Influence of Tillage, Crop Rotation and Crop Residue Management on Soil Erosion and Maize Yield

E. Dugan[1], R. N. Issaka[1], M. M. Buri[1], E. Sekyi-Annan[1]*, H. Omae[2] and F. Nagumo[3]

[1] *CSIR-Soil Research Institute, Private Mail Bag, Academy Post Office, Kwadaso, Ghana*

[2] *Japan International Research Center for Agricultural Sciences (JIRCAS), Tropical Agriculture Research Front, Maezato 1091-1, Ishigaki, Okinawa, 907-002, Japan*

[3] *Japan International Research Center for Agricultural Sciences (JIRCAS), 1-1, Ohwashi, Tsukuba, Ibaraki, 305-8686, Japan*

*Corresponding Author: *sekyiannan@yahoo.com*

Abstract

An experiment was conducted in 2014 and 2015 in the forest zone of Ghana to evaluate the effects of tillage, maize-cowpea rotation, and residue management on runoff, soil erosion and maize grain yield. Four treatments consisting of full tillage with continuous maize cropping and removal of crop residue (T1), full tillage with maize-cowpea rotation with incorporation of plant residues (T2), minimum tillage with maize-cowpea rotation and plant residues applied as mulch (T3), and minimum tillage with continuous maize cropping with residue mulch (T4) were imposed on a randomized complete block design with three replications. Results showed a very high runoff coefficient (15.53%) for T1, while runoff was significantly lower for T2 followed by T3 and T4. This translated into very high total suspended sediments (5.7 t ha^{-1}) and subsequently higher ($p = 0.007$) total eroded soil (9.2 t ha^{-1}). There seem to be a synergy between the presence of plant cover/mulch and residue incorporation resulting in the lowest runoff for T2, as the combined effect probably improved infiltration and soil permeability. In 2014, maize grain yield was lowest in the T1 (2.3 t ha^{-1}) which was similar to T4 (2.4 t ha^{-1}). Grain yields for T3 (4.2 t ha^{-1}) and T2 (4.1 t ha^{-1}) were also similar but higher than the other two treatments. In 2015, however, maize grain yields were significantly different among the various practices in the following order: T1 (1.2 t ha^{-1}) < T4 (2.2 t ha^{-1}) < T3 (3.4 t ha^{-1}) < T2 (4.0 t ha^{-1}). The inclusion of a legume in T2 and T3 probably enhanced the soil fertility status resulting in higher grain yields. Hence, tillage practices including cereal-legume rotation systems, coupled with effective management of crop residue is a promising strategy to address soil and nutrient loss to water erosion and increase crop yield.

Keywords: Cereal-legume rotation, cropping system, full-tillage, minimum tillage, nutrient mining

Introduction

Agriculture remains the single largest consumer of fresh water globally and accounts for 75% of anthropogenic fresh water use (Wallace, 2000). According to Hashemi et al. (2019), for example, nearly 92% of total water is allocated to the agricultural sector in Iran. However, an average of 63% of this water applied to agricultural soils is lost to evaporation, causes run-off and soil erosion. Soil erosion has been recognized as a primary cause of soil degradation since it adversely affects soil quality by reducing infiltration rates, water-holding capacities, nutrients and organic matter contents, soil biota and soil depth (Pimentel et al. 1995; Basic et al. (2004). Reduction in infiltration rate, water holding capacity and loss of water through evaporation could impact negatively on aquifer recharge and thus affect water balance, beside the negative effects on the environment (Hashemi et al., (2019). Owusu (2012) predicted annual soil loss rates ranging between 0 and 63 t ha^{-1} yr^{-1} with an average of 2.2 t ha^{-1} yr^{-1} in the Densu basin in southern Ghana and indicated that some areas were even above tolerance level of 5.0 t ha^{-1} yr^{-1}. The study provides relevant information for planning soil and water conservation interventions in the Densu basin, which could be extended to Ghana as a whole. A simulation study by Badmos et al. (2015) shows that opening up cropland on soil with a high erosion risk has implications for soil loss. Hence, effective measures should be put in place to prevent such practices. Other studies on soil erosion in watersheds in Ghana have also been reported by Adongoa, et al. (2019), Dumedah, et al. (2019) and Sekyi-Annan et al. (2021). Excess water from rain and irrigation on cropping fields is capable of transporting soil, fertilizers and pesticides through erosion into water bodies thereby creating non-point pollution. More than two decades ago, Ofori (1995) observed that erosion – with particular focus on soil erosion by water coupled with declining soil fertility, constituted a major threat to agricultural development and sustainable natural resources management in Africa. A more recent study by Bashagaluke, et al. (2019) alluded to this threat and reported a seasonal soil loss range from 9.75–14.5 t ha^{-1} on bare plots, due to soil erosion in the semi-deciduous forest zone of Ghana. This is because the decline in soil fertility resulting from erosion has been the major factor exacerbating the already low fertility levels of the severely weathered soils in the semi-humid and humid forest regions. Similarly, Vlek et al. (2017) have found that more than 40% of farmlands in Africa is experiencing annual nutrient losses of approximately 30 kg ha^{-1}, and thus the vicious trend could be reversed by restoring soil fertility through the adoption of good agronomic practices, controlling soil erosion, and improving the water retention capacity of the soils. Soils in these regions, including Ghana, have been subjected to severe water erosion and depletion of organic matter and nutrients through continued cropping as well as inappropriate agronomic practices (Ramos et al. 2011; Amoako and Ampadu 2015; Sekyi-Annan et al. 2021). Most of the old agricultural practices in Ghana including slash-and-burn, deforestation, poor soil fertility management, increased dependence on agro-chemicals still persist and could best describe the cropping systems as "exploitative" rather than "balance" or "generative agriculture (Ofori 1995; Amoako and Ampadu 2015; Bashagaluke, et al. 2018). This challenge if not addressed, and with continual loss of vegetative cover due to farming and other land uses, soil erosion would continue to threaten food security by reducing soil quality as a result of nutrient depletion and destruction of soil structure (Vlek et al. 2017; Pimentel and Burges, 2013). Farmers can mask the effect of soil erosion depending on their present and future access to soil conservation practices such as tree/cover crop intercropping, crop rotation and tillage methods (Blaikie 2016; Sekyi-Annan et al. 2021). The adoption of effective soil management strategies such as appropriate tillage methods and crop residues management could increase the soil's resilience to erosion as well as improve carbon sequestration and crop productivity; as tillage influences soil erosion (Lal 2009; Basic et al. 2004). Zero-till or minimum tillage farming practices reduce surface runoff, suspended sediment discharge and soil erosion (Matisoff et al. 2002). According to Panagos et al. (2015), cover cropping and application of crop residues are management practices that are efficient in reducing soil and nutrient loss caused by soil erosion. Crop residues are precursors of the soil organic carbon pool, and thus returning more crop residues to the soil is associated with increasing organic carbon concentration, which help bind soil particles together by acting as cement agent (Russell et al. 2009; Lal 2004). Soil erosion increases with combined effect of less crop rotation, mechanical tillage or conventional plough-based farming systems and clean fallow (Rasmussen and Collins 1991). These aforementioned practices could accelerate carbon mineralization and thus reduce soil carbon content. Therefore, it is crucial to develop programs that provide cost-effective and farmer-friendly management practices that protect the soil against erosion, compaction, as well as ensure realization of productive capacity of the soil.

