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Effect of Mulch and Strengthened Terrace Strips on Erosion, Sediment Enrichment Ratio, and Nutrient Loss Through Erosion

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ABSTRACT

Mulching technology is accessible to farmers and can also reduce soil erosion and nutrient loss through erosion. This research aimed to observe the effectiveness of the combination treatment of strengthened terrace strips and maize stalk mulch on runoff, erosion, sediment enrichment ratio (SER), and nutrient loss through erosion. The experiment was conducted on upland farming on Andisol at the end of the rainy season. The erosion plot experiment was arranged in a Randomized Block Design (RBD) with the treatment of 4 doses of maize stalks mulch (0, 4, 8, and 12 Mg ha^{-1}) and three types of strengthened terrace strips (Jali, Vetiver, and Kalanjana grass) put in groups/blocks, giving 12 experiments. The combination treatment of maize stalk mulch and strengthened terrace strips has not significantly reduced runoff and soil loss. The treatment mulch dose of 12 Mg ha^{-1} reduced runoff and soil loss by 9.9% and 21.9% compared to without mulch. The application of maize stalks mulch tends to reduce the sediment concentration and the number of nutrients (N and Organic C) lost through erosion but increases the nutrient concentration in sediments (SER value).

Keywords: Crop residues mulch, erosion, nutrient loss through erosion, strengthened terrace strips

INTRODUCTION

Erosion is a severe problem worldwide and is the leading cause of land degradation. The annual global cost of land degradation is estimated at least US$40 billion, not including hidden costs such as the loss of ecosystem services essential for food production, water provision, and regulation of the global carbon cycle (FAO 2013).

Erosion in developing countries because of land-use changes at large scales without considering land capabilities (Sadeghi *et al.* 2015a). For fifty years, the pressure on the population has encouraged farmers to exploit the land. Land degradation due to erosion in Indonesia continues to increase, especially in upstream areas (Abdurrachman 2008; Wahyunto and Dariah 2014). Further, the land is categorized in classes VI, VII, and VIII, resulting in land degradation in several upper watersheds in Central Java, including the Serang sub-watershed (Suyana and Muliawati 2014) and Progo Hulu sub-watershed (Suyana *et al.* 2010; Suyana 2012). Land degradation is due to rapid erosion (106.63 Mg ha^{-1} year^{-1} or 8.8 mm year^{-1}), which was much bigger than the tolerable soil loss (33.40 Mg ha^{-1} year^{-1} or 2.8 mm year^{-1}) (Suyana 2014).

Land degradation caused by erosion has decreased soil fertility and land damage. The first cause of soil fertility decline is the amount of organic matter and soil nutrients, inducing the rougher soil texture and denser soil structure (Abdurrachman 2008), the decrease of soil organic C, less soil respiration, and a quick loss of N which is faster than the increase of C or C/N value (Traorea *et al.* 2015).

In general, land degradation causes stock depletion of soil organic C (SOC) and soil organic N (SON), an increase in soil bulk density, a decrease in soil aggregate stability, decrease in essential nutrients (such as Ca, Mg, K, Mn, Cu, and Zn) and decreases in plant growth (Dlamini *et al.* 2014). Therefore, land degradation reduces land productivity, function, and ability to provide other environmental services (Wahyunto and Dariah 2014). Land degradation or environmental degradation causes a decrease in agricultural production (Tesfa and Mekuriaw 2014), and it also reduces water availability and quality and water storage on a watershed scale (Gao *et al.* 2014).

The World Overview of Conservation Approaches and Technologies (WOCAT 2007) defines land-management technologies or soil-and water-conservation (SWC) techniques as "agronomic, vegetative, structural and management measures that prevent and control land degradation and enhance productivity in the field". These solutions may include mechanical structures (e.g., terraces, check-dams, contour sMg ewalls, and contour ridges), biological structures (e.g., afforestation and strips of vegetation), manipulation of the surface soil (e.g., tillage, mulching and soil amendments such as surfactants, compost, and animal and green manure), rainwater harvesting (e.g., reservoirs and retaining dams) and agronomic measures (e.g., drought-resistant species and varieties, short-cycle varieties, crop rotation, animal and green manures, appropriate fertilizer use, compost, and weed control). These SWC practices improve soil quality (Araya and Stroosnijder, 2010; Tesfaye *et al.* 2014), decrease erosion (less runoff and nutrient losses), and increase infiltration (less surface evaporation) (Xu et al., 2012; Zhao et al., 2013) and the efficient use of green water, i.e., the fraction of rainwater used for biomass production (Stroosnijder 2003). Some of these measures succeed under certain conditions but may fail in other settings, so they require testing under specific conditions, taking into account the perception and knowledge of the farmers.

Baptista *et al.* (2015) asserted that the main strategy of SWC techniques focuses on constructing rural structures that inhibit surface flow and increase infiltration, including implementing a series of actions in mechanical and biological structures. According to Abdurrachman (2008), many vegetative methods are recommended in soil, and water conservation technology uses because they can reduce erosion and guarantee increasing land productivity, cheap and easy for farmers to implement. According to The World Bank (1995), vetiver grass (*Vetiveria zizanioides*, Linn Nash) can grow in all fields and weather and has many functions including e.i. vetiver grass contour hedges. Vetiver grass is perfect for supporting various existing conservation technologies, mainly used as permanent strips, strips on terraces, and strips in alley cropping systems (Dariah *et al.* 1994). Vetiver grass can be used as a plant for soil conservation and slope stabilization (Noor *et al.* 2011), also effective in controlling surface landslides on road slopes (Andiyarto and Purnomo 2017). Other plants can be used as strengthened terrace strips, including Setaria grass (*Setaria spacelata*) with low growth, growing tightly and spreading, and thick fibrous roots to reduce runoff and filter soil particles from erosion (Suyana 2012).

