THE EFFECTIVENESS OF MAIZE STALKS MULCH ON RUNOFF, EROSION, SEDIMENT ENRICHMENT RATIO (SER), AND THE GROWTH OF CABBAGE AND RED BEANS IN ANDISOLS, CENTRAL JAVA, INDONESIA†

[LA EFECTIVIDAD DEL MANTILLO DE TALLO DE MAÍZ EN LA ESCORRENTÍA, LA EROSIÓN, LA RELACIÓN DE ENRIQUECIMIENTO DE SEDIMENTOS (RES), Y EL CRECIMIENTO DE REPOLLO Y FRIJOLES ROJOS EN ANDISOLES, JAVA CENTRAL, INDONESIA]

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SUMMARY

Mulching technology is not only easy for farmers to use but it can also reduce soil erosion and increase plant growth. This research aimed to observe the effectiveness of maize stalk mulch on runoff, erosion, sediment enrichment ratio (SER), and plant growth. The experiment was carried out on upland farming in Andisols at the beginning of the dry season (April to June 2015). Mulch treatment was undertaken on bench terraces farms with doses of 0, 4, 8, and 12 tons ha^{-1} on 2 types of plants (cabbage and red beans). Maize mulch application has not significantly reduced runoff and erosion. The mulch dose of 12 tons ha^{-1} reduced runoff and erosion by 5.1-5.2% and 25.6-26.5% compared to soil without mulch. The spread of maize stalks mulch reduced sediment concentration but increased the nutrient concentration in sediments (SER value). The application of 12 tons ha^{-1} of maize stalks mulch increased the cabbage fresh weight by 33.5% and the red beans dry weight by 41.4%.

Keywords: Erosion; soil nutrient; mulch; crop residues; upland

RESUMEN

La tecnología de mantillo no solo es fácil de usar para los agricultores, sino que también puede reducir la erosión del suelo y aumentar el crecimiento de las plantas. El objetivo de esta investigación fue observar la efectividad del uso de mantillo con tallo del maíz en la escorrentía, la erosión, la relación de enriquecimiento de sedimentos (RES) y el crecimiento de las plantas. El experimento se llevó a cabo en la agricultura de tierras altas en Andisoles al comienzo de la estación seca (abril a junio de 2015). El tratamiento con mantillo se llevó a cabo en granjas con terrazas con dosis de 0, 4, 8 y 12 toneladas ha^{-1} en 2 tipos de plantas (repollo y frijoles rojos). La aplicación de mantillo de maíz no redujo la escorrentía y la erosión. La dosis de mantillo de 12 toneladas ha^{-1} redujo la escorrentía y la erosión en 5.1-5.2% y 25.6-26.5% en comparación con el suelo sin mantillo. La distribución del mantillo de los tallos de maíz redujo la concentración de sedimentos pero aumentó la concentración de nutrientes en los sedimentos (valor RES). La aplicación de 12 toneladas ha^{-1} de mantillo de tallos de maíz aumentó el peso fresco de la col en un 33.5% y el peso seco de los frijoles rojos en un 41.4%.

Palabras clave: Erosión; nutrientes del suelo; mantillo; residuos de cultivos; tierras altas.

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INTRODUCTION

Erosion is a serious problem worldwide, human activity in land management is a major cause of accelerating erosion. According to Morgan (2005), the damage caused by erosion occurs in two places, namely on land where erosion is (on-site) and at a place where transported land is deposited (off-site). Soil erosion costs the US economy between US$30 billion (Uri and Lewis,1988) and US$44 billion (Pimental *et al.*, 1993) per year. In Indonesia, the cost is US$400 million per year in Java alone (Magrath and Arens, 1989).

Erosion in developing countries, because of land-use changes at large scales without considering land capabilities (Sadeghi *et al*., 2015a). Land degradation due to erosion in Indonesia also continues to increase, especially in upstream areas (Abdurrachman, 2008; Wahyunto and Dariah, 2014). For the past fifty years and beyond, the pressure on population has encouraged farmers to exploit the land which is categorized in classes VI, VII, VIII, and resulting in land degradation in several upper watersheds in Central Java, including Serang sub-watershed (Suyana and Muliawati, 2014), and Progo Hulu sub-watershed (Suyana, 2012) due to fast erosion (106.63 tons ha^{-1} $year^{-1}$ or 8.8 mm $year^{-1}$) which was much bigger than the tolerable soil loss (33.40 tons 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 soil texture to be rougher, and soil structure denser (Abdurrachman, 2008), the decrease of soil organic C, less soil respiration and a quick loss of N which is faster than C or the increase of C/N value (Traorea *et al*., 2015).

In general, it is clear that land degradation causes stock depletion of soil organic C (SOC) and soil organic N (SON), increase in soil bulk density, 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 reducing productivity and reducing their 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/or 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 stonewalls 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).

