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SOIL AND NUTRIENTS LOSSES UNDER DIFFERENT MANAGEMENT PRACTICES IN GHANA*

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Abstract. Integrated soil nutrient management is required to increase and sustain agricultural productivity. Assessment of soil, organic matter and nutrient losses was carried out in a 3-year integrated maize cropping system in Ghana. The treatments: no-till (NT), minimum tillage (MT), conventional tillage (CT) and soil amendments (Control, NPK, poultry manure and their combination), were arranged in a factorial design. The results showed soil loss to range from 0.140-4.907 Mg ha^{-1} in the order of NT < MT < CT < Bare. Soil loss reduction over the Bare was 88% by ½ Rates of NPK+PM, 87% by PM and 85% by NPK. Soil depth reductions in NT and MT were 92% lower than in CT. The loss of organic matter ranged from 47.6 kg ha^{-1} to 120.70 kg/ha and was in the order of Bare > CT > MT > NT. Nutrient losses followed the same trend. Losses in soil organic matter, N, P, K, Ca, Mg and Na under tillage x soil amendments interactions were higher in the CT and bare plots. NT and MT, which were recognised as conservation tillage systems, amended with combination of organic and mineral fertilisers were found as better options in minimising soil quality degradation.

Keywords: soil productivity, conservation agriculture, soil erosion, nutrients management

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INTRODUCTION

Increasing food production on small holder farms in Sub-Saharan Africa remains a major source of concern (Lal 2009, Godfray *et al*. 2010). Many factors have been alluded to low food production in the region, a major one being loss of soil fertility through erosion and the use of inappropriate technologies that are not adapted to site-specific conditions (Stocking 2003, Morgan 2005). Information on the extent of soil erosion on cropland in Africa remains largely qualitative with little and scattered quantitative data.

Erosion-induced loss in soil productivity does not only diminish the quality of soil resources, but also makes gaining livelihood from the land increasingly difficult (Bakker *et al*. 2005). According to Mesele (2014), a loss in soil corresponds to loss of plant nutrients and subsequent reduction in soil productivity. Nutrients losses on croplands per hectare per year could be up to several bags of fertilisers when quantified in terms of nitrogen, phosphorus and potassium which are the major limiting nutrients in tropical agro-ecosystem (Munodawafa 2012). Blanco and Lal (2008) observed that loss of soil nutrients as influenced by soil erosion has significantly reduced productivity. Loss of soil organic matter is a critical problem under low resource agriculture as this is the main source of plant nutrients under this system.

With the shallow nature of tropical soils, soil productivity loss has been found to be more severe on shallow soils than on deep soils with the same level of soil erosion (Blanco and Lal 2008). This underscores the need to ensure effective management practices that control soil erosion for the sustenance of the productivity of shallow soils which are common in the tropics.

Soil erosion control measures cannot be effective until the effects of various soil management practices on soil and nutrients losses are quantified. This will not only support conservation planning but raise soil and crop productivity by identifying those practices that could help minimise losses in soil organic matter and plant nutrients, particularly under low-input farming system. It is, however, noteworthy that such information is scarce in Sub-Saharan Africa. Cultural practices such as tillage, fertilisers and manure applications affect soil and crop productivity. The magnitude of these, particularly their interactions, are not widely reported in scientific literature. For these reasons, this paper therefore quantifies the impact of tillage, soil amendments and their interactions on soil loss, topsoil reduction, organic matter and nutrient losses in a maize cropping system. This enables us to identify the practices that could effectively conserve soil, plant nutrients and organic matter, thereby maintaining soil and crop productivity, especially in this period of changing climate.

MATERIALS AND METHODS

This study was conducted at the Kwame Nkrumah University of Science and Technology, Faculty of Agriculture Research Station at Anwomaso, Kumasi. The study area falls within the semi-deciduous forest zone of Ghana (latitude 1°31'32.88"W and longitude 6°41'51.24"N). The soil is sandy loam, it belongs to Asuansi series and is classified as Ferric Acrisol (FAO 2006).

Treatments and experimental design

The treatments were grouped into two categories: the tillage systems and the soil amendments.

The tillage treatments comprised:

1. No-till (NT): 100% surface-contact cover was maintained at the start of the experiment on the no-till plot (NT) with no soil disturbance.

