P_2O_5$$
$$K = 1.67 \text{ kg/ha} \times 1.22 = 2.0040 \text{ kg/ha } K_2O$$
$$\text{Total} = 10.2764 \text{ kg NPK/ha}$$

If 22.5 kg NPK is contained in 50-kg fertilizer (1 bag), then 10.2764 kg NPK is contained in 22.84-kg (0.4567 bag) fertilizer per hectare. This is equivalent to ¢34,000 × 0.4567 = ¢15,527.8

Results

Soil and water losses

Table 2 shows the mean soil and water losses in

TABLE 2

Nutrient, Runoff and Soil Losses due to Tillage

Treatment	Organic matter (kg/ha)	Total nitrogen (kg/ha)	Available P (kg/ha)	Exch. K (kg/ha)	Runoff (ha mm)	Soil loss (t/ha)
Excessive tillage	234.89	6.99	0.56	1.67	31.2	4.01
Hand tillage	105.68	2.58	0.22	1.37	12.2	1.40
Plough-harrow-plant	24.11	0.85	0.11	0.24	8.1	0.91
Plough-plant	5.71	0.15	0.05	0.21	3.3	0.19
LSD (P<0.05)	32.37	1.38	0.08	0.51	3.8	0.56

Experiment 1. Soil loss and runoff were greatest on the excessively tilled plots, followed by hand, plough-harrow-plant, and plough-plant treatments in a decreasing order. Compared with the other treatments, plough-plant significantly (P<0.05) reduced soil and water losses. Hand tillage with the local hoe and all tillage in excess of plough-plant increased both soil and water losses.

In Experiment 2 (Table 3), mulching reduced soil and water losses. Soil loss was in a decreasing order of $T_0>T_1>T_2>T_3>T_4$. Although soil loss from the cropped treatments was greater than that from the bare plot, the difference, apart from T_4, was not significant. Differences among the cropped treatments were also not significant. On the other hand, as mulch rate increased, the amount of runoff decreased. Runoff was in a decreasing order of $T_0>T_1>T_2>T_3>T_4$. Mulching and maize + no mulch significantly (P<0.05) reduced runoff volume compared with that from the bare plot. Among the cropped treatments, there was no significant difference between any two treatment means.

Organic matter losses

Table 2 shows the losses of organic matter in Experiment 1. The plough-plant and conventional tillage treatments lost significantly (P < 0.05) smaller amounts of organic matter than the excessive and hand tillage treatments. The respective amounts of organic matter losses from excessive, hand, and conventional tillage treatments were 41, 18.5 and 4.2 times greater than that from the plough-plant.

In Experiment 2 (Table 3), the losses of organic matter were in the order of $T_0 >T_1 >T_2 > T_3 >T_4$. The loss of organic matter from the bare soil was significantly higher than that from the cropped plots. Organic matter loss from T1, which was cropped with no-mulch, was significantly higher than that from the mulched plots. Although the losses among the mulched plots were not significant, organic matter losses decreased as

TABLE 3

Nutrient, Runoff and Soil Losses due to Different Mulching Rates

Treatment	Available P (kg/ha)	Available K (kg/ha)	Total N (kg/ha)	Organic matter (kg/ha)	Runoff (ha mm)	Soil loss (t/ha)
Bare (T_0)	0.019	0.677	8.694	165.375	59.42	2.835
No mulch (T_1)	0.011	0.559	5.188	70.144	39.287	2.192
2 t/ha (T_2)	0.006	0.281	3.418	38.103	30.929	1.335
4 t/ha (T_3)	0.005	0.240	2.799	36.607	29.010	1.615
6 t/ha (T_4)	0.002	0.130	1.553	24.987	26.578	1.013
LSD (P<0.05)	0.0027	0.010	0.775	21.66	22.151	1.774

mulching rate increased.

Total nitrogen losses

Table 2 shows the order of nitrogen losses in Experiment 1 as excessive > hand > conventional > plough-plant tillage treatments. The small losses recorded for the plough-plant is noteworthy. The losses of total nitrogen in Experiment 2 were in the order of $T_0 > T_1 > T_2 > T_3 > T_4$ (Table 3). Nitrogen losses under T_0 were significantly higher than all the other treatments. The losses from the mulched plots were also significantly lower than that from T_1.