Baptista *et al*. (2015) asserted that the main strategy of soil and water conservation technology focuses on the construction of rural structures that inhibit surface flow and increase infiltration, including the implementation of a series of actions both in mechanical and biological structures. According to Abdurrachman (2008), many vegetative methods are recommended in soil and water conservation technology uses because it can reduce erosion and guarantee increasing land productivity, cheap and easy for farmers to implement. Zougmore *et al*. (2003) proposed the 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. Mulching is the covering of the soil with crop residues such as straw, maize stalks, palm fronds or standing stubble (Morgan, 2005). The purpose of this study was to observe the effectiveness of maize stalk mulch treatment on runoff, erosion, sediment enrichment ratio (SER), and the growth of cabbage and red bean plants 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 7º44'44.60'' S and 111º11'2.89'' E with an elevation of 1,193 m asl. The research was conducted within the dry season (April to September) during three months at the beginning of the dry season (April to June 2015), on Andisols with a slope of 15%.

Materials and research tools

The materials used in this study include materials for erosion plots manufacture, soil collector and drums, rain gauge, cabbage seedlings, red bean seeds, 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 site which will be analyzed at the laboratory, including observation of rainfall data, runoff, soil loss, organic C levels and nutrients (N, P, K) in sediments and their origin (plot experiment), weeds, and plant growth and yields.

The erosion plot experiments were chosen in length (15m) and width (5m) on land set on bench terraces with a slope of 15%. The erosion plot experiment was arranged in a Randomized Block Design (RBD), using 4 doses of maize stalks mulch (0, 4, 8 and 12 tons ha^{-1}) and 2 types of plants (cabbage and red beans) put in groups/blocks, giving 8 experiments in total as presented in Figure 1. There are treatments on 4 doses of maize stalk mulch, which include:

T-M0 = bench terrace + maize stalk mulch 0 tons ha^{-1} (without mulch)
T-M1 = bench terrace + maize stalk mulch 4 tons ha^{-1}
T-M2 = bench terrace + maize stalk mulch 8 tons ha^{-1}
T-M3 = bench terrace + maize stalk mulch 12 tons ha^{-1}

The mulching application was obtained from the remains of maize stalks cut in 20 cm long, and then spread evenly on the soil surface in accordance with the treatment dose (Figure 2), and then immediately applied once the cabbage seeds and red bean seeds are planted on the plot experiment.

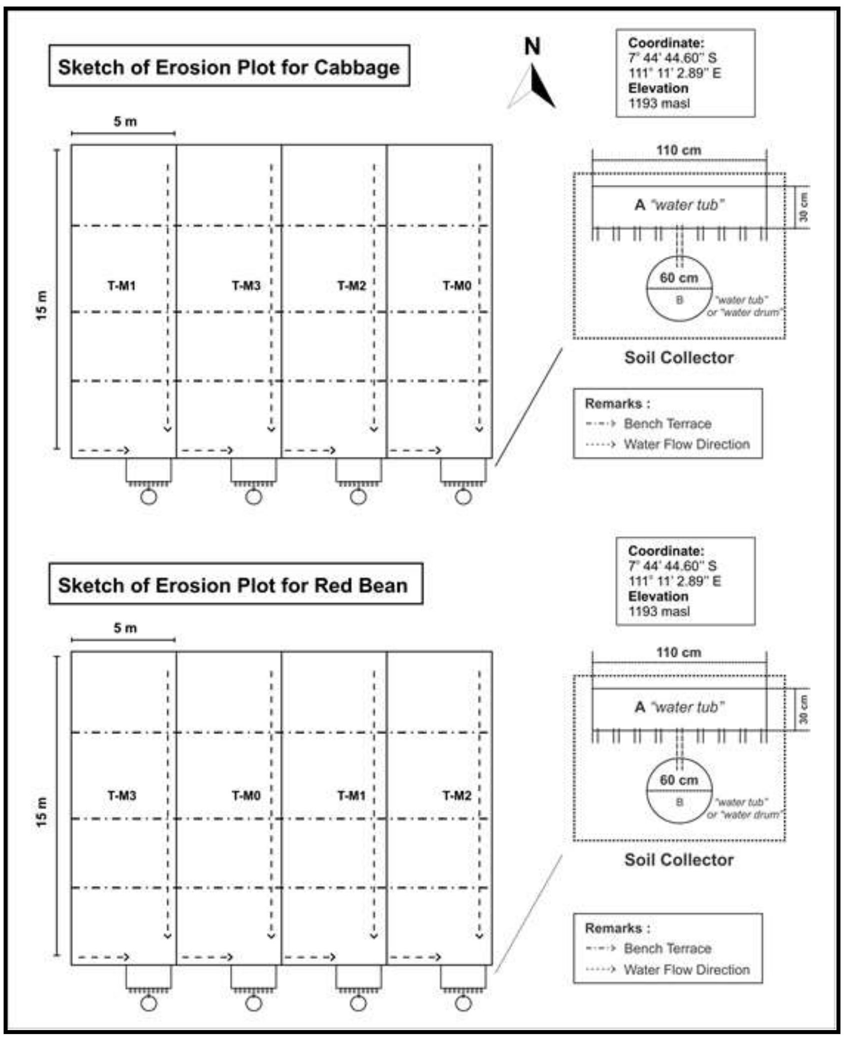


Figure 1. A Sketch of erosion plot experiments for cabbage and red beans.