2. Minimum tillage (MT): The minimum tillage treatment (MT) was disc ploughed with two traffic passes to a depth of 20 cm after which planting was done manually.

3. Conventional tillage (CT): The conventional tillage (CT) was disc ploughed and harrowed with four to five traffic passes to 20 cm soil depth, after which planting was done.

Table 1. Soil amendment treatment composition

Soil amendment	Rate of Application
Control	No NPK and no Poultry Manure
100% NPK fertilizer (15-15-15) + Urea	60-60-60 kg N-P_2O_5-K_2O/ha + 30 kg N ha^{-1} (Urea)
Poultry Manure (PM)	3 t PM ha^{-1}
½ PM + ½ NPK	30- 30-30 kg N-P_2O_5-K_2O ha^{-1} + 15 kg N ha^{-1} (Urea) + 1.5 t PM ha^{-1}

The composition of the soil amendments is presented in Table 1. The amendments (poultry manure, poultry manure + NPK fertiliser and NPK fertiliser) were applied to the respective treatment plots two weeks after planting (WAP). However, the control plots did not receive any amendment. At five WAP, plots amended with poultry manure + NPK fertiliser, and NPK fertilisers, were top dressed with N in the form of urea. The experiment was a split plot arranged in randomised complete block design (RCBD), with three replications. The treatments were arranged in Randomised Complete Block Design with three replications. The main plot dimension was 12 m by 7.32 m and that of subplot was 12 m by 2.44 m. Maize crop was the test-crop. These treatments were applied continuously for three years on a maize cropland. The parameters measured in this study were assessed at the third cropping season with a view of quantifying the residual effects of the treatments.

Soil loss prediction and topsoil reduction assessment

Universal soil loss equation (USLE) developed by Wischmeier and Smith (1978) was used to predict the amount of soil loss after three (3) consecutive seasons of treatment application. The input parameters of the USLE were quantified as follows:

$$A = R\ K\ LS\ CP \tag{1}$$

where, A – amount of soil loss (Mg ha^{-1} yr^{-1}); R – rainfall erosivity (MJ mm/ha.h.yr); the erosivity value obtained by Mesele (2014) for the semi-deciduous forest zone of Ghana using the modified Fournier index was used; K – soil erodibility (Mg ha h/MJ mm h); this was determined by quantifying the input parameters of the erodibility nomograph developed by Wischmeier and Smith (1978) and the data obtained were used to read the nomograph; LS – topographic factor: line level method was used to obtain the slope length and percent slope from the experimental field. The values obtained were used to read the LS factor from the topographic chart developed by Wischmeier and Smith (1978); CP – crop and support practice factor: integrated CP values based on the cropping system were obtained from Adama (2003) and Nill *et al*. (1999).

Topsoil reduction was calculated as the amount of soil loss per area per bulk density.

Assessment of organic matter and nutrients losses

The pedo-transfer equations developed by Adama (2003) for the study area were used in quantifying the organic matter and nutrients losses under the different tillage and soil amendments. The functions were developed on an Acrisol cultivated with maize in the semi-deciduous forest zone of Ghana. The equations are as follows:

$$\mathrm{OM} = 15.31\ SL + 45.53 \qquad R^2 = 0.99 \tag{2}$$

$$\mathrm{Ca} = 0.03\ SL + 0.22 \qquad R^2 = 0.99 \tag{3}$$

$$\mathrm{Mg} = 0.02\ SL + 0.03 \qquad R^2 = 0.96 \tag{4}$$

$$\mathrm{N} = 1.56\ SL + 8.24 \qquad R^2 = 0.63 \tag{5}$$

$$\mathrm{K} = 0.03\ SL + 0.23 \qquad R^2 = 0.98 \tag{6}$$

$$P = 0.008\ SL + 0.09 \qquad R^2 = 0.76 \qquad (7)$$

$$Na = 0.03\ SL + 0.08 \qquad R^2 = 0.99 \qquad (8)$$

where: *SL* is soil loss (Mg ha^{-1}), OM, Ca, Mg, N, P, K, and Na are the total nutrient losses (kg ha^{-1}) in the eroded sediment.