Conservation Agriculture (CA), founded on the principles of minimum soil disturbance, application of organic soil surface mulch, and legume-based cropping, has proven to provide solutions to common agro-hydro-climatic challenges such as low soil fertility, poor land preparation, rainfall variability and recurrent soil erosion resulting from high-intensity rainfall in several sub-Saharan African countries including Kenya, Uganda, Malawi, Swaziland as well as Bangladesh, Brazil and Australia (Haque et al. 2018; Moyo 2013). CA improves infiltration, reduces the cost of land preparation, reduces soil erosion and evaporation, and ultimately enhances soil organic matter accumulation for increased food production (Moyo 2013). According to Haque et al. (2018), both mulching and minimum soil disturbance yield independent benefits for crop yield, soil health, decreased weed seed bank and infestation. The aforementioned benefits of adopting CA do not come without some notable challenges such as weed pressure, labour requirement for land preparation and potential unavailability of crop residue for mulch due to the existing multiple uses of crop residues including livestock feed, making compost and thatching for some types like pearl millet (Haque et al. 2018; Moyo 2013). Resilience, concern for the environment and the formulation and implementation of the requisite policies are required in order to realize the full benefits of CA as have been reported in Brazil and Western Australia by Haque et al. (2018). There, government programs incentivize farmers to adopt conservation agriculture in order to control soil erosion.

The Food and Agriculture Organization of the United Nations (FAO) in Kleinman et al. (1995) initiated a program on "Conservation and Rehabilitation of African Lands". It sought to develop national soil conservation and rehabilitation programs. The present low yields of food crops obtained by farmers could increase substantially by threefold; as shown in the extensive demonstrations and experiments carried out by Issaka et al. (2016).

Hitherto, soil management programs have been focusing attention mostly on soil fertility experiments to solve immediate soil nutrient replenishment, with emphasis on increasing crop yields in the short and medium term by the use of fertilizers. However, little attention has been paid to long-term evolution of soil fertility and productivity maintenance. A study by Ikazaki et al. (2018) in the drier Sudan Savanna ecology of Boukina Faso sought to examine whether all three components of conservation agriculture are required for reducing water erosion. The study concluded that crop association did not contribute to the reduction in runoff and thus had no effect on soil erosion control. They attributed reduction in runoff to holes or gullies bored by termites and wolf spiders, which were prevalent in the region, and their activities enhanced water infiltration. Moreover, the study by Issaka et al. (2016) focused on evaluating the effects of tillage and cropping systems on the growth attributes and grain yield of maize, and hypothesized that less soil disturbances coupled with adequate residue retention could reduce soil erosion, improve soil quality and as a result enhance crop productivity.

Against the foregoing context, this study investigated the effect of tillage and other cropping systems on soil erosion and maize grain yield. The objectives of this study were to evaluate (i) the influence of tillage on runoff, total soil loss and maize grain yield, (ii) the effect of residue management on runoff, total soil loss and maize grain yield, and (iii) the effect crop rotation on runoff, total soil loss and maize grain yield.