Doses of maize stalk mulch 0, 4, 8, 12 tons ha^{-1} applied on cabbage (from left to right)

The dosage of maize stalks mulch 0, 4, 8, 12 tons ha^{-1} applied on red beans (from left to right)

Figure 2. Application of maize stalk mulch on cabbage and red beans.

Data collection and calculations

Soil properties in erosion plots. The observation of land 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, pH meter was used to measure the soil pH, Kjeldahl digestion for nitrogen (N) content, Olsen for phosphorus (P) content, K content by ext. 25% HCl, and Walkley Black was used for organic C content.

Rainfall, runoff, and erosion. The observation of rainfall data, runoff and erosion were carried out each time it rained during April to June 2015. Rainfall data were obtained from rain gauge Ombrometer. 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 equations:

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

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 the 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). Sediments sampling was carried out using a 'gutter'/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. Nitrogen (N) analysis content by Kjeldahl digestion, phosphorus (P) content by Olsen, K content by ext. HCL 25% and organic C content by Walkley Black.

Data on plant growth. The data of cabbage plant growth (3 months old) and red beans (75 days old) are: (a) the height and plant canopy was observed every 2 weeks, (b) the cabbage crop yields include: weight of fresh and dry cabbage, (c) the yields of red bean plants include: plant stems dry weight, pod dry weight, bean dry weight, and (d) weeds dry weight.

Data analysis

The data obtained from the observation of rainfall, runoff, soil loss, sediment enrichment values (nutrient N, P, K, and organic C), the growth of cabbage and red beans (height, canopy, crop yields), and weeds were analyzed descriptively. We used the variance analysis (F test) to find out the influence of each treatment, followed by DMRT test level of 5%. All statistical analyses were performed using SPSS 16.0.

RESULTS AND DISCUSSION

Characteristics of soil properties in erosion plots experiment

The erosion plot experiments were carried out on Andisol, and the characteristics of soil properties were presented in Table 1. The plot experiment for cabbage plants 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 (2.95%), high N-total nutrient content (0.75%), with medium P-total (0.019 me $100g^{-1}$ soil), and low availability of P (5.71 ppm), the K-total was low (0.098 me $100g^{-1}$ soil), while the plot experiment for red beans had silty sandy soil texture (40.5% of sand, 37.1% of silt, and 22.4% of clay), and the bulk density was 0.82 g cm^{-3}, having a fast permeability (10.75 cm $hour^{-1}$), and the neutral pH (6.75), with medium organic C (2.84%), and high N-total nutrient content (0.69%), with medium P-total (0.019 me/100g soil), and low availability of P (5,07 ppm), and the K-total was very low (0.093 me $100g^{-1}$ soil).

Effect of treatments on runoff

The total of rainfall observations from April to June 2015 was 318.5 mm with daily rainfall ranging from 3.0-65.0 mm day^{-1} and an average of 26.5 mm day^{-1}. Statistically speaking, (DMRT test at 5% level) the treatment of maize stalks mulch in cabbage plants did not significantly reduce the average runoff and its coefficient from daily rainfall and the total of rainfall (from April to June 2015), but the more doses of mulch was applied, the less value of runoff and its coefficient were obtained (Table 2). The T-M3 treatment (bench terrace + maize stalks mulch of 12 tons ha^{-1}) was able to reduce the runoff (5.1%) compared to T-M0 (bench terrace + maize stalks mulch 0 tons ha^{-1}), followed by T-M2 treatment (bench terrace + 8 tons ha^{-1} of maize stalks mulch) which was also able to reduce the runoff (2.3%), and the T-M1 treatment (bench terrace + maize stalks mulch 4 tons ha^{-1}) reduced the runoff (2.1%). The same with the red bean plants, statistically speaking, the maize stalks mulch treatment did not significantly reduce the mean runoff and its coefficient from daily rainfall events and the total of rainfall (during April to June 2015), but the more doses of mulch was applied, the less value of runoff and its coefficient were obtained (Table 3). The T-M3 treatment was able to reduce the runoff (5.2%) compared to T-M0 (without mulch), followed by the T-M2 treatment which was, in turn, able to reduce the runoff (3.1%), and the T-M1 treatment reduced the runoff (2.8%). This corresponds to the research results of Suyana (2012; Suyana, 2014), which was the treatment of tobacco mulch at a dose of 14 tons ha^{-1} on bench terraces that significantly reduced the runoff by 31.6-36.7% compared with those without mulch. 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).