Mulching is the soil covered with crop residues such as straw, maize stalks, palm fronds, or standing stubble (Morgan 2005). Zougmore *et al.* (2003) proposed mulch technology as a system that maintains the protective layer on the land surface that has been widely used to reduce runoff and erosion from agricultural fields. Goldman *et al.* (1986) argued that mulch materials include straw, wood fiber, wood chips, bark, fabric or plastic mats, and gravel. According to Kader *et al.* (2017), mulching materials are broadly classified into three main groups: organic materials (e.g., plant products, geo-textile, materials husks, paper, animal wastes), inorganic materials/synthetic materials (e.g., biennial color plastic film, black plastic film, silver plastic film, transparent plastic film, a plastic film with holes, spray able polymer film), and unique materials (e.g., gravel/sand-grave, concrete, tephra mulch).

In Kader *et al.* (2017), mulching has improved agricultural soil fertility and crop productivity. Mulching practices in the agricultural field have a number of advantages. They protect the soil from physical, chemical, and biological degradation and reduce irrigation requirements by conserving water. The various mulching materials affect the hydrothermal soil regime, which alters the moisture and temperature environment of the soil. The soil environment altered soil microbiology to create a favorable soil environment for plant growth. The materials' availability, durability, and cost are important issues to consider in selecting mulching materials. Organic mulching saves labor costs and, after decomposition, adds plant nutrients to soils; this is an extra advantage of organic mulches over plastic mulches. According to Qin *et al.* (2015), soil mulching can significantly increase yields (as well as WUE/water use efficiency and NUE/nitrogen use efficiency) of wheat and maize by 20% and 60%, respectively. Mean effects were more significant for plastic films than for straw mulching. Straw mulching is limited by the availability of straw in the field, which is often used for feeding ruminants or biofuel. The use of plastic films is limited by the financial cost and the cost of collecting and recycling plastic residues. Therefore, guidelines for mulching practices should consider the effects of water and N input levels, crop type, and the side effects of mulching. This study aimed to observe the effectiveness of maize stalk mulch and strengthened terrace strip treatment on runoff, erosion, sediment enrichment ratio (SER), and nutrient loss through erosion in Andisols.

MATERIALS AND METHODS

Place and Time of Research

The present research was undertaken in Setren village, an area settled in Slogohimo District, Wonogiri Regency, in the Province of Central Java, Indonesia. Geographically speaking, it is located at 7°44'44.60'' S and 111°11'2.89'' E with an elevation of 1,193 m asl. The research was conducted for four months at the end of the rainy season (February to May 2016) on Andisol with a slope of 15-17% in upland farming at Keduang Sub-watershed, Central Java.

Materials and Research Tools

The materials used in this study include: materials for erosion plots manufacture, soil collector and drums, rain gauge, cabbage seedlings, remains of crop maize stalks, chemical fertilizers, pesticides, and chemical substances for laboratory analysis.

The research tools are ground drill, clinometer, ring sample, bottle sample, cup measurement, plastic bag sample, plastic wrap, label and observer blank, hoe, field knife, meter, equipment for soil property analysis at site and laboratory, pens, and computer units equipped with MS Office 2007 Software, MS Excel 2007, SPSS 16.0, scanners, digitizers, and printers.

Research Methods

The study was conducted by making erosion plots at the site, which was analyzed at the laboratory, including observation, i.e., rainfall data, runoff, soil loss, organic C levels, and nutrients (N, P, K) in sediments and their origin (plot experiment).

The erosion plot experiments were chosen in length (15m) and width (5m) on land set on bench terraces with a 15-17% slope. The erosion plot experiment was arranged in a Randomized Block Design (RBD) in Split Plot Design, using three types of strengthened terrace strips (vetiver, jali, and kalanjana grass) as main plot and four doses of maize stalks mulch (0, 4, 8, and 12 Mg ha^{-1}) as sub plot which put in groups/blocks, giving 12 experiments in total as presented in Figure 1.

The main plot were 3 types of strengthened terrace strips, which include:

T_J = bench terrace + strips of Jali (*Coix lacryma-jobi L.*)

T_V = bench terrace + strips of Vetiver (*Vetiveria zizanioides Stafp*)

T_K = bench terrace + strips of Kalanjana grass (*Pennisetum purpureum*)

The sub plot were 4 doses of maize stalk mulch, which include:

M0 = maize stalk mulch 0 Mg ha^{-1} (without mulch)