Materials and Methods

Study area

The field is located in the Forest agro-ecological zone of Ghana on latitude 6°40'40"N and longitude 1°40'0.6"W. The area receives an annual rainfall ranging from 1,250 mm to 1,630 mm. Rainfall distribution is bimodal, which defines a major season from March to July with peak rainfall in June, and a minor season from September to November with peak rainfall in October (Issaka et al. 2016). The month of August is cool and dry, while the main dry season characterized by desiccating harmattan winds occurs from December to March. Rainfall at the experimental site is high with cumulative average of 1,474.0 mm yr^{-1} for the past 15 years. The total rainfall during the experimental growing periods were; 482.8 mm and 409 mm during the 2014 major and minor growing seasons,

TABLE 1
Detailed description of treatments in 2013

	2013 Major season			2013 Minor season		
Treatment	Cropping system*	Tillage practice	Residue Management	Cropping system	Tillage practice	Residue Management
T1	Maize	Full tillage	Removal	Maize	Full tillage	Removal
T2	Maize/PP intercrop	Full tillage	Incorporate	Cowpea/PP intercrop	Full tillage	Incorporate
T3	Maize/PP intercrop	Minimum tillage	Mulch	Cowpea/PP intercrop	Minimum tillage	Mulch
T4	Maize	Minimum tillage	Mulch	Maize	Minimum tillage	Mulch

* Sole maize or maize/pigeon pea intercrop. ** Sole maize or cowpea/pigeon pea intercrop. Each treatment received 30 kg N ha^{-1}

respectively and 461.4 mm during 2015 major season. The annual temperature ranges between 19 °C and 33 °C, averaging at 26 °C throughout the year (Ghana Meteorological Agency 2010). The relative humidity (RH) is generally high (83.2%) throughout the year. Major food crops grown are maize, cassava, plantain, banana and cocoyam. The soils of the Forest Agroecological Zone of Ghana are largely developed over Phyllites, Granites, Tarkwaian and Voltaian sandstones (Adu 1992). These soil types are generally deep and well drained on the uplands with top-soils being generally loam or sandy loam. The soils are broadly classified as *Lixisols*, *Luvisols* and *Acrisols* (FAO 2014) on the uplands. The soil texture of the experimental site is silt loam with 30.6% sand, 54.3%, silt 16.1% clay, and a bulk density of is 1378.9 (±48.9) kg m^{-3} (Issaka et al. 2016). It is dominated by very fine silt particles and considerable sand and clay content. Under such circumstances, loss of mobile nutrients from top soil is enhanced by the high rainfall if soil erosion is not controlled. The soil is acidic (i.e., pH = 4.48) and low in organic carbon (i.e., OC = 16.2 g kg^{-1}). Other selected initial chemical properties of the soil include exchangeable cation exchange capacity (eCEC) of 10.7 cmol(+) kg^{-1}, total nitrogen (N) of 1.54 g kg^{-1}, Potassium (K) of 0.63 cmol (+) kg^{-1}, and available phosphorus (P; Bray 1) of 73.0 mg kg^{-1} (Issaka et al. 2016).

Experimental design and treatments

The experiment was established on plots which were previously used for a different trial in 2013. Detailed treatment description for the earlier trial has been presented in Table 1, maize was either mono-cropped or intercropped with pigeon pea. In 2014, the treatments were modified and the cropping system changed from intercropping to rotational system. However, the pigeon pea was pruned and residue was either mulched or incorporated when maize or cowpea was cropped to avoid competition. Test crops used during this study were maize (*Zea mays*) and cowpea (*Vigna unguiculata*). Four treatments including full tillage with continuous maize cropping with crop residue removed (T1); full tillage with maize-cowpea rotation with crop residue incorporated (T2), minimum tillage with maize-cowpea rotation with residue retained as mulch (T3); and minimum tillage with continuous maize cropping with residue applied as mulch (T4) (Table 2), were imposed

TABLE 2
Detailed description of treatments in 2014 and 2015

Treatment code	Tillage	Residue	Description
T1 (FT/MM-RR)	Full tillage	No residue	Full tillage with maize-maize mono-cropping. All residue was removed after harvesting
T2 (FT/MC-RI)	Full tillage	Residue incorporated	Full tillage with maize-cowpea-maize rotation. All residues were retained and incorporated up to 10cm depth with hoe.
T3 (MT/MC-RM)	Minimum tillage	Residue spread	Minimum tillage with maize-cowpea rotation and ground covered with residue after harvesting.
T4 (MT/MM-RM)	Minimum tillage	Residue spread	Minimum tillage with maize-maize mono-cropping with the ground covered with residue after harvesting.

on a randomized complete block design with three replications. Plot size was 14.0 m by 4.2 m and with slope of 5°. In the major seasons, sole maize was cropped on all the plots. However, in the minor season, maize mono-cropping was repeated for the treatments FT/MM-RR and MT/MM-RM, while cowpea was cultivated on plots where maize-cowpea rotation was practiced.