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

Soil properties	Trial plots cabbage		Trial plots red beans	
	Value	Grade rating*	Value	Grade rating*
Soil orders	Andisols		Andisols	
Texture:				
Sand (%)	39.7	Silty sandy	40.5	Silty sandy
Silt (%)	37.6		37.1	
Clay (%)	22.7		22.4	
Permeability (cm $hour^{-1}$)	9.15	Fairly fast	10.75	Fairly fast
Bulk density (g cm^{-3})	0.82	-	0.82	-
pH	6.50	Neutral	6.75	Neutral
Organic C (%)	2.95	Medium	2.84	Medium
N total (%)	0.75	High	0.69	High
P total (me $100g^{-1}$ soil)	0.019	Medium	0.019	Medium
P available (ppm)	5.71	Low	5.07	Low
K total (me $100g^{-1}$ soil)	0.098	Very Low	0.093	Very Low

*Appreciation according to Bogor soil research center (2005)

Table 2. Effects of maize stalk mulch on runoff value in cabbage plants.

Treatment	N	Runoff (Daily rainfall)			Runoff (Rainfall from April to June 2015)			
		Rainfall Average (mm)	Runoff Average (mm) *	Runoff coefficient value (% Rf) *	Rf (mm)	Runoff (mm) *	Runoff coefficient value (% Rf) *	Rr (%)
T-M0	12	26.5	6.84[a]	21.1[a]	318.5	82.11[a]	25.8[a]	0
T-M1	12	26.5	6.70[a]	20.7[a]	318.5	80.43[a]	25.3[a]	2.1
T-M2	12	26.5	6.69[a]	20.6[a]	318.5	80.22[a]	25.2[a]	2.3
T-M3	12	26.5	6.49[a]	20.0[a]	318.5	77.93[a]	24.5[a]	5.1
Average	12	26.5	6.68	20.6	318.5	80.17	25.2	
SEM		2.1	0.73	1.6		7.31	1.9	

Rf : Rainfall
Rr : % reduction in runoff: decrease of runoff value compared to T-M0 (without mulch)
* Numbers in the same column 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 on runoff values in red bean plants.

Treatment	N	Runoff (Daily rainfall)			Runoff (Rainfall from April to June 2015)			
		Rainfall Average (mm)	Runoff Average (mm) *)	Runoff coefficient value (% Rf) *)	Rf (mm)	Runoff (mm) *)	Runoff coefficient value (% Rf) *)	Rr (%)
T-M0	12	26.5	6.50[a]	18.4[a]	318.5	78.03[a]	24.5[a]	0
T-M1	12	26.5	6.32[a]	17.9[a]	318.5	75.87[a]	23.8[a]	2.8
T-M2	12	26.5	6.29[a]	17.8[a]	318.5	75.58[a]	23.7[a]	3.1
T-M3	12	26.5	6.17[a]	17.4[a]	318.5	73.97[a]	23.2[a]	5.2
Average		26.5	6.32	17.9	318.5	75.86	23.8	
SEM		2.1	0.80	1.4		7.94	1.8	

Rf : Rainfall
Rr : % reduction in runoff: decrease of runoff value compared to T-M0 (without mulch)
* Numbers in the same column followed by the same letters showed no significant difference from the DMRT (Duncan's multiple range test) standards of 5%.

In general, the magnitude of daily runoff is positively correlated with daily rainfall (Figure 3). The level of daily runoff increases the daily rainfall, and which was also influenced by the soil moisture content before the raindrops (Figure 4). The treatment of plant residual mulch can increase the infiltration, the levels of soil moisture and available water capacity (AWC) in the field (Mulumba and Lal, 2008). As shown in Table 2 & 3 and Figure 3 that cabbage plants experienced an average runoff coefficient value for daily rainfall events (20.6%) and as far as the rainfall obtained during April to June 2015 (25.2%) was concerned, it was higher compared to red bean plants which had an average runoff coefficient value for daily rainfall events (17.9%) and rainfall during April to June 2015 (23.8%). Such thing was caused by land characteristics of erosion plot (Table 1) in cabbage plants which had soil texture and sand content (39.7%) and permeability (9.15 cm $hour^{-1}$) lower than that of red beans having soil texture with sand content (40.5%) and permeability (10.75 cm $hour^{-1}$). The increase of soil permeability value (on red bean plants) will increase the speed of water to penetrate the soil (infiltration), causing rainfall to end up as runoff also known as runoff coefficient value.