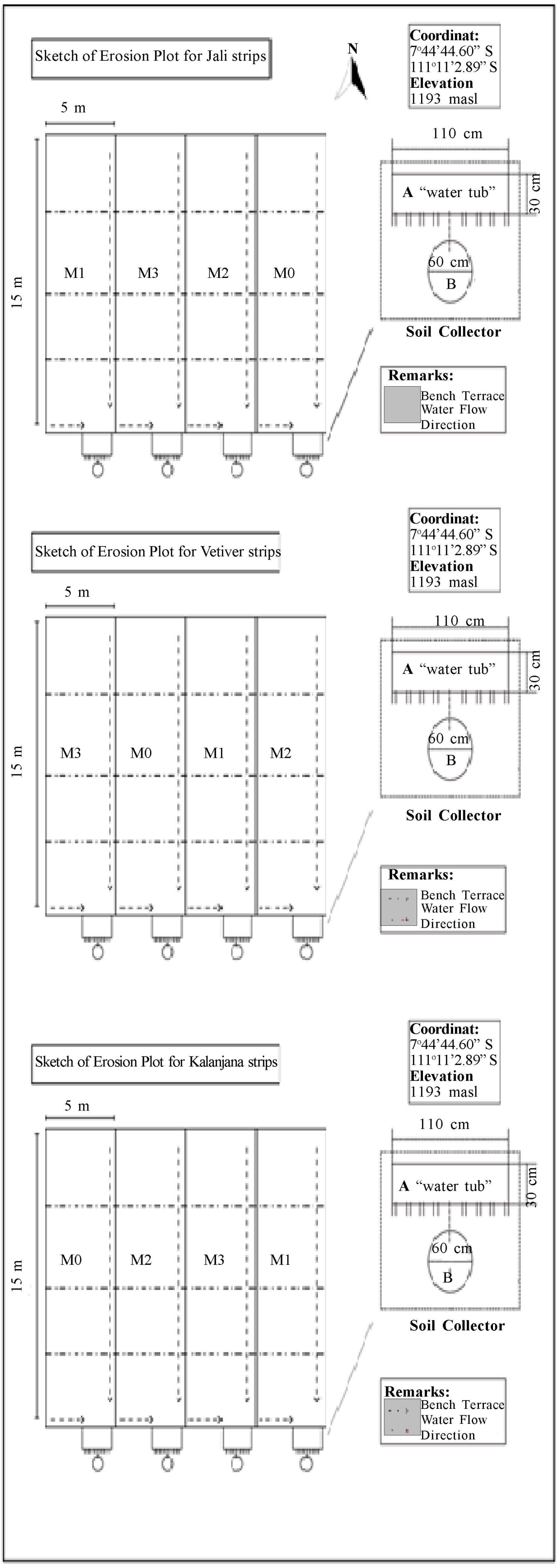

Figure 1. A Sketch of erosion plot experiments for jali strips, vetiver strips, and kalanjana strips.

M1 = maize stalk mulch 4 Mg ha^{-1}
M2 = maize stalk mulch 8 Mg ha^{-1}
M3 = maize stalk mulch 12 Mg ha^{-1}

The plot experiment was planted with cabbage (100 days old). Before the experiments were treated, soil samples were taken from each plot for soil physical and chemical analysis; soil preparation was conducted as required on each plot. The mulching application was obtained from the remains of maize stalks cut 20 cm long and then spread evenly on the soil surface following the treatment doses (Figure 2), and then immediately applied once the cabbage seeds were planted on the plot experiment.

The mulching application was obtained from the remains of maize stalks cut 20 cm long and then spread evenly on the soil surface following the treatment dose (Figure 2), and then immediately applied once the cabbage seeds were planted on the plot experiment. At the same time, the treatment of strengthened terrace strips is presented in Figure 3.

Figure 2. Application of maize stalk mulch on cabbage (from left to right: Doses of maize stalk mulch of 0, 4, 8, 12 Mg ha^{-1}).

Jali strips 3, 8, and 12 weeks after planted (from left to right)

Vetiver strips 3, 8, and 12 weeks after planted (from left to right)

Kalanjana strips 4, 6, and 12 weeks after planted (from left to right)

Figure 3. Treatment of strengthened terrace strips for jali strips, vetiver strips, and kalanjana strips.

Data Collection And Calculations

Soil Properties in Erosion Plots

The observation of soil characteristics data was carried out on erosion plots for cabbage and red beans by taking soil samples at a depth of 0-20 cm, including intact soil samples, which were used to analyze soil physical properties (texture, bulk density, and permeability) and soil composite samples for chemical properties analysis (pH, N, P, K, and organic C). Pipette method was used to get the texture analysis, and gravimetric method for bulk density, Electrometer for soil pH, Kjeldahl digestion for nitrogen (N) content, Olsen for phosphorus (P) content, extraction 25% HCl for K content, and Walkley Black for organic C content.

Rainfall, Runoff and Erosion

Rainfall data were obtained from the rain gauge Ombrometer. Rainfall data, runoff, and erosion were observed each time it rained from February to May 2016. The calculation of the amount of runoff and soil loss for each rainfall obtained from the erosion plot observation (Figure 1) was calculated by the following equation:

$$V = (A + 9\ B) - E / Bd$$

Where:
V : Runoff volume for one period of rain which is one day (m^3)
A : Filling the tub A (m^3)
B : Filling the tub B or drum (m^3)
E : Transported erosion (kg)
Bd : Bulk density (kg m^{-3})

$$E = EA + 9\ (EB)$$

Where:
E : The amount of erosion for a period of rain which is one day (g)
EA : Soil weight eroded in tub A (fill x g l^{-1} = g)
EB : Soil weight eroded in the tub B or drum (fill x g l^{-1} = g)

Sediment Enrichment Ratio (SER)

The value of sediment enrichment is the ratio between nutrient content and organic C in sediments to nutrient content and organic C taken from their original land (erosion plot). Sediment sampling was carried out using tub A (Figure 1) at each rain event. Examples of sediments and soil from which the laboratory was analyzed included levels of N, P, K, and organic C. Analysis of nitrogen (N) content by Kjeldahl digestion, phosphorus (P) content by Olsen, K content by ext. HCL 25%, and organic C content by Walkley Black.

Data Analysis

The data obtained from observing rainfall, runoff, soil loss, sediment enrichment values (nutrient N, P, K, and organic C), and nutrient loss

Table 1. Characteristics of soil properties in erosion plot experiment.

Soil properties	Trial plots Jali as strengthened terrace strips (Blocks I)		Trial plots Vetiver as strengthened terrace strips (Blocks II)		Trial plots Kalanjana as strengthened terrace strips (Blocks III)	
	Value	Grade rating*)	Value	Grade rating*)	Value	Grade rating*)
Soil orders	Andisols		Andisols		Andisols	
Slope (%)	17		16		15	
Texture:						
Sand (%)	39.7	Silty Sandy	40.5	Silty Sandy	41.2	Silty Sandy
Silt (%)	37.6		37.1		37.4	
Clay (%)	22.7		22.4		21.4	
Permeability (cm $hour^{-1}$)	9.15	Fairly fast	9.75	Fairly fast	10.75	Fairly fast
Bulk density (g cm^{-3})	0.82	-	0.82	-	0.82	-
pH	6.50	Neutral	6.55	Neutral	6.75	Neutral
Organic C (%)	2.95	Medium	2.84	Medium	2.93	Medium
Total N (%)	0.75	High	0.69	High	0.66	High
P_2O_5 Olsen (ppm)	5.71	Low	5.30	Low	5.07	Low
K_2O HCL 25% (me $100g^{-1}$ soil)	12.30	Low	10.35	Low	10.52	Low

Note: * Appreciation according to Pusat Penelitian Tanah Bogor (2009) through erosion were analyzed descriptively and by statistical methods. The parameters were analyzed descriptively, i.e., data on soil properties in erosion plot experiments, rainfall, sediment concentration, and soil loss. In comparison, the parameters were analyzed statistically, i.e., data runoff, soil loss, sediment enrichment ratio, and nutrient loss through erosion. We used the variance analysis (F test) to determine each treatment's influence, followed by a DMRT test level of 5%. All statistical analyses were performed using SPSS version 16.0.