All treatments received 30:20:20 kg N-P_2O_5-K_2O ha^{-1} at planting, and 30 kg N ha^{-1} top-dressing at five weeks after planting. During land preparation, the experimental area was sprayed with herbicide (Glyphosate 480g l^{-1}), applied at 1 l in 53 l of water ha^{-1} or at rate of 1 l ha^{-1}. Table 2 shows detailed description of the treatments. Under minimum tillage (MT), planting was done using a cutlass with minimum surface disturbance, while a hoe was used to till the surface to about 10 cm depth before planting under full tillage (FT). A farm cutlass was used to control weeds by slashing for MT, whereas hoe was used for weeding in FT. A maize variety (*Obatampa* local name) was used as the test crop. Sowing dates for the major cropping seasons were 12th May 2014 and 7th May 2015. Maize was spaced at 80 cm x 40 cm with two plants hill^{-1}. The leguminous crop (white black-eyed cowpea variety – locally referred to as *Pedeitua*) was planted on 16th September, 2014, the same day as the maize in the minor season under the maize-cowpea rotation. The cowpea was spaced at 60 cm x 30 cm with 2 plants hill^{-1}. The cowpea was sprayed twice with an insecticide (Karate 2.5% EC) at the rate of 500 ml in 150 l of water ha^{-1} against stem borers. This was done at pre-flowering and when pods were 50% filled. The maize was harvested on 3rd September, 2014 and 19th January, 2015 for major and minor seasons, respectively; at an average of about 114 days after sowing (DAS), when all the maize plants had turned brown. In the 2015 major season, maize was harvested on 28th August, at 113 DAS. The cowpea in the maize-cowpea rotation was however harvested earlier, on 28th November, 2014 at 74 DAS. Harvested plants were separated into leaves, stems and cobs, noting the number of cobs per harvested area. The leaves and stems constituted the stover; its weight was taken in the field, directly after harvest and returned to MT plots. Fresh weight of cobs (kg), including the husk was also taken in the field. Husk was removed and the cobs weighed again. Removed husks was returned to MT fields.

After the fresh weight had been taken, the de-husked cobs were shelled and air-dried to 12% moisture content and weighed. The yields of maize stover, and grains were determined and computed in t ha^{-1}.

Measurement of rainfall

Close to the experimental plots was an automatic meteorological station – HOBO® U30 Station. The HOBO U30 is a data logging and monitoring device on which a rain gauge, temperature, humidity, and solar radiation sensors, connected to a data logger through cables plugged into smart sensor ports. The HOBO® U30 and the sensors were mounted on a mounting kit to measure rainfall and other weather parameters. Rainfall data was recorded at 5 mins interval by the data logger. The stored data were later downloaded on a computer running HOBOware Software for analysis.

Measurement of water runoff

A water level logger (HOBO, Onset, U20001-04) was installed to monitor water runoff (mm) from the experimental plots. The instruments were installed in 12 buckets, in which runoff discharge and sediments from respective aprons fixed at the edge of the 12 experimental plots were collected.

The HOBO water level logger recorded absolute pressure at 5 minutes logging interval, which was later converted to water level readings by an inbuilt software (HOBOware Pro). A V-type weir provided a reference water level (from the bottom of the weir to the discharge point), which was set as 0 m. Using the reference water level (barometric pressure data), HOBOware Pro automatically converts the pressure readings into water level/depth readings. In this application, absolute pressure includes atmospheric pressure and water head. Reading out the water depth data from the Water level logger in the field, required transfer of data via coupler lever (COUPLER2-B) to a HOBO Waterproof Shuttle (U-DTW-1). The data from the Shuttle is then downloaded by an Optic USB Base Station (BASE-U-4) via a laptop computer for analysis. The absolute pressure data downloaded from the loggers were compensated with barometric pressure data from the logger installed in the air using the Barometric Compensation Assistant in the HOBOware Pro software. The compensated pressures were consequently converted to water depths with the same Barometric Compensation Assistant.

The runoff discharge rates, RD (l 5 $mins^{-1}$) were calculated from the water depths (WD) using the relation described by Tucker (2004)

$$Q = RA^c \ldots\ldots\ldots (1)$$

below:

where Q = discharge (l s^{-1}); R and c are empirically derived constants, A = runoff area

$$RD\ (l\ 5\ mins^{-1}) = 5 \times (0.434\ \times 2.281^{wd}) \ldots\ldots (2)$$

(km^2). From our study,

where, *RD* = runoff discharge rate in l 5 $mins^{-1}$, *wd* = water depth (Barometric Compensation Assistant converted compensated pressures to water depths), *R* and *A* are 0.434 and 2.281 respectively.

Measurement of suspended sediments

Turbidity meter INFINITY-CLW (ACLW2-USB - Logger Version of Turbidity Sensor, JFE Advantec, Hyogo, Japan), was used for measuring suspended sediments in the runoff discharge from the experimental plots. The instruments were installed in the bucket as in the case of the water level logger. The instrument is an autonomously deployable data logger for high accurate, long-term and stable turbidity measurements. It measures turbidity with a light source (LED) sensors using backscattering principle in the range of 0-1,000 FTU (Formazan reference). This is shown to have a good correlation with suspended solids/sediments (SS) over the range. The light source is highly stable and minimizes changes over time. The instrument is fitted with a mechanical wiper that periodically sweeps to clean and inhibits biological growths on the optical window.

Measurement can be in a burst (1-1,440 minutes interval) or continuous mode; it was however, set to 5 minutes burst mode in this experiment. This was to reduce dissipation of cell energy – if set at continuous mode. However, too wide interval before bursting could reduce the capacity to clean and inhibit biological growth and thus reduce the effectiveness. Before deploying into the field, the logger was programmed with software (INFINITY SERIES Acquisition Tools Version 1.03) installed in a laptop computer, using USB 2.0 communication cable. Data from the logger was downloaded using the same cable via the laptop computer and read out by the same software. INFINITY SERIES Data Processing Software Ver. 1.02 was used to analyze the data to obtain SS in mg l^{-1} by following formula described by Ikazaki et al.

$$SS\ (mg\ L^{-1}) = 0.0005x^2 + 0.8959x + 4.8123 \ldots\ldots (3)$$

(2018):

where x = reading from the turbidity meter. This is further computed in t ha^{-1}.