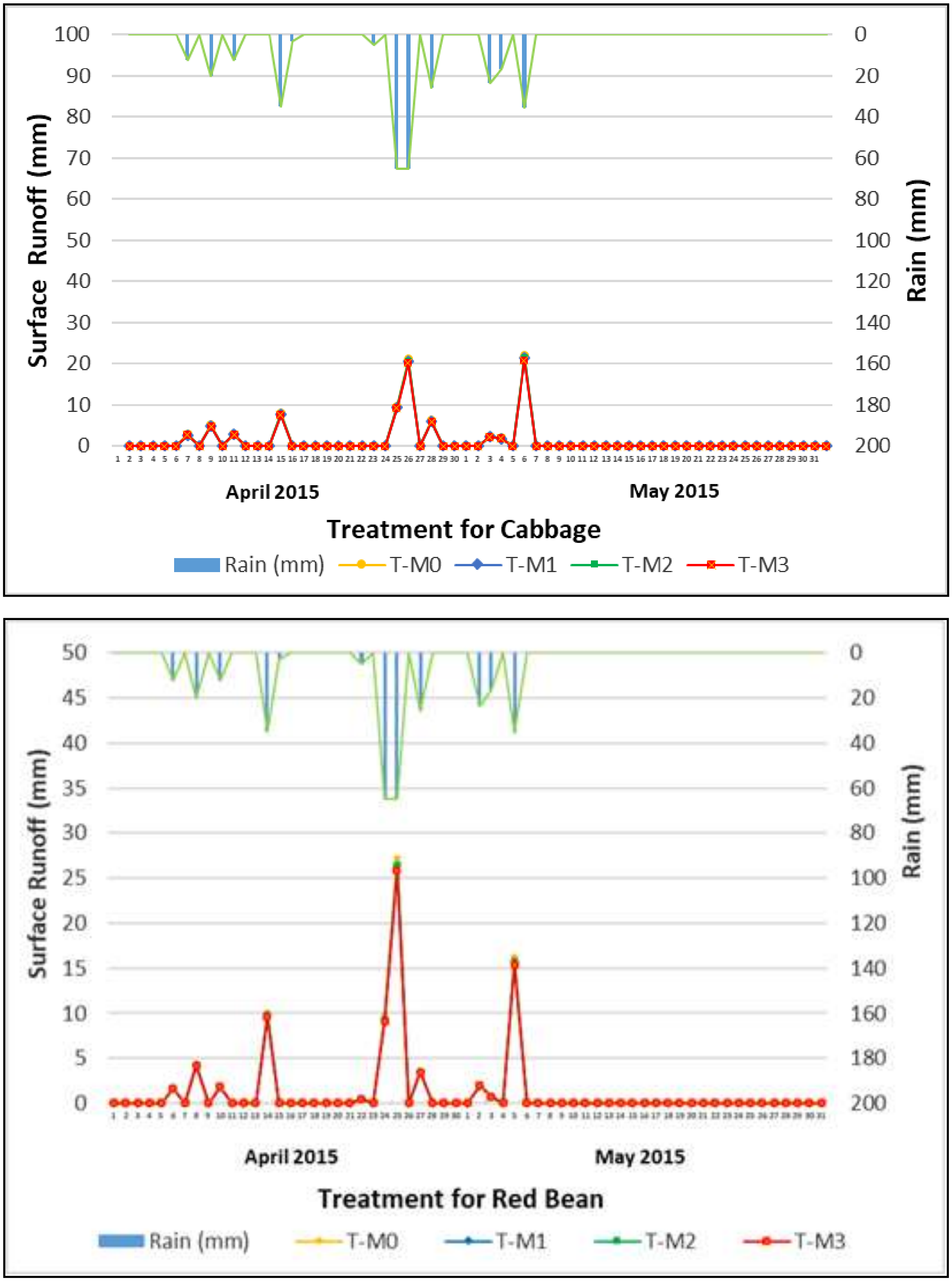
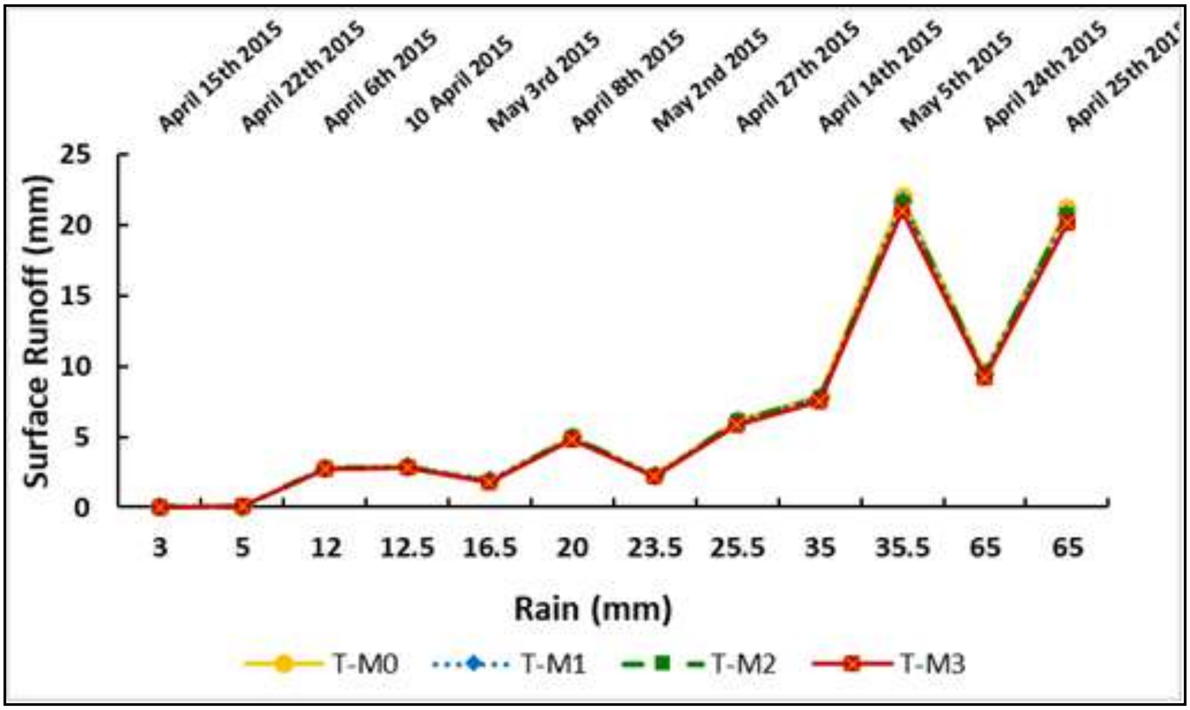