RESULTS AND DISCUSSION

Characteristics of Soil Properties in Erosion Plots Experiment

The erosion plot experiments were carried out on Andisol, slope (15-17%), and the characteristics of soil properties are presented in Table 1. The plot experiment for Jali as strengthened terrace strips had silty sandy soil texture (39.7% of sand, 37.6% of silt, and 22.7% of clay), the bulk density was 0.82 g cm^{-3}, having a fast permeability (9.15 cm $hour^{-1}$), with neutral pH (6.50), and medium organic C content (2.95%), high total N nutrient content (0.75%), with low P_2O_5 Olsen/P-available (5.71 ppm), and the K_2O HCL 25%/K-total was low (12.30 me $100g^{-1}$ soil); while the plot experiment for Vetiver as strengthened terrace strips had silty sandy soil texture (40.5% of sand, 37.1% of silt, and 22.4 % of clay), the bulk density was 0.82 g cm^{-3}, having a fast permeability (9.75 cm $hour^{-1}$), with neutral pH (6.55), and medium organic C content (2.84%), high N-total nutrient content (0.69 %), with low P-available (5.30 ppm), and the K-total was low (10.35 me $100g^{-1}$ soil); and from the plot experiment for Kalanjana as strengthened terrace strips had silty sandy soil texture (41.2% of sand, 37.4% of silt, and 21.4 % of clay), the bulk density was 0.82 g cm^{-3}, having a fast permeability (10.75 cm $hour^{-1}$), with neutral pH (6.75), and medium organic C content (2.93%), high N-total nutrient content (0.66 %), with low P-available (5.07 ppm), and the K-total was low (10.52 me $100g^{-1}$ soil). The erosion plot experiments (Table 1) in Blocks I with soil texture having a sand content (39.7%) and permeability (9.15 cm hour-1) lower than in Blocks II with soil texture having sand content (40.5%) and permeability (9.75 cm hour-1), and Blocks III with soil texture having sand content (41.2%) and permeability (10.75 cm hour-1). The increasing content of the sand fraction increases soil permeability, affecting soil infiltration and reducing runoff (Tabel 2) and soil loss (Tabel 3)

Effect of Treatments on Runoff

The total rainfall observations from February to May 2016 were 1212 mm, with daily rainfall ranging from 10.0-95.0 mm day^{-1} and an average of 32.7 mm day^{-1}. Statistically speaking (DMRT test at 5% level), the treatment of maize stalks mulch did not significantly reduce the average runoff and its coefficient from the total rainfall (February to May 2016), but the more doses of mulch were applied, the less value of runoff and its coefficient were obtained (Table 2). According to Abrantes *et al.* (2018), the effect of 70% of rice straw mulch coverage significantly reduces the runoff from laboratory soil flume experiments. In this study (Figure 2), application doses of maize stalk mulch 4,

Table 2. Effects of maize stalk mulch and strengthened terrace strips on runoff values.

Treatment	Rainfall		Runoff (Rainfall from February to May 2016)					
	Total Rainfall (mm)	Rainy day (N)	Jali as strengthened terrace strips (T_J) (Blocks I) (mm)	Vetiver as strengthened terrace strips (T_V) (Blocks II) (mm)	Kalanjana as strengthened terrace strips (T_K) (Blocks III) (mm)	Average Runoff (mm) *	Runoff Coefficient Value (% Rf)	Rr (%)
M_0	1212	37	312.7	328.4	296.9	312.7^a	25.8	0
M_1	1212	37	306.6	298.2	288.4	297.7^a	24.6	4.8
M_2	1212	37	304.2	281,2	287.2	290.9^a	24.0	6.9
M_3	1212	37	296.9	266.6	281.1	281.5^a	23.2	9.9
Average*			305.1^a	293.6^a	288.4^a			

Notes: Rf : Rainfall (mm). Rr : % reduction in runoff: decrease of runoff value compared to M_0 (without mulch)
* Numbers in the same column and row followed by the same letters showed no significant difference from the DMRT (Duncan's multiple range test) standards of 5%.

Table 3. Effects of maize stalk mulch and strengthened terrace strips on soil loss values.

Treatment	Rainfall		Soil loss (Rainfall from February to May 2016)				
	Total Rainfall (mm)	Rainy day (N)	Jali as strengthened terrace strips (T_J) (Mg ha^{-1})	Vetiver as strengthened terrace strips (T_V) (Mg ha^{-1})	Kalajana as strengthened terrace strips (T_K) (Mg ha^{-1})	Average Soil loss (Mg ha^{-1})*	Re (%)
M_0	1212	37	58.03	51.56	49.05	52.88^a	0
M_1	1212	37	52.09	48.17	44.67	48.31^a	8.6
M_2	1212	37	51.60	47.11	41.55	46.75^a	11.6
M_3	1212	37	49.43	37.90	36.49	41.27^a	21.9
Average *			52.78^a	46.18^a	42.94^a		

Notes: Re: % reduction in erosion decrease of runoff value compared to M_0 (without mulch)
* Numbers in the same column and row followed by the same letters showed no significant difference from the DMRT (Duncan's multiple range test) standards of 5%.