Collection of sediment load from apron and bucket

Runoff water in both the apron and bucket was carefully separated, removed from the sediment load using foam and discarded. The sediment load was carefully collected and transferred into a moisture can, oven dried at 105 ^oC to a constant weight, and the weight (kg) recorded after cooling (Polyakov and Lal 2008). This was converted into t ha^{-1} using the

$$L = \frac{W}{A} \ldots\ldots\ldots\ldots (4)$$

equation:

where, L = weight of sediment load per unit area (t ha^{-1}), *W* = weight of load and *A* = area where sediments were collected.

$$L\ (t\ ha^{-1}) = w\ (kg)\ \text{x}\ \frac{10{,}000\ m^2\ (a\ (m^2))^{-1}}{1000} \ldots (5)$$

From the study, this is given as:
where, L = as earlier defined, W = weight total sediments in kg and A = experimental plot area.

Total eroded soil
The total eroded soil (t ha^{-1}) was obtained by adding sediments from apron and bucket to total suspended sediment SS (t ha^{-1}) to obtain

$$\text{Total eroded soil } (t\ ha^{-1}) = \text{ L + total SS} \ldots (6)$$

the total eroded soil in t ha^{-1}.
Statistical analysis
Statistical analyses were undertaken, with initial exploratory data analysis performed on all data using Microsoft Excel (2013 version). Graphical display of arithmetic means of triplicate samples on column, X-Y scatter plots and lines, with error bars were performed. Data sets were checked for normality, using Shapiro-Wilk test for Normality in GenStat 13th Edition, before ANOVA was used for parametric data analysis. Using one-way (and in some cases two-way) ANOVA, independent samples were tested for statistically significant differences at 5% probability level.

Results and Discussion

Effect of treatments on runoff
Figures 1 a and b illustrate runoff occurrences during rainfall events in the major (MJ) and minor (MN) cropping seasons of the year 2014. In both seasons the highest rainfall events recorded the highest runoffs, this supports observation by Rose (1993) and Wei et al. (2007), who reported higher runoff over infiltration rates at high rainfall events (Kavian and Mohammadi 2012). There were instances, however, when the rainfall amounts were not proportional to the runoffs, as it depends on duration and intensity (even though this was not measured) of rainfall events (Mohammadi and Kavian 2015). Such situations mostly result in less chocking of pore-spaces (Hendrickson 1934), ensuring higher infiltration rates of rain drops and filling the void pores and spaces between the soil particles until all available spaces are filled up before the excess water begin to flow overland as run-off (Rose 1993). Runoff was significantly affected by treatments (Figures 1 a and b). During the highest rainfall (40mm) on June 6, 2014, runoff was significantly lower for T2 followed by T3 and T4 with T1 (Fig. 1a) showing the highest runoff (T2<T3=T4<T1). This trend was similar in the minor season.

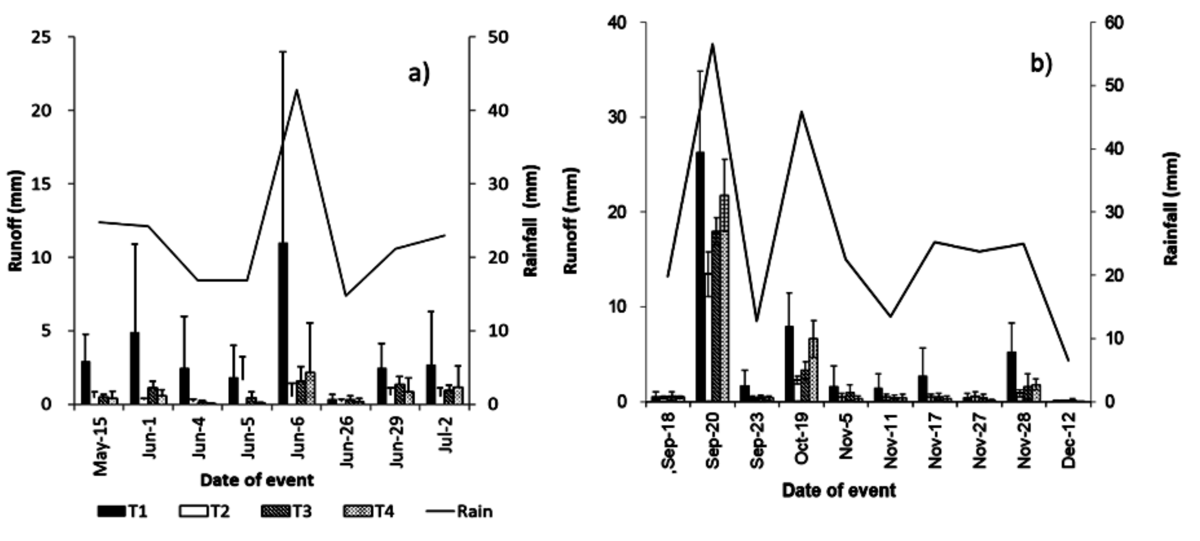

Fig. 1. The effect of treatments on runoff with eight and ten rainfall events during 2014 (a) major and (b) minor cropping seasons respectively