Validity of soil loss assessment

Soil loss was predicted by the USLE, the use of which requires the development of site-specific input parameters. Since this was done in this study, the variable impacts of the treatments could be used to discuss the results of the predicted soil loss. It is also recognised that the accuracy of a prediction model is usually tested by comparing predicted with measured values. This can be achieved by dividing the predicted by the measured value to give a ratio (Morgan 2005). Ideally, the ratio should be equal to 1.0 but, since this rarely is the case, its value has to be related to some guideline in order to judge whether it is acceptable. Morgan (2005) suggested the use of a less stringent range of 0.5 to 2.0 for the ratio between the predicted and measured values to accept a model as successful in predicting realistic values.

In this study, the measured soil loss on an Acrisol within the environs of this study reported by Quansah (1974) was used for validation. The measured soil loss of 4.0, 0.9 and 0.2 Mg ha^{-1} for severely tilled plot, conventional tillage and minimum tillage, respectively, was compared with the predicted values of 4.907, 1.507 and 0.154 Mg ha^{-1} for the bare, conventional tillage and minimum tillage. These gave respective predicted: measured soil loss ratios of 1.2, 1.7 and 0.8 which fell within the acceptable range of 0.5-2.0.

Statistical analysis

The data was then subjected to analysis of variance (ANOVA) using Genstat package Edition 9, first to compare the effect of the main treatments and then their interactions. Significant treatment means were separated using Least Significant Difference (LSD) at 5% probability.

RESULTS

Tillage systems and soil loss

The impact of different tillage systems on soil loss is presented in Table 2. Soil loss under different tillage systems showed significance ($P < 0.05$). Soil loss was significantly the highest under NT and significantly the lowest under NT and MT.

Table 2. Means of soil loss as affected by tillage

Tillage system	Soil loss (Mg ha^{-1} yr^{-1})
NT	0.140
CT	1.507
MT	0.154
Bare	4.907
LSD ($P < 0.05$)	0.08
CV (%)	42.4

Impact of soil amendments on soil loss

The results in Table 3 show the mean soil loss ranging from 0.582-4.907 Mg ha^{-1} under the different soil amendments. The values show the soil amendments to significantly decrease the soil loss compared to that of the bare plot. However, there was no significant difference in soil loss under the different soil amendments. Soil loss reduction over the bare was 88% by ½ Rates of NPK+PM, 87% by poultry manure (PM) and 85% by NPK.

Table 3. Means of soil loss under different soil amendments

Soil amendment	Soil loss (Mg ha^{-1} yr^{-1})
½ NPK+ ½ PM	0.582
PM	0.638
NPK	0.736
Bare	4.907
LSD ($P < 0.05$)	0.252
CV (%)	42

Effect of tillage and soil amendment interaction on soil loss

The interaction between tillage and soil amendments effect is presented in Fig 1. The results showed tillage and soil amendment interaction to reduce soil loss compared to that of the bare fallow. However, the differences in the interaction effects were not significant. The main effect of soil amendments on soil loss showed the NT and the soil amendments and the MT x soil amendments interactions to reduce soil loss considerably. The CT and amendment interactions, however, significantly increased soil loss relative to the main effects of soil amendments.

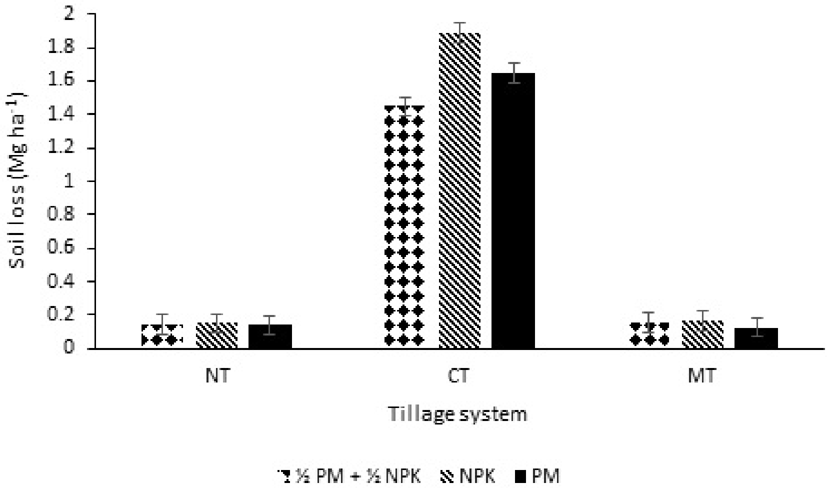

Fig. 1. Integrated effect of tillage and soil amendment on soil loss

Impact of tillage on soil depth reduction

The means of soil depth reduction under different tillage are presented in Table 4. The results showed that the differences were significant at $P < 0.05$. Soil depth reductions in NT and MT systems were 92% lower than in the conventional tillage.