8, and 12 Mg ha^{-1} could only cover the soil surface by 10-15%, 25-30%, and 45-55%, respectively; so more than 12 Mg ha^{-1} doses of maize stalk mulch are needed in order to reduce the runoff significantly. Table 2 shows that the combination treatment of strengthened terrace strips (0-4 months) with M3 (maize stalks mulch 12 Mg ha^{-1}) was able to reduce runoff (9.9%) compared to M0 (without mulch/ maize stalks mulch 0 Mg ha^{-1}), followed by M2 treatment (maize stalk mulch 8 Mg ha^{-1}) was able to reduce runoff (6.9%), and the M1 treatment (maize stalk mulch 4 Mg ha^{-1}) reduced the runoff (4.8%). Suyana (2012) concluded that the treatment of tobacco stems mulch at a dose of 14 Mg ha^{-1}, Setaria spacelata grass on bench terraces (in Entisol), and broad base terraces (in Alfisol) significantly reduced the runoff by 31.6-36.7% compared with those without mulch. The treatment of maize stalk mulch at a dose of 8 Mg ha^{-1} with three types of strengthened terrace strips (Jali, Setaria, and Vetiver) on traditional terraces (in Alfisol) reduced runoff by 10.2-16.3% (Suyana *et al.* 2017). Moreover, applying maize stalk mulch at a dose of 12 Mg ha^{-1} on cabbage and red beans reduced runoff by 5.1-5.2% (Suyana *et al.* 2019). According to Baptista *et al.* (2015), the influence of mulch residue plants could increase the soil cover by providing physical barriers which restrain the runoff, decrease its speed, and eventually increase the soil infiltration capacity. Straw mulch protection can control the splash of rain, the power of soaking runoff flow, its speed, and increase the infiltration (Mulumba and Lal 2008), and also plant residues would have an indirect effect of increasing porosity and soil sorptivity through improved soil aggregation (Shaver *et al.* 2013).

According to Mulumba and Lal (2008), mulching plant residues can increase the infiltration, the levels of soil moisture, and available water capacity (AWC) in the field. Table 2 shows that the highest average runoff value was in Jali as strengthened terrace strips (T_J)/Blocks I, followed by Vetiver as strengthened terrace strips (T_V)/Blocks II, and Kalanjana as strengthened terrace strips (T_K)/Blocks III. Such thing was caused by soil properties from erosion plot experiments (Table 1) in Blocks I (17% land slope) with soil texture having a sand content (39.7%) and permeability (9.15 cm hour^{-1}) lower than in Blocks II (16% land slope) with soil texture having sand content (40.5%) and permeability (9.75 cm hour^{-1}), and Blocks III (15% land slope) with soil texture having sand content (41.2%) and permeability (10.75 cm hour^{-1}). In addition to the lower slope of the land, increasing the value of soil permeability (in Blocks II and Blocks III) will increase the speed of water entering the soil (infiltration), thereby reducing the portion of rainwater that becomes surface runoff. Besides this, Kalanjana grass has a faster growth rate than Vetiver and Jali (Figure 3). With faster growth in Kalanjana, strengthened terrace strips can further reduce the runoff rate and allow runoff water to seep into the ground (infiltration). Kalanjana grass grows densely, spreads, and has thick and deep fibrous roots. The protection of strengthened terrace vegetation and plant residue mulch can control rain splash, runoff soaking capacity, and runoff mass flow (Baptista *et al.* 2014), decrease runoff velocity, as well as increase infiltration, the levels of soil moisture, and available water capacity (AWC) in the field, total porosity, and soil aggregation (Mulumba and Lal 2008).

Effect of Treatments on Soil Loss

The erosion rate induced by the combination treatment of maize stalk mulch and strengthened terrace strips (0-4 months) on cabbage plants is presented in Table 3. Statistically speaking, the combination treatment of maize stalk mulch and strengthened terrace strips did not significantly reduce the soil loss from the total rainfall that occurred from February to May 2016, but more mulch doses caused the soil erosion to decrease. According to Sinukaban (2007b), the effect of 60% of straw mulch coverage significantly reduces the soil loss from cropping pattern ground nuts, field corn, and rice-ground nuts; while the effect of 90% of straw mulch coverage significantly reduces the soil loss from cropping pattern rice-field corn. 50% and 70% of rice straw mulch coverage significantly reduce the soil loss from laboratory soil flume experiments (Abrantes *et al.* 2018). In this study (Figure 2), application doses of maize stalk mulch 4, 8, and 12 Mg ha^{-1} could only cover the soil surface by 10-15%, 25-30%, and 45-55%; so more than 12 Mg ha^{-1} doses of maize stalk mulch are needed in order to reduce the soil loss significantly. Table 3 shows that the combination treatment of strengthened terrace strips (0-4 months) with M3 compared to M0 (without mulch) was able to reduce erosion by 21.9%, followed by M2 treatment was able to reduce erosion by 11.6%, and M1 treatment was able to reduce erosion by 8.6%. Based on Suyana (2012), the combination treatment of tobacco stems mulch at a dose of 14 Mg ha^{-1}, Setaria spacelata grass on bench terraces (in Entisol), and broad base terraces (in Alfisol) significantly reduced the erosion by 30.6-42.9% compared with those without mulch. The combination treatment of maize stalk mulch at a dose of 8 Mg ha^{-1} with three types of strengthened terrace strips (Jali, Setaria, and Vetiver) on traditional terraces (in Alfisol) reduced erosion by 25.9-31.2% (Suyana *et al.* 2017). Applying maize stalk mulch at a dose of 12 Mg ha^{-1} on cabbage and red beans reduced erosion by 25.6-26.5% (Suyana *et al.* 2019). Plant residual mulch prevents soil erosion by creating a cover that protects the soil (Díaz-Ravina *et al.* 2012). Arsyad (2010) argued that the effectiveness of mulch residues in suppressing erosion depends mainly on the amount and power of mulch materials in the decomposition process and the percentage of soil covered by mulch material. Sinukaban *et al.* (2007a) asserted that the mulch cover of rice straw is greater or equal to 60%, which reduces erosion by at least 54%, and the closure of straw mulch restrains the erosion by 30%, which can only be suppressed by 37%. The treatment of residual plant mulch can control rain splashes, runoff, and runoff mass flow (Baptista *et al.* 2015) and reduce sediment concentration and soil loss (Sadeghi *et al.* 2015a; Sadeghi *et al.* 2015b). Such thing was caused by the plant residual mulch which was spread on the soil surface meant to thwart raindrops energy that falls into the ground, and as a result, the rain was suppressed by the mulch so that the soil would be not washed away and transported by runoff. Also, mulch scattered above the surface of the ground slowed down the speed of runoff while reducing the destructive power and carrying capacity of runoff (Suyana 2012; Suyana *et al.* 2019).