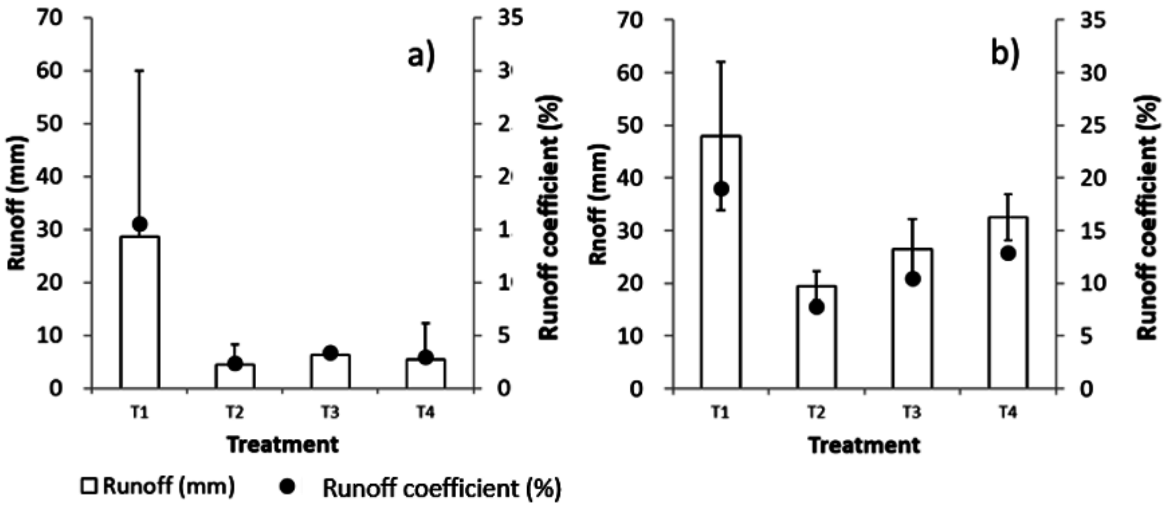

Fig. 2. Water runoff and runoff coefficient at different treatments during the 2014 major (a) and minor (b) growing seasons

During a high rainfall (55mm) on the 20th of September, T2 again gave the lowest runoff, however there was no difference between the other treatments (T2<T1=T3=T4). On the 19th of October, at a rainfall regime of 40 mm, runoff for T2 was the lowest but similar to T3 while runoff for T4 and T1 were significantly higher (T2=T3<T4=T1). There seem to be a synergy between the presence of plant cover/ mulch and residue incorporation explaining the consistent better performance of T2, as the combined effect probably improved infiltration and soil permeability (Ikazaki et al. 2018), even though there was no evidence of presence of termites and wolf spiders in the field. The observation was alluded to by Matisoff et al. 2002; Panagos et al. 2015; Haque et al. 2018 and many others, which reported that minimum tillage with residue cover reduces surface runoff, suspended sediment discharge and soil erosion. In general, the effect of rainfall on runoff was more pronounced in the fully tilled plots with maize mono-cropping and residues removed (T1) than other treatments.

Differences among the treatments in relation to total runoff and runoff coefficients during the major and minor cropping seasons are presented graphically in Figures 2 a and b. In both cropping seasons, the runoff (28.63 mm - MJ; 47.90 mm - MN) and runoff coefficient (15.53 % MJ; 19.10% MN) were considerably higher in T1 plots compared to other treatments. In Figure 2 b runoff and runoff coefficient were significantly lower for T2 than T1 and T4 but similar to T3. The lower runoff coefficient in other treatments in this experiment might be explained by the higher infiltration rate and surface storage induced by the cover crop (cowpea) in the plots with maize-cowpea rotations (T2 and T3) and application of the left over plant residues either as mulch (i.e. T4) or incorporated in the soil (T1). The increased infiltration rate and surface storage associated with cover crop and residue management had also been reported by Romero et al. (2007) and Gomez et al. (2009). In the case of T2, the effect of full tillage was masked by the presence of residues either incorporated or spread as mulch and the introduction of cowpea as cover crop. The cowpea cover crop and mulch residue in the T2 treatment caused greater improvement in infiltration and surface storage than the clean-tilled T1. The improvement of soil properties (i.e. soil permeability) by addition of organic matter (Schmidt et al. 2011 and Chenu et al. 2000) must have played a role in the decrease in the runoff and runoff coefficient in T2.

Effect of tillage on suspended sediments

After every storm causing runoff, a clear distinction could be made between the treatments by the color of runoff soil suspension and sediment concentration collected in the apron and bucket. The differences were visibly evidenced, after every rainfall event, by intensity of color of the collected runoff. Qualitatively, the color of soil sediment loss from the runoff of the plot with the full tillage practice and maize mono-cropping with removed residues (T1) was most intense compared to the rest of the treatments. On the other hand, the color of runoff water of plot with minimum tillage with maize cowpea rotation and with residues used as mulch (T3) was less intense. The decrease in sediment production and suspension in the runoff, similarly, followed a reduction in runoff and runoff coefficient, and this can be explained by the same reasons discussed above for the runoff reduction. These findings are consistent with those of Ikazaki et al. (2018), where runoff and soil loss under minimum tillage and crop residue mulching decreased by 32% and 54%, respectively due to improved infiltration and soil permeability. The observation clearly suggests that clean tillage exposes soil more and makes it prone to detachment and transport of soil sediments by overland runoff.