The reduction in nitrogen losses by mulching was considerable, with the rate of loss significantly decreasing as mulching increased. This suggests the importance of mulching as a simple agronomic measure for conserving and maintaining soil fertility.

Losses of available phosphorus

Losses of phosphorus (Tables 2 and 3) were generally lower than losses noted for the other nutrients. This may be attributed rather to the lower mobility of soil phosphorus. The loss from excessive tillage (Table 2) was significantly (P<0.05) greater than the losses from other tillage treatments. The losses followed the trend of excessive > hand >conventional > plough-plant.

The results of Experiment 2 (Table 3) showed that as the rate of mulch application increased, available phosphorus content in the eroded sediment decreased. The order of decrease was $T_0 > T_1 > T_2 > T_3 > T_4$. The loss of phosphorus under T_0 was significantly higher than the losses under all the cropped treatments (P<0.05). Among the cropped treatments, the loss of available P from T_1 was significantly higher than the losses under the others. Statistically, the differences among the various mulch levels were not significant, except between T_2 (2 t/ha) and T_4 (6 t/ha).

Losses of available potassium

The losses of potassium in Experiment 1 (Table 2) were significantly smaller in the plough-plant and conventional tillage treatments than in the excessive and hand tillage. In Experiment 2 (Table 3), the order of potassium loss was ranked as $T_0 > T_1 > T_2 > T_3 > T_4$. The loss from the bare plot (T_0) was significantly higher than losses from all the cropped treatments. The differences in the losses among the cropped treatments were significant (P<0.05).

Enrichment ratios

Tables 4 and 5 show the enrichment ratios for Experiments 1 and 2, respectively. In Experiment 1, the enrichment ratios for organic matter for all the tillage treatments exceeded 1. This indicates that the eroded sediment was richer in organic matter than the parent soil. Enrichment ratio was in the order of excessive > hand > plough-plant > plough-harrow-plant. For potassium, the trend was hand > excessive > plough-harrow-plant >

TABLE 4

Effect of Tillage on Enrichment Ratios

Treatment	*Organic matter*	*Total N*	*Available P*	*Exch. K*
Excessive tillage	10.36	1.45	2.22	1.35
Hand tillage	6.67	2.11	3.27	3.95
Plough-harrow-plant	2.37	0.85	0.97	1.21
Plough-plant	2.98	0.15	1.29	1.03

TABLE 5

Effect of Mulch on Enrichment Ratios

Treatment	*Organic matter*	*Total N*	*Available P*	*Available K*
Bare (T_0)	2.279	1.806	4.323	2.718
No mulch (T_1)	1.250	1.394	3.097	2.898
2 t/ha (T_2)	0.886	1.194	2.344	1.902
4 t/ha (T_3)	0.886	1.108	1.826	1.687
6 t/ha (T_4)	0.964	0.900	1.505	1.461

plough-plant. The enrichment ratios for nitrogen showed that only the eroded sediments from the excessive and hand tillage were richer in N than the parent soil with the following trend: hand > excessive > plough-harrow-plant > plough-plant treatments. The order of decreasing enrichment ratios for phosphorus was hand > excessive > plough-plant > plough-harrow-plant.

In Experiment 2, the ranked order of the enrichment ratios of available potassium was $T_1 > T_0 > T_2 > T_3 > T_4$. The values for total nitrogen were in a decreasing order of $T_0 > T_1 > T_2 > T_3 > T_4$. However, T_4 recorded an enrichment ratio less than 1. The concentration of organic matter in the eroded sediments from the mulched plots was also lower than that of the parent soil (i.e. values were less than 1). However, the eroded sediments from the unmulched treatments were richer in organic matter with a trend of $T_0 > T_1 > T_4 > T_2 > T_3$.

The cost of NPK removed

Tables 6 and 7 show the conversion of NPK losses to bags of fertilizer and the associated financial loss. In Experiment 1 (Table 6), the cost of the lost nutrients was in the order of excessive > hand >plough-harrow-plant > plough-plant tillage treatments.