Figure 3. Data on daily rainfall and runoff on cabbage and red beans.

A)



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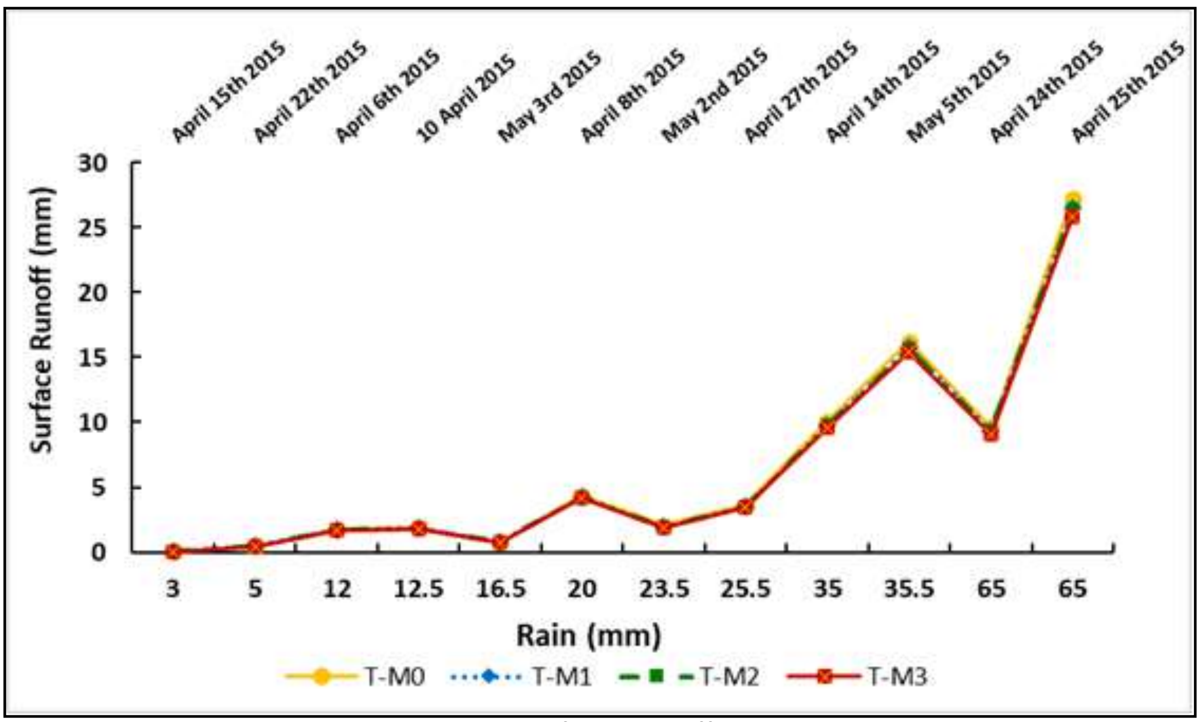


Figure 4. The relationship between rainfall and runoff in A) cabbage and B) red beans.