Tables 3 presents the results of suspended sediments recorded by the Turbidity meter INFINITY-CLW (ACLW2-USB described in Section 2.4 above. During the 2014 MJ growing season, of the six erosive rainfall events, five produced significantly higher suspended sediment in the collected runoff samples from T1 than other treatments. Similarly, from ten erosive rainfall events sampled during the MN season, six suspended sediments from T1 in different rain days, were significantly higher than the remaining treatments. The reduced sediment load from other treatments was the result of either the residue cover or the rotation with cover crop, which many scientists have reported similar observation (Gyssels et al. 2005, Matisoff et al. 2002). Matisoff et al. (2002) reported that nature, properties, extent of soil erosion and differences in rates of sediment concentration results from differences in soil usage and the processes contributing to sediment. According

TABLE 3

Suspended sediments during 2014 growing seasons

Date	T1 (t ha^{-1})	T2 (t ha^{-1})	T3 (t ha^{-1})	T4 (t ha^{-1})	Rainfall (mm)
Major					
19/05/14	0.226 b	0.022 a	0.010 a	0.012 a	24.8
01/06/14	0.378 b	0.015 a	0.022 a	0.018 a	24.2
04/06/14	0.189 b	0.009 a	0.002 a	0.001 a	16.8
05/06/14	0.132 a	0.085 a	0.008 a	0.003 a	16.8
06/06/14	0.844 b	0.028 a	0.032 a	0.067 a	42.8
29/06/14	0.191 b	0.032 a	0.027 a	0.026 a	21.2
Total	1.960	0.191	0.101	0.127	146.6
Minor					
18/09/14	0.0436 a	0.0221 a	0.0121 a	0.0139 a	19.8
20/09/14	2.0147 b	0.6921 a	0.3776 a	0.6751 a	56.6
23/09/14	0.1314 a	0.0181 a	0.0094 a	0.0113 a	12.8
19/10/14	0.6074 b	0.1146 a	0.0682 a	0.2044 a	45.8
05/11/14	0.1287 b	0.0259 a	0.0204 a	0.0113 a	22.6
11/11/14	0.1201 a	0.0259 a	0.0099 a	0.0143 a	13.4
17/11/14	0.2096 b	0.0219 a	0.0097 a	0.0103 a	25.2
27/11/14	0.0356 b	0.0308 b	0.0094 a	0.0064 a	23.8
28/11/14	0.4019 b	0.0441 a	0.0327 a	0.0550 a	25.0
12/12/14	0.0123 a	0.0033 a	0.0026 a	0.0003 a	6.6
Total	3.7053	0.9988	0.5520	1.0023	251.6

Within a row figures followed by similar letter(s) are not different at LSD 5%

to Gyssels et al. (2005), soil loss rates decrease exponentially as vegetation cover increases. Thus, the clean-tilled T1 clearly and consistently showed highest sediment concentration in the collected surface runoff. The suspended sediment concentration in the surface runoff, primarily, forms part of the total eroded soil and this can be correlated with total soil eroded, and thus, loss of soil nutrients (Kattan et al. 1987).

Effect of tillage on soil erosion

Soil management and land use influence the rate of soil loss (Panagos et al. 2015). In this study, the results of effect of tillage and crop residue management on total eroded soil are presented in Table 4. It should be noted that for some rainfall events, even though there were accompanying runoff and suspended sediments as recorded in Tables 3, the eroded soil was negligible and those were neglected and were not recorded in Table 3. The total eroded soil, as presented, was the total of dried sediment load which was in the runoff suspension and that which had settled in the bucket and apron after the runoff water had been carefully removed. Out of the eight erosive rainfall events during the study period, it was observed that six events recorded significantly higher eroded soils in T1 than other treatments. The observation also suggests that apart from T1, there was no significant difference among the rest of the treatments, even though there were consistent numerical differences in the order of T2 > T3 > T4.

From the observations, full tillage with cover crop rotation with maize (T2) reduced soil loss compared to the full tillage with maize mono-cropping (T1). The observation underscores cover-cropping effect of reducing soil loss by improving soil structure and increasing water infiltration (Smith et al. 1987). In particular, the cowpea cover crop masked the effect of erosive rainfall on the fully-tilled soil by protecting the surface, scattering raindrop energy and reducing the velocity of the movement of water over the soil surface (Panagos et al. 2015). Many scientists have alluded to this by reporting reduction of soil erosion due to cover crops within the range of 15-23% (Nyakatawa et al. 2001 – 15%; Wall et al. 2002 and Bazzoffi 2007 – 20%; Verstraeten et al. 2002 – 23%).

The presence of plant residues in treatments T2, T3 and T4 also contributed to the reduction

TABLE 4

Eroded soil under different Treatments during 2014 and 2015 experimental seasons

Sampled Dates	T1	T2	T3	T4
2014 Major Season				
04/03/14	0.37 (0.03)b	0.16(0.01)a	0.10(0.08)a	0.04(0.00)a
06/06/14	2.60(0.36)c	0.44(0.12)b	0.18(0.11)a	0.16(0.02)a
23/07/14	1.64(0.39)b	0.15(0.02)a	0.09(0.04)a	0.07(0.03)a
2014 Minor Season				
29/09/14	1.87(0.07)c	0.36(0.05)b	0.30(0.10)b	0.12(0.04)a
21/10/14	1.58(0.49)b	0.29(0.17)a	0.24 (0.05)a	0.19(0.02)a
12/12/14	0.20(0.11)a	0.13(0.09)a	0.09(0.04)a	0.03(0.02)a
Total (t ha^{-1})	**8.26**	**1.53**	**1.00**	**0.61**
2015 Major Season				
03/06/15	0.75(0.19)c	0.32(0.15)b	0.15(0.02)b	0.07(0.02)a
19/06/15	0.19(0.14)a	0.12(0.06)a	0.10(0.10)a	0.02(0.00)a
Total (t ha^{-1})	**0.94**	**0.44**	**0.25**	**0.09**

Within a row figures followed by similar letter(s) are not different at LSD 5%; Values in bracket are standard errors of means calculated from 3 replicates in soil loss, even though the numerical differences were not enough to be supported statistically. Unger and Vigil (1998), and Greenland (1975) as reported in Panagos et al. (2015) observed that maintaining crop residues on soil surfaces not only protects the soils from splash erosion, but also increases infiltration rates and reduces surface runoff, resulting in less soil loss. However, in this current study, T2 with incorporation of the residues up to 10 cm beneath the soil caused soil particles to be loosened and rendered the soil, on the face value, more erodible than the cases of T3 and T4 where residue was spread as mulch and with minimum tillage.