A comparison of the cost incurred in fertilizer losses for the excessive tillage with those of the other tillage practices indicated a percentage reduction of 52.6, 86.1, and 94.8 as tillage changed from excessive to hand, plough-harrow-plant, and plough-plant, respectively. Maximum savings were recorded by the plough-plant tillage.

In Experiment 2 (Table 7), mulching generally reduced the financial losses due to the removal of NPK through fertility erosion, with the magnitude of reduction increasing as mulching rate increased. The financial losses were in the order of $T_0 > T_1 > T_2 > T_3 > T_4$. The percentage reduction in financial losses was in the reverse order of $T_4 > T_3 > T_2 > T_1 > T_0$.

These analyses indicate that if fertilizers were to be bought to compensate for the losses of NPK, the total cost in cedis per hectare would be 15 527.8, 7 353.5, 2 163.0 and 805.0 for excessive, hand, plough-harrow-plant and plough-plant tillage, respectively. The cost in cedis per hectare

TABLE 6

Financial Analysis of Fertility Erosion under Different Tillage Practices

Treatment	*Total NPK per ha (kg)*	*Kg of fertilizer per ha*	*Bags of fertilizer per ha*	*Cost (¢) per ha*	*% reduction in financial loss*
Excessive tillage	10.28	22.84	0.457	15,527.8	0
Hand tillage	4.73	10.51	0.210	7,353.5	52.6
Plough-harrow-plant	1.39	3.09	0.062	2,163.0	86.1
Plough-plant	0.52	1.15	0.023	805.0	94.8

TABLE 7

Financial Analysis of Fertility Erosion under Mulching

Treatment	*Total NPK per ha (kg)*	*Kg of fertilizer per ha*	*Bags of fertilizer per ha*	*Cost (¢) per ha*	*% reduction in financial loss*
Bare (T_0)	9.550	21.222	0.424	14,416	0
No mulch (T_1)	5.884	13.076	0.262	8,908	38.2
2 t/ha (T_2)	3.769	8.375	0.168	5,712	60.4
4 t/ha (T_3)	3.098	6.885	0.138	4,692	67.5
6 t/ha (T_4)	1.714	3.808	0.076	2,584	82.1

when mulching is applied at the rates indicated by T_0, T_1, T_2, T_3 and T_4 would be 14 416, 8 908, 5 712, 4 692 and 2 584, respectively.

Discussion

Generally, the losses of soil and water increased as tillage intensity increased. This may be because increased tillage pulverized the soil and made it more susceptible to detachment and transport by rainfall and runoff. The reduction in surface roughness as the soil was pulverized and compacted due to increased wheel traffic may account for the higher losses of water. Although hand tillage by the hoe is often regarded as a form of reduced tillage, the significant scraping and breaking down of soil aggregates during hoeing could result in higher losses of soil and water.

The plough-plant, on the other land, reduced soil pulverization, and the larger clods were less vulnerable to erosion. The increased surface roughness due to the clods provided a greater opportunity for depressional water storage and infiltration, thereby reducing the amount of runoff. Soil and water losses were also lower under mulching. The maintenance of mulch on the soil surface protects the soil against raindrop impact, impedes the flow of runoff, reduces nutrient losses, soil detachment and dispersion, and maintains high soil infiltration rate (Roose, 1975; Lawes, 1966; Lal, 1976).

As a result of the higher losses of soil and water due to increased tillage intensity, the total losses of NPK and organic matter also increased. Blevins *et al.* (1985) further indicated that increased tillage intensity enhances the rate of organic matter oxidation and losses. Because of its concentration in the surface soil and its low density, organic matter is one of the first soil constituents to be removed through erosion, yet it is among the most difficult to replace.

The high losses of organic matter are of particular concern because it plays a significant role in the nutrient and water-holding capacities of the soil (Acquaye, 1990). Moreover, nutrients applied to the soil in the form of mineral fertilizers are far less effective on soils in which organic matter has been lost than on soils which contain adequate amounts of it (Barrows & Kilmer, 1963; Swift, 1997).