Effect of treatments on soil loss

The erosion rate induced by the maize stalks mulch treatment on cabbage and red beans are presented in Table 4 and Table 5. Statistically speaking, maize mulch treatment on cabbage plants did not significantly reduce the soil erosion from daily rainfall events and the total of rainfall occurred during April to June 2015, but with more mulch doses caused the soil erosion to decrease. The T-M3 treatment compared to T-M0 (without mulch) was able to reduce erosion by 26.5% in cabbage and 25.6% in red beans, followed by T-M2 treatment which was able to reduce erosion by 8.6% in cabbage and 20.7 % in red beans, and T-M1 treatment could reduce erosion by 6.5% in cabbage and 8.9% in red beans. This finding exactly corresponds to the research results undertaken by Suyana (2012; Suyana, 2014), concerning tobacco mulch dose of 14 tons ha^{-1} on bench terraces that significantly reduced soil erosion by 30.6-42.9% compared to those without mulch. Plant residual mulch prevented 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 largely on the amount and power of mulch materials on decomposition process, and as well as determined by the percentage of soil cover by mulch material. Sinukaban *el al*. (2007) asserted that mulch cover of rice straw is greater or equal to 60% which was able to reduce erosion at least 54% and at the closure of straw mulch restraining the erosion by 30% which can only be suppressed 37%. The treatment of plant residual mulch can control rain splashes, runoff and runoff mass flow (Baptista *et al*., 2015), 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 *et al*., 2010).

In Tables 4 and 5, it is described that cabbage plants have an average erosion value for daily rainfall (1011.36 kg ha^{-1}) and the total of rainfall dropped during April to June 2015 (12.14 tons ha^{-1}) was higher than in red bean plants with an average erosion value on daily rainfall basis (925.98 kg ha^{-1}) and for the total of rainfall during April to June 2015 (11.11ton ha^{-1}). Such thing was caused by soil properties from erosion plot experiments (Table 1) in cabbage plants which had lower soil permeability (9.15 cm hour^{-1}) compared to red beans (10.75 cm hour^{-1}); the increase of soil permeability (in red beans) will increase infiltration, and as a result it will reduce the amount of runoff (Tables 2 & 3) and ultimately reduce soil loss. It is also thought to have been caused by the percentage of plant canopy (on a 2-weeks period) on the red bean plants which are relatively higher than cabbage plants (Figure 8).

Table 4. Effect of maize stalk mulch on the value of soil loss in cabbage plants.

Treatment	N	Soil loss (Daily rainfall)		Soil loss (Rainfall from April to June 2015)		
		Rainfall Average (mm)	Soil loss Average (kg ha^{-1}) *	Rf (mm)	Soil loss (tons ha^{-1}) *	Re (%)
T-M0	12	26.5	1128.83 [a]	318.5	13.55[a]	0
T-M1	12	26.5	1054.92 [a]	318.5	12.66[a]	6.5
T-M2	12	26.5	1031.42 [a]	318.5	12.38[a]	8.6
T-M3	12	26.5	830.25 [a]	318.5	9.96[a]	26.5
Average		26.5	1011.36	318.5	12.14	
SEM		2.1	148.38		1.49	

Rf : Rainfall
Rr : % reduction in runoff: decrease of runoff value compared to T-M0 (without mulch)
* Numbers in the same column followed by the same letters showed no significant difference from the DMRT (Duncan's multiple range test) standards of 5%.

Table 5. Effect of maize stalks mulch on soil loss values in red bean plants.

Treatment	N	Soil loss (Daily rainfall)		Soil loss (Rainfall from April to June 2015)		
		Rainfall Average (mm)	Soil loss Average (kg ha^{-1}) *	Rf (mm)	Soil loss (tons ha^{-1}) *	Re (%)
T-M0	12	26.5	1074.25 [a]	318.5	12.89[a]	0
T-M1	12	26.5	978.33 [a]	318.5	11.74[a]	8.9
T-M2	12	26.5	851.75 [a]	318.5	10.22[a]	20.7
T-M3	12	26.5	799.58 [a]	318.5	9.59[a]	25.6
Average		26.5	925.98	318.5	11.11	
SEM		2.1	102.83		1.03	

Rf : Rainfall
Rr : % reduction in runoff: decrease of runoff value compared to T-M0 (without mulch)
* Numbers in the same column followed by the same letters showed no significant difference from the DMRT (Duncan's multiple range test) standards of 5%.