Maize Yield

Table 5 shows the effect of the various treatments on maize yield (stover and grain). In 2014, cob weight and stover weights under T2 and T3 were significantly higher than T1 and T4. These Treatments also gave significantly higher grain yield than T1 and T4. The inclusion of a legume in T2 and T3 enhanced the soil fertility status and may largely explain the observed differences (T2=T3>T1=T4). The use of leguminous crops in the earlier (2013) experiment could have also contributed in the fertility built-up for T2 and T3. Probably nutrient mining effect from maize-maize rotation masked the effect of minimum tillage in T4. Using maize stover as mulch may need a longer period to decompose (T4) and may partly explain the similarity in grain yield with T1.

In 2015, significant differences in maize yield among the treatments was observed. Cob weight was significantly different and varied among the treatments as follows: T2>T3>T4>T1. Stover yield was similar for all the treatments signifying that grain production was most efficient under T2 followed by T3. Grain yield followed the same trend as cob weight (T2>T3>T4>T1). Under T2, incorporation of plant biomass (both maize and cowpea) hastened decomposition releasing nutrients for the maize crop. Decomposition of plant materials under T3 is slower than T2 but faster than T4 since the plant residue is a combination of maize and cowpea materials. This has a lower Carbon-to-Nitrogen ratio than sole maize material. Even though both T2 and T3 benefited from the effect of pigeon pea (PP) in 2013 it seems the effect of PP in 2015 was minimal hence T2 performing better than T3 largely due to incorporation of plant residue. Similarly, Coppens et al. (2007) found that the location of plant residue in the soil either as mulch or incorporated influenced its decomposition, Nitrogen mineralization and the availability to Carbon, as incorporated residues had a faster decomposition rate even

TABLE 5

Maize yield results from 2014 and 2015

Sampled Dates	T1	T2	T3	T4
2014				
Cobs weight (t ha^{-1})	5.81(0.3)a	9.57(0.7)c	9.88(0.4)c	6.72(0.1)b
De-husked cobs (t ha^{-1})	4.89(1.0)a	7.78(0.4)b	8.08(0.1)b	5.23(0.2)a
Stover weight (DM) t ha^{-1}	7.56(1.0)a	11.92(0.3)b	11.67(0.7)b	8.89(0.3)a
Grain weight (t ha^{-1})	2.33(0.6)a	4.23(0.2)b	4.07(0.3)b	2.41(0.1)a
2015				
Cobs weight (t ha^{-1})	3.80(0.5)a	8.76(0.1)c	8.13(0.3)d	5.25(0.2)b
De-husked cobs (t ha^{-1})	2.37(0.4)a	5.93(0.5)c	6.80(0.2)d	4.58(0.2)b
Stover weight (DM) t ha^{-1}	5.58(0.8)a	8.72(1.6)a	8.90(0.6)a	7.45(0.6)a
Grain weight (t ha^{-1})	1.20(0.2)a	3.97(0.1)c	3.42(0.2)d	2.17(0.1)b

**Within a row figures followed by similar letter(s) are not different at LSD 5%; Values in bracket are standard errors of means calculated from 3 replicates* though moisture content of the plant residue played a significant role. Overall, the relative availability of plant nutrients under the various treatments largely explains the observed yield differences.

The effect of leaving residues after harvest (incorporated or spread as mulch) also contributed to the higher yields of T2 and T3 compared to the T1. This is supported by Santhi et al. (2006) which reported that sheet and rill erosion are reduced, by leaving adequate residue on the ground after harvest, as also evidenced in Sections 3.2 and 3.3 in this study. The reduction in soil erosion means nutrient was retained for utilization by the crops. Additionally, the presence of nitrogen-fixing legume, from the maize-cowpea rotations, which were absent in the exhaustive maize mono-cropping system contributed to the observation. It is worthy to note that the continued loss of soil and thus nutrient (not measured) by erosion resulted in the reduction of yield parameters of all plots, even as the treatments were repeated in the 2015 experiment.

Conclusion

The evidence from this research concludes a reduction in soil lost to erosion, which supports the view that soil erosion can be positively modified through cereal-cover crop rotation, residue cover and less disturbance of the soil through conservation tillage practices. Moreover, the nitrogen fixing capability of leguminous cover crop provides additional nutrient to supplement crop nutrition and increase crop productivity. Thus, cereal-legume rotation systems, coupled with effective management of residue, is a promising strategy to address challenges of soil degradation in forest zone of Ghana.

Investigations into the influence of minimum tillage, residue mulch and cover crop rotation on nutrients loss, water infiltration, water-holding capacity and evapotranspiration would be worthwhile, as the current study did not measure these parameters. In addition, whether these promising combinations will improve and sustain maize yield to the levels observed in the first year remains an open-ended question considering the short duration of the study.

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