The implication is that if losses of NPK recorded in these studies were to be replenished by applying 15-15-15 compound fertilizer, the desired effect on crop yield would hardly be attained because of the low soil organic matter content. It has, therefore, been advocated that soil fertility replenishment in Africa should aim at an integrated nutrient management (Swift, 1997; Sanchez *et al.*, 1997; Quansah, 1996; Quansah *et al.*, 1997). This involves the combined use of organic and inorganic inputs for sustaining soil fertility and crop yield. However, by reducing soil and water losses, plough-plant and mulching significantly reduced the loss of NPK and organic matter. The decomposition of the mulch, on the other hand, may have replenished some nutrients and organic matter that might have been lost.

A comparison made between the enrichment ratios of NPK and organic matter in the eroded sediments and those in the parent soil showed that, with a few exceptions, the eroded sediments were richer. Enrichment ratios are important, not only from the soil fertility depletion viewpoint, but also for predicting the effects of soil erosion and erosion control on the quality of water (Menzel, 1980).

The results further showed that although losses of soil may be small, the concentration of nutrients in the eroded sediments could be high. It is, therefore, apparent that smaller erosion losses such as those of the plough-plant treatment, which may seem unimportant in the volume of soil removed, may be very important as far as the nutritional depletion and the general fertility of the soil is concerned. Any soil management practice that reduces soil loss, runoff, nutrient loss and enrichment ratios has, therefore, the potential to maintain the productive capacity of the soil for sustainable agricultural production.

The financial analysis presented in this study represents losses of only the major nutrients

(NPK). However, the analysis is a pointer to the magnitude of the financial loss that could be incurred due to NPK losses within a season of cropping maize, using different tillage practices and mulching rates. The financial loss associated with the loss of the major nutrients through erosion represents a hidden cost to the maize production enterprise. In this respect, the performance of the tillage practices in reducing the cost of replacing the lost NPK may be ranked as plough-plant> plough-harrow-plant > hand > excessive. For the mulch, the ranking is $T_4 > T_3 > T_2 > T_1 > T_0$.

The cost figures presented in this study, at best, represent only the cost of the mineral fertilizers required to replace the lost NPK. These costs neither account for the losses of other nutrient elements including micronutrients, nor the cost of transporting the fertilizers to the field as well as their application. Interpretation of the results of the Replacement Cost approach for assessing the cost of erosion as it affects productivity should, therefore, recognize the following limitations (Enters, 1998):

1. Soil erosion does not only affect the nutrient status of the soil, but also its organic matter content and its physical structure.
2. Soil nutrients may not be the most limiting factor in crop production.
3. Fertilizer applications are not necessarily the most cost effective options available to farmers for maintaining yields; in extreme cases, i.e. on deep and fertile soils, farmers may not even experience any yield decline with nutrient losses (Stocking, 1996).
4. It is only a proxy for actual productivity loss.
5. Mineral fertilizers supply nutrients in plant available form, whereas erosion also removes fixed elements.

Conclusion

The preliminary analysis of one-season records on fertility erosion indicates that hand tillage by the local hoe and all tillage in excess of plough-plant increased the losses of NPK and organic matter. The losses of nutrient and organic matter due to tillage were in the decreasing order of excessive > hand > plough-harrow-plant > plough-plant tillage. Mulching, generally, reduced soil, water, nutrient and organic matter losses. The magnitude of reduction increased as mulching rate increased at 2 t/ha intervals from 0 to 6 t/ha. With a few exceptions, the eroded sediments were richer in plant nutrient and organic matter than the parent soil. Mulching significantly conserved soil organic matter, since all the mulched treatments recorded enrichment ratios less than 1 for organic matter. Smaller erosion losses, which may be unimportant for volume of soil removed, still contributed significantly to soil fertility loss.

The cost incurred as a result of fertility erosion represents a hidden cost to agricultural production. Reduced tillage, such as plough-plant and mulching, significantly reduced the losses of NPK and their associated cost of replacement. Traditional hand tillage should always be accompanied by a cover of vegetation or residues to reduce soil loss, runoff, and fertility erosion. On the other hand, sustainable production under mechanized agriculture should aim at reduced tillage.

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