Table 4. Means of soil depth reduction under different tillage practices

Tillage system	Soil Depth Reduction ($x10^{-3}$ mm)
No-till	10
Conventional tillage	103
Minimum tillage	11
Bare	340
LSD ($P < 0.05$)	7
CV (%)	42.4

Impact of soil amendment on soil depth reduction

The means of soil depth reduction under different tillage are presented in Figure 2. The values ranged from 0.01 to 0.34 mm. The bare plot with no amendment recorded 0.34 mm depth reduction which was significantly higher than all the depth reductions under each of the amendments. Other differences were not significant at P < 0.05. The soil amendments, however, significantly decreased the loss of topsoil as compared to where no amendment was applied.

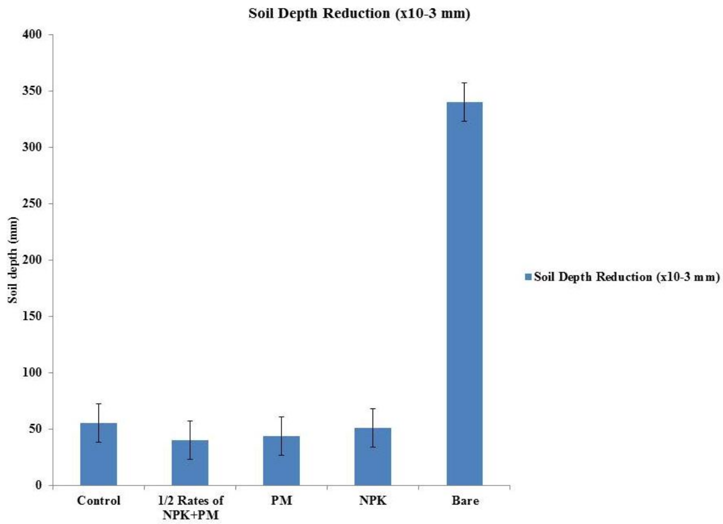

Fig. 2. Effect of soil amendment on soil depth

Impact of tillage x soil amendments interactions on soil depth reduction

The interactive effects of tillage and soil fertility amendment on the mean values of soil depth reduction are presented in Table 5. The results show that soil depth reduction was significantly higher in conventional tillage plot under the various amendments but slightly lower with ½ rates of NPK+PM. Combined effect of tillage and soil fertility amendment significantly abridged soil depth reduction compared to the bare plot.

Table 5. Means of soil depth reduction under the tillage x amendments interactions

	Soil Depth Reduction ($x10^{-3}$ mm)		
	½ Rates of NPK+PM	NPK	PM
NT	10	11	10
CT	99	129	113
MT	11	12	9
Bare	340	340	340
LSD (P = 0.05)	7		
CV (%)	42		

Tillage and nutrient loss

The results of the mean soil organic matter and nutrient losses are presented in Table 6. The analysis of variance showed significant differences in nutrient loss under the different tillage practices. The loss of organic matter ranged from 47.67 kg ha^{-1} to 120.70 kg ha^{-1} and was in the order of bare > CT > MT > NT. The nutrient losses followed the same order. Nutrient losses in the conservation tillage systems (NT and MT) were not significantly different from one another; however the latter considerably reduced nutrient losses, especially nitrogen, compared to the bare and CT systems.

Table 6. Means of nutrient losses under different tillage practices

Tillage system	Organic matter	Nutrient losses (kg ha^{-1})					
		N	P	K	Ca	Mg	Na
NT	47.67	8.46	0.09	0.23	0.22	0.03	0.08
CT	67.68	10.59	0.1	0.28	0.27	0.06	0.13
MT	47.89	8.48	0.09	0.23	0.22	0.03	0.08
Bare	120.7	15.9	0.13	0.38	0.38	0.13	0.23
LSD (P < 0.05)	16.55	1.69	0.01	0.03	0.03	0.02	0.03
CV (%)	13.3	8.1	4	5.8	6	22.7	14.6

Effect of soil amendment on nutrient loss

Loss of organic matter, NPK and exchangeable cations were slightly higher in fields amended with NPK (Table 7). Loss of organic matter and plant nutrients were almost the same in soils amended with PM and combination of PM and NPK. At 5% probability level, these differences were not significant.