Table 3 also shows that the highest average soil loss was in Jali as strengthened terrace strips (T_J)/Blocks I, followed by Vetiver as strengthened terrace strips (T_V)/Blocks II, and Kalanjana as strengthened terrace strips (T_K)/Blocks III. Such thing was caused by soil properties from erosion plot experiments (Table 1) in Blocks I (17% land slope) with soil texture having a sand content (39.7%) and permeability (9.15 cm hour^{-1}) lower than in Blocks II (16% land slope) with soil texture having sand content (40.5%) and permeability (9.75 cm hour^{-1}), and Blocks III (15% land slope) with soil texture having sand content (41.2%) and permeability (10.75 cm hour^{-1}). In addition to the lower slope of the land, increasing the value of soil permeability (in Blocks II and Blocks III) will increase the speed of water entering the soil (infiltration), thereby reducing the portion of rainwater that becomes surface runoff and ultimately reducing soil loss. Besides this, Kalanjana grass grows faster than Vetiver and Jali (Figure 3). With the growth of Kalanjana grass, which is faster, grows densely and spreads out, and has thick fibrous roots, it will further reduce runoff, filter soil particles carried by runoff, and reduce erosion and landslides (Suyana 2012). Many researchers have also published the effectiveness of the combination treatment of crop residue mulch and strengthened terrace strips in reducing erosion rates. Mulching can control runoff and soil loss by protecting the surface and reducing sediment concentration and soil loss (Mulumba and Lal 2008; Sadeghi *et al.* 2015). The protection of mulch and strengthened terrace vegetation can control rain splash, runoff soaking capacity, and runoff mass flow. This finding corresponds to the report undertaken by Morgan (2005), which asserted that the average annual sediment yield correlates positively with the annual rainfall. The effect of residual crop mulch not only reduces the volume of runoff but also changes the erosion and runoff relationships. There are many interrelated factors, such as rain erosivity and soil cover rate, where the level of soil cover is the main factor, followed by rainfall. The level of soil cover and soil properties (soil texture and permeability) will then affect the infiltration rate, runoff, and soil loss (Baptista *et al.* 2015).

Effects of Maize Stalk Mulch on Sediment Enrichment Ratio (SER)

The sediment concentrations in runoff and nutrients N, P, K, and organic C washed away by erosion from the combined treatment of maize stalks mulch and strengthened terrace strips are presented in Tables 4 and 5 and Figure 4. Statistically, the combination treatment of maize stalks mulch and strengthened terrace strips had not significantly increased the value of sediment enrichment (SER) at doses of 4, 8, and 12 Mg ha^{-1} for N, K, and

Table 4. Effect of maize stalks mulch on sediment concentration and sediment enrichment ratio (SER) on strengthened terrace strips of Jali, Vetiver, and Kalanjana.

Treatment	Sediment concentration on jali as strengthened terrace strips (g l^{-1})	N	Value of sediment enrichment ratio (SER) on jali as strengthened terrace strips			
			N *	P *	K *	Organic C *
M_0	18.56	12	1.06^a	2.01^a	1.01^a	1.04^a
M_1	16.98	12	1.09^a	2.20^a	1.08^a	1.07^a
M_2	16.96	12	1.11^a	2.28^a	1.27^a	1.12^a
M_3	16.64	12	1.12^a	2.53^a	1.53^a	1.21^a
Average	17.29		1.10	2.26	1.22	1.11
Treatment	Sediment concentration on vetiver as strengthened terrace strips (g l^{-1})	N	Value of sediment enrichment ratio (SER) on vetiver as strengthened terrace strips			
			N *	P *	K *	Organic C *
M_0	15.70	12	1.11^a	2.06^a	1.15^a	1.09^a
M_1	16.15	12	1.15^a	2.35^a	1.29^a	1.07^a
M_2	16.75	12	1.18^a	2.53^a	1.31^a	1.22^a
M_3	14.21	12	1.24^a	2.81^a	1.58^a	1.24^a
Average	15.72		1.17	2.44	1.33	1.16
Treatment	Sediment concentration on kalanjana as strengthened terrace strips (g l^{-1})	N	Value of sediment enrichment ratio (SER) on kalanjana as strengthened terrace strips			
			N *	P *	K *	Organic C *
M_0	16.52	12	1.03^a	2.21^a	1.02^a	1.02^a
M_1	15.48	12	1.11^a	2.67^a	1.08^a	1.04^a
M_2	14.46	12	1.12^a	3.65^b	1.34^a	1.09^a
M_3	12.98	12	1.18^a	3.67^b	1.50^a	1.14^a
Average	14.88		1.11	3.05	1.24	1.07

Notes: SER: Comparison of concentration between elements in sediments and concentration of these elements obtained from their origin soil. * The numbers in the same column followed by the same letters had no significant difference in DMRT (Duncan's multiple range test) standards of 5%.