Table 7. Effect of soil amendment on nutrient loss

Soil amendment	Organic matter	Nutrient Losses (kg/ha)					
		N	P	K	Ca	Mg	Na
Control	52.33	8.93	0.090	0.24	0.23	0.04	0.09
½ NPK + ½ PM	54.45	9.15	0.090	0.25	0.24	0.04	0.10
PM	55.31	9.24	0.100	0.25	0.24	0.04	0.10
NPK	56.79	9.39	0.100	0.23	0.24	0.40	0.10
LSD (P > 0.05)	3.86	0.39	0.002	0.01	0.01	0.01	0.01
CV (%)	13.3	8.1	4	5.8	6	22.7	14.6

Effect of tillage and soil amendment interaction on soil organic matter and plant nutrient losses

The mean values of soil organic matter and plant nutrient losses are presented in Table 8. The NT x amendments and MT x amendments interactions significantly reduced the amount of organic matter and plant nutrient losses relative to CT and amendment interaction. CT x NPK recorded the highest loss of organic matter and plant nutrients. Soil organic matter and total nitrogen losses were significantly ($P < 0.05$) lower under the tillage soil amendment interactions than on the bare plot.

Table 8. Mean values of soil organic matter and plant nutrient losses under tillage x soil amendments interactions

Treatment	Organic matter	N	P	K	Ca	Mg	Na
		(kg ha^{-1})					
NT x Control	47.38	8.43	0.09	0.23	0.22	0.03	0.08
NT x ½ NPK + ½ PM	47.73	8.47	0.09	0.23	0.22	0.03	0.08
NT x NPK	47.86	8.48	0.09	0.23	0.22	0.03	0.08
NT x PM	47.70	8.46	0.09	0.23	0.22	0.03	0.08
MT x Control	48.06	8.50	0.09	0.24	0.23	0.03	0.09
MT x ½ NPK + ½ PM	47.92	8.48	0.09	0.23	0.22	0.03	0.08
MT x NPK	48.07	8.50	0.09	0.24	0.23	0.03	0.09
MT x PM	47.49	8.44	0.09	0.23	0.22	0.03	0.08
CT x Control	61.54	9.87	0.10	0.26	0.25	0.05	0.11
CT x ½ NPK + ½ PM	67.68	10.50	0.10	0.27	0.26	0.06	0.12
CT x NPK	74.45	11.19	0.11	0.29	0.28	0.07	0.14
CT x PM	70.72	10.81	0.10	0.28	0.27	0.06	0.13
LSD ($P < 0.05$)	16.19	1.65	0.01	0.03	0.03	0.02	0.03
CV (%)	7.1	4.3	2.1	3.1	3.2	12.1	7.8

DISCUSSION

Impact of tillage and soil amendments on predicted soil loss

The soil loss values have amply shown that tillage can cause significant variations in soil loss. The bare plot recorded significantly the highest soil loss relative to those from the tillage practices and grass fallow. This is not surprising since high rates of soil loss have been generally observed to coincide with periods in the cropping cycle when the soil is essentially bare. Foster and Meyer (1975) thus indicated that soil loss is proportional to the bare area exposed. In this study, the absence of any cover on the plough-harrow bare plot contributed significantly to the greater soil loss. The underlying reasons include the greater detachment and transport of soil particles by raindrops and runoff.

All tillage practices recorded less soil loss than the bare plot due to their cover and soil conservation factors. Even under these conditions, the no-till and minimum tillage recorded significantly less soil loss than the conventional tillage. The latter tillage practice created conducive conditions for erosion through producing pulverised and more erodible soil particles, surface sealing and enhanced runoff generation for rilling and sediment transport, as evidenced in Fig 3.

The minimum tillage and no-till, on the other hand, produced greater surface roughness elements by large clods and residue cover, respectively, to cushion the soil against the erosive forces of raindrops and runoff with a consequent reduction in soil loss. The no-till and minimum tillage thus offer the best erosion control practices in the cultivation of maize. It is noteworthy to point out that soil loss on inherently highly erodible soil can be significantly reduced through effective cover and residue management. In this study, although the no-till had the highest erodibility (Mesele 2014), its soil loss was the least due to the cover and residue management.