Table 5. Effect of maize stalks mulch on sediment concentration and value of sediment enrichment ratio (SER)

Treatment	Sediment concentration (g l^{-1})	N	Value of sediment enrichment ratio (SER)			
			N *	P *	K *	Organic C *
M_0	17.59	36	1.07^a	2.09^a	1.06^a	1.05^a
M_1	16.20	36	1.12^a	2.41^a	1.15^a	1.06^a
M_2	15.72	36	1.14^a	2.82^{ab}	1.31^a	1.14^a
M_3	14.61	36	1.18^a	3.01^b	1.54^a	1.19^a
Average	15.96		1.23	2.58	1.26	1.11

Notes: SER: Comparison of concentration between elements in sediments and concentration of these elements obtained from their origin soil. * The numbers in the same column followed by the same letters had no significant difference in DMRT (Duncan's multiple range test) standards of 5%.

organic C nutrients; but for P nutrients significantly increased SER values at doses of 8 and 12 Mg ha^{-1} for Kalanjana strengthened terrace strips (Table 4) and at doses of 12 Mg ha^{-1} (Table 5). The enormity of SER value is influenced by factors that, in turn, affect the destruction of soil aggregates into primary particles and runoff (Arsyad 2010) and the process of selective erosion (Sinukaban 1981). If runoff becomes slow due to dense crop cover or a massive amount of residual plants scattered on the ground, thus, erosion selectivity will be tremendous, as well as the SER value (Arsyad 2010).

Table 4 shows the SER value for N nutrients amounting to 1.03-1.24, with P nutrients of 2.01 - 3.67, K of 1.01-1.58, and organic C of 1.04-1.24. Meanwhile, Table 5 also shows the SER values for N nutrients amounting to 1.07-1.18, with P nutrients of 2.09-3.01, K nutrients of 1.06-1.54, and organic C of 1.05-1.19. Gachene et al. (1997), from an experiment undertaken at the erosion research station in the Faculty of Agriculture and Veterinary Science, University of Nairobi, Kenya, obtained an SER value with an average of N of 1.10 and P 5.25 (3.47-10.36), K for 1.96, and organic C averaging 1.22 (1.09-1.32), and for Ca and Mg showing 1.12, and for Na the average is 2.10 (1.14-3.33). Meanwhile, the results of the research by Sinukaban and Adnyana (2007) from the experiment of giving straw mulch in Alfisol obtained SER values for P nutrients of 8.96-17.40, K nutrients of 1.20-3.00, and organic C of 1.41-2.93.

The overall results showed that the increase in mulch doses caused sediment concentrations in the runoff to decrease (Tables 4 and 5), but on the other hand, the SER values tended to increase (Tables 4 and 5, Figure 4). Sinukaban (2007a) and Sinukaban and Adnyana (2007) assert that increasing mulch doses causes more selective erosion on fine soil particles. Adding more mulch on the surface will slow down the runoff and which in turn causes the runoff transporting capacity to decrease. Such a move has caused rough sediment to be deposited behind the mulch, but fine sediments such as clay and colloids were still washed away by runoff. In other words, adding more mulch doses in the treatment would bring about a more selective runoff for clay-sized and colloidal sediments (Sinukaban 1981). Since these fine sediments (clay and colloid) are more active in binding organic C and nutrients, adding mulch dose would eventually trigger an

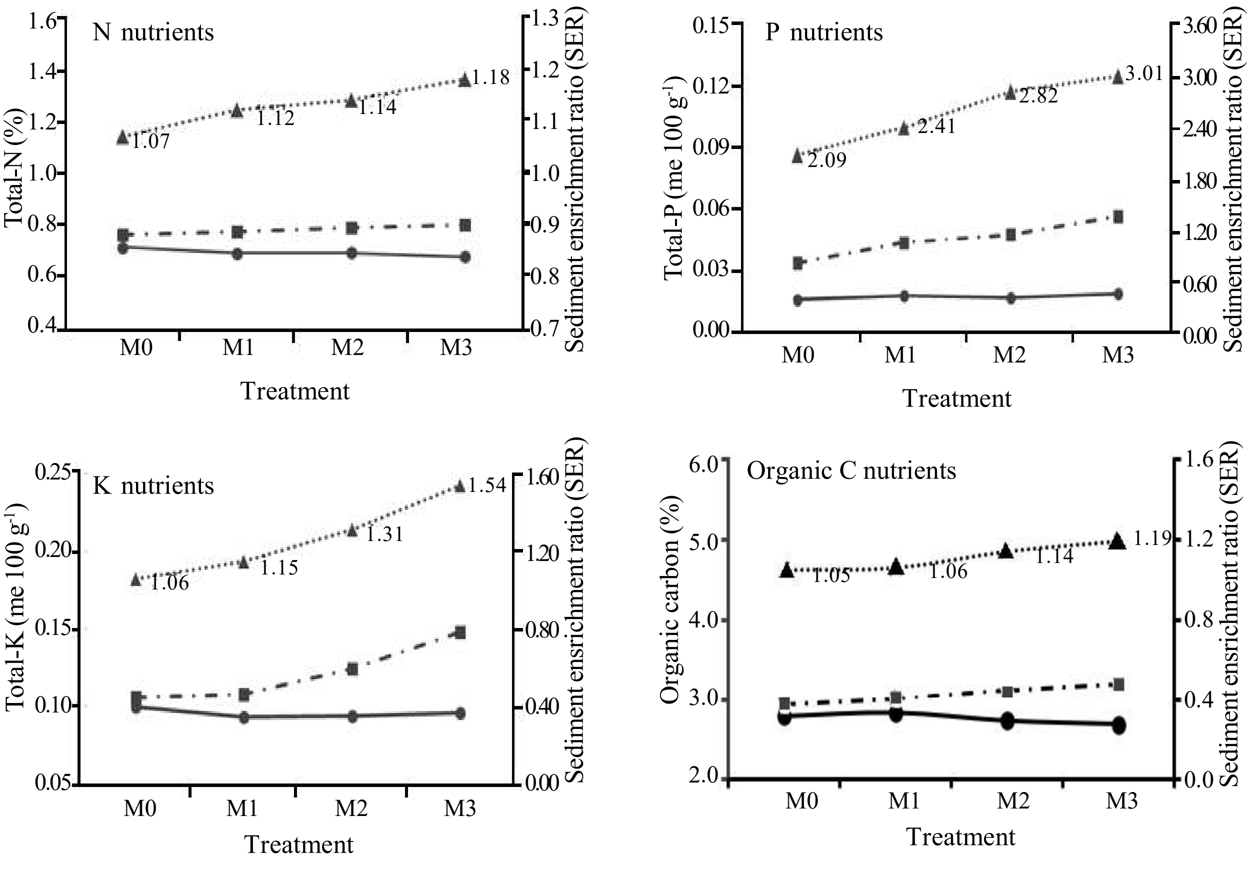

Figure 4. Soil nutrients in eroded soil, in sediment, and value of sediment enrichment ratio (SER). —●—: Eroded soil, –■–: sediment soil, ···▲···: SER.

erosion (sediment) that contains higher organic C concentrations and nutrients.

Effects of Maize Stalk Mulch on Nutrient Loss Through Erosion

Sinukaban (2007a) that giving straw mulch (30, 60% of straw mulch coverage) in Alfisol tends to decrease the N, P, K, Mg, and Organic C nutrients loss through erosion but tends to increase when given the straw mulch (90% of straw mulch coverage) for P, K, and Mg nutrients. Statistically speaking, the treatment of maize stalk mulch did not significantly reduce nutrient loss through erosion. Following Sinukaban (2007b), the effect of straw mulch coverage (30%, 60%, and 90%) did not significantly affect the total nutrient loss through erosion or loss of soil fertility constituents (P, Ca, and Organic-C). Tables 6 and 7 show that increasing doses of mulch causing soil loss, N and Organic C of nutrient loss through erosion tend to decrease. While the P and K of nutrients lost through erosion did not decrease and even tended to increase/

Table 6. Effect of maize stalks mulch on soil loss and nutrient loss through erosion on strengthened terrace strips of Jali, Vetiver, and Kalanjana.

Treatment	Soil loss ($Mg\ ha^{-1}$)	Value of nutrient loss through erosion on jali as strengthened terrace strips ($kg\ ha^{-1}$)			
		N*	P*	K*	Organic C*
M_0	58.03	388.80[a]	19.73[a]	61.51[a]	1702.01[a]
M_1	52.09	359.42[a]	22.91[a]	56.25[a]	1567.38[a]
M_2	51.60	366.36[a]	24.76[a]	63.98[a]	1609.92[a]
M_3	49.43	360.84[a]	28.17[a]	73.15[a]	1.584.72[a]
Average	52.78	368.86	23.89	63.72	1616.01
Treatment	Soil loss ($Mg\ ha^{-1}$)	Value of nutrient loss through erosion on vetiver as strengthened terrace strips ($kg\ ha^{-1}$)			
		N*	P*	K*	Organic C*
M_0	51.56	345.45[a]	17.53[a]	54.65[a]	1512.25[a]
M_1	48.17	332.37[a]	21.19[a]	52.02[a]	1449.43[a]
M_2	47.11	334.48[a]	22.61[a]	58.41[a]	1469.83[a]
M_3	37.90	276.67[a]	21.60[a]	56.09[a]	1215.07[a]
Average	46.18	322.24	20.73	55.29	1411.64
Treatment	Soil loss ($Mg\ ha^{-1}$)	Value of nutrient loss through erosion on kalanjana as strengthened terrace strips ($kg\ ha^{-1}$)			
		N*	P*	K*	Organic C*
M_0	49.05	328.63[a]	16.67[a]	51.99[a]	1438.63[a]
M_1	44.67	308.22[a]	19.65[a]	48.24[a]	1344.12[a]
M_2	41.55	295.01[a]	19.94[a]	51.52[a]	1296.36[a]
M_3	36.49	266.37[a]	20.79[a]	54.01[a]	1169.86[a]
Average	42.94	299.56	19.26	51.44	1312.24

Note: *The numbers in the same column followed by the same letters had no significant difference in DMRT (Duncan's multiple range test) standards of 5%.

Table 7. Effect of maize stalks mulch on soil loss and nutrient loss through erosion.

Treatment	Soil loss ($Mg\ ha^{-1}$)	N	Value of nutrient loss through erosion ($kg\ ha^{-1}$)			
			N*	P*	K*	Organic C*
M_0	52.88	36	354.29[a]	17.97[a]	56.05[a]	1550.96[a]
M_1	48.31	36	333.34[a]	21.25[a]	52.17[a]	1453.64[a]
M_2	46.75	36	331.95[a]	22.43[a]	57.97[a]	1458.70[a]
M_3	41.27	36	301.29[a]	23.52[a]	61.08[a]	1323.21[a]
Average	47.30		330.22	21.29	56.81	1446.63

Note: *The numbers in the same column followed by the same letters had no significant difference in DMRT (Duncan's multiple range test) standards of 5%.

fluctuate, this was due to the decrease in erosion value due to mulching of 8.6-21.9% (Table 3), while the SER value of P nutrients (1.77-3, 67) and K (1.01-1.58) (Table 4).

Mulching decrease the amount of soil eroded, although the nutrient concentration in the sediment increases.

The overall results showed that the increase in mulch doses caused the sediment enrichment ratio (SER value) tended to increase (Table 4), but the number of nutrient losses through erosion tended to decrease, primarily N and Organic C nutrients (Table 7). With the decrease in nutrient loss through erosion due to the application of maize stalks mulch, crop residue mulch can be a conservation technique to reduce nutrient pollution (especially N and Organic C nutrients) in reservoirs/lakes and rivers.

CONCLUSIONS

The combination treatment of strengthened terrace strips and maize stalk mulch to a dose of 12 Mg ha^{-1} has not significantly reduced runoff and soil loss. It takes a dose of maize stalk mulch of more than 12 Mg ha^{-1} to reduce the runoff and soil loss significantly. A mulch dose of 12 Mg ha^{-1} could decrease runoff and soil loss by 9.9% and 21.9%, a mulch dose of 8 Mg ha^{-1} decreased runoff and soil loss by 6.9% and 11.6%, and a mulch dose of 4 Mg ha^{-1} decreased runoff and soil loss of 4.8% and 8.6% compared to soil without mulch. The application of maize stalk mulch tends to reduce the sediment concentration but increases the nutrient concentration in sediments (SER value). In addition, applying maize stalk mulch also tends to reduce a nutrient loss (N and Organic C) through erosion.

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