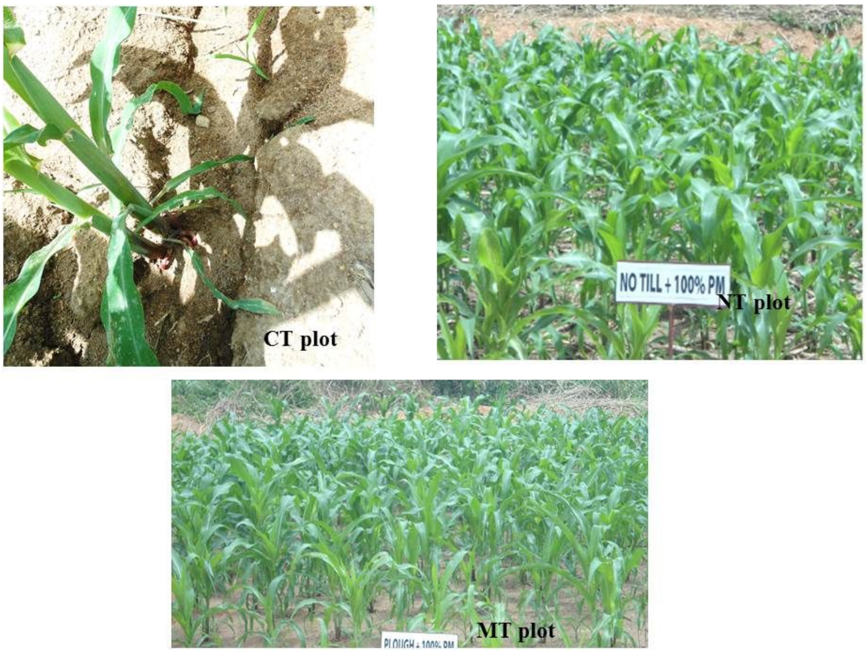

Fig. 3. Visual observation of rills and exposure of plant roots due to soil loss

The impact of the various soil amendments on soil loss did not differ significantly. However, all the soil amendments had significantly less soil loss than the bare plot. In general, poultry manure only, as well as in combination with NPK, recorded lower soil loss than the soil with NPK treatment. Similarly, their interaction with tillage produced less soil loss than tillage NPK interaction. The higher organic matter recorded under these practices may be implicated in the observed reduced soil loss.

Impact of tillage and soil amendments on soil depth reduction

Soil loss through erosion, being a surface activity, is almost invariably accompanied by reduction in soil depth. Consequently, the depth of the A horizon of soil profiles under undisturbed cover is often used as a proxy for erosion or soil degradation when compared with reduced depth of A horizon under degraded vegetative cover or cultivated soils (Lal 2009).

In this study, the reduction in soil depth under the different tillage practices followed the same trend as soil loss, with higher values under bare and conventional tillage. The implications of soil depth reductions include exposure of plant roots, reduced water holding and nutrient retention capacities of the soil, rooting depth and exploitable soil volume for water abstraction and nutrient uptake by plant roots. These, in turn, constrain soil productivity and sustainable crop production. Therefore the choice of tillage and soil management practices is of prime importance, particularly in rainfed agriculture which depends solely on in-situ moisture storage after rainfall for crop growth.

Impact of tillage and soil amendments on organic matter and nutrient losses

The on-site impact of soil erosion on arable land is the loss of soil and crop productivity (Stocking 2003). Apart from soil depth reduction, soil loss is almost always accompanied by loss of organic matter and plant nutrients. The process, termed fertility erosion (Ellison 1950), is selective in that finer particles, relatively high in plant nutrients and organic matter, are the most susceptible to erosion. Consequently, the eroded sediment is usually the most fertile (Quansah1996, Adama 2003). In spite of the importance of fertility erosion to productivity, most erosion studies are directed at the measurement of runoff and soil loss. As a result, information on fertility erosion is scarce.

Not surprisingly, greater losses of soil resulted in higher total nutrient losses. The losses in soil organic matter, total nitrogen, available phosphorus and exchangeable cations were greater on the bare and CT plots (Table 6). The NT and MT had the least nutrient losses with an implicit better sustenance of soil fertility and productivity.

It must be noted that generally the eroded sediments often contain higher concentrations of organic matter and nutrients than the parent soil (Quansah and Ampontuah 1999, Adama 2003) and this is expressed as enrichment ratio. This suggests that small losses of soil that might appear insignificant could be important from soil fertility point of view, particularly for shallow soils. In tropical soils, humus content accounts for 90% of the cation exchange capacity under forest and 80% under savanna conditions (Acquaye 1990). Therefore, if organic matter is lost, the soil is not only depleted of one of its most valuable components, but significant quantities of nutrients, such as nitrogen and phosphorus, are removed as evidenced by the results of this study which corroborates the observations by Munodawafa (2012).

The results of the study further showed erosion to impact negatively the chemical properties of the soil through the removal of organic matter and plant nutrients. Total loss of nutrients increased as the amount of soil loss increased. Specifically, a unit increase in soil loss (Mg ha^{-1}) results in the loss of 284 kg NPK per hectare. The progressive loss of organic matter and nutrients reduces the stock of these fertility constituents and implicitly decreases soil productivity, which can adversely affect crop yield, as observed in this study. The implication is that if the losses of N, P, and K recorded in this study were to be replenished by applying mineral fertilisers, the profitability of the project would be elusive. In this study, the NT and MT system amended with combination of organic and mineral fertilisers were the better option in reducing the amount of organic matter and nutrient losses while enhancing crop yield.

CONCLUSION

The combined use of conservation tillage systems with soil amendments resulted in a reduction in the amount of soil and nutrients losses, minimised topsoil reduction and organic matter losses. Loss of soil depth may be insignificant in one or two years of cultivation, however, if the process continues without control measures, it would result in severe losses in crop productivity through reduction in water and nutrients holding capacities, and reduce the resilience of the soil to degradation. No-till and minimum tillage which were recognised as conservation tillage systems, amended with combination of poultry manure and NPK fertiliser, were found as better options in minimising losses in soil quality with the potential to enhance crop yield and sustain soil productivity. Practices that halt nutrient depletion and ensure adequate stocks are needed for sustained crop production and food security for the present and future generations. In this regard, conservation tillage of NT and MT coupled with integrated plant nutrition hold a better promise in achieving the above desired goals.

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STRATY GLEBY I SUBSTANCJI ODŻYWCZYCH W WARUNKACH RÓŻNYCH SPOSOBÓW UPRAWY W GHANIE

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Streszczenie. Zintegrowana gospodarka substancjami odżywczymi jest konieczna dla uzyskania wzrostu oraz utrzymania produktywności upraw rolniczych. Przeprowadzono oceną strat gleby, materii organicznej oraz substancji odżywczych w 3-letnim zintegrowanym systemie uprawy kukurydzy w Ghanie. Czynniki doświadczenia obejmowały sposoby uprawy: bezpłużny (NT), uprawa minimalna (MT), uprawa tradycyjna (CT), oraz zastosowane rodzaje nawożenia (Kontrola, NPK, nawóz kurzy, oraz ich kombinacje). Wyniki nadań wykazały straty gleby w zakresie 0,140-4,907 $Mg \cdot ha^{-1}$ w sekwencji rosnącej NT < MT < CT < Ugór. Redukcja strat gleby w stosunku do Ugoru wyniosła 88% dla ½ dawki NPK+PM, 87% dla PM oraz 85% dla NPK. Ubytek miąższości gleby w obiektach NT i MT był 92% niższy niż w obiekcie CT. Spadek zawartości substancji organicznej wahał się od 47,6 $kg \cdot ha^{-1}$ do 120,70 $kg \cdot ha^{-1}$, w następujący sposób: Ugór > CT > MT > NT. Straty substancji odżywczych wykazywały ten sam trend. Straty materii organicznej, N, P, K, Ca, Mg i Na pod wpływem współdziałania sposobów uprawy i nawożenia były wyższe w obiektach CT i nie uprawianym. Obiekty NT i MT, które traktowano jako systemy uprawy konserwującej, nawożone kombinacją nawozów organicznych i mineralnych, okazały się lepszą opcją w zakresie minimalizacji degradacji jakości gleby.

Słowa kluczowe: produktywność gleby, uprawa konserwująca, erozja gleb, gospodarka substancjami odżywczymi