In general, the enormity of erosion observed at each daily raindrop is positively correlated with the daily rainfall (Figure 5). The level of daily erosion increases as caused by the increase of daily rainfall and also influenced by soil moisture content just before the rain comes (Figure 6). This finding corresponds to the report undertaken by Morgan (2005) which asserted that the average annual sediment yield correlates positively with the annual average rainfall. The effect of crop residual mulch not only reduces the volume of runoff but also changes the erosion and runoff relationships. There are many interrelated factors as the rain erosivity and soil cover rate, where the level of soil cover is the main factor and followed by rainfall. Erosivityis the amount and frequency of rainfall that affects the level of soil-moisture content and time on the groundwater saturation. The level of soil cover and soil properties (soil texture and permeability) will then affect the rate of infiltration, runoff, and soil loss (Baptista *et al*., 2015).

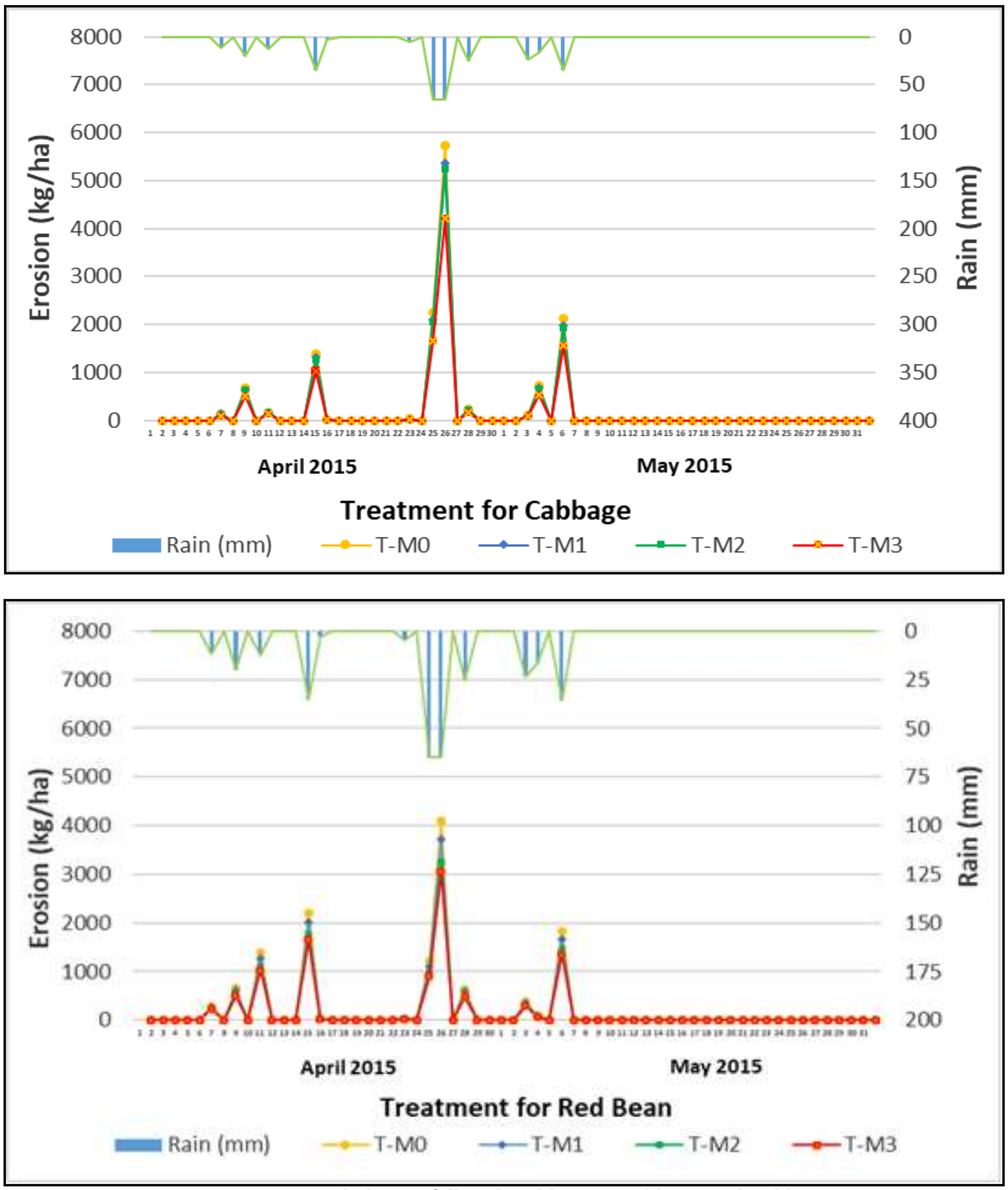


Figure 5. Data on daily rainfall and soil loss on cabbage and red beans.

A)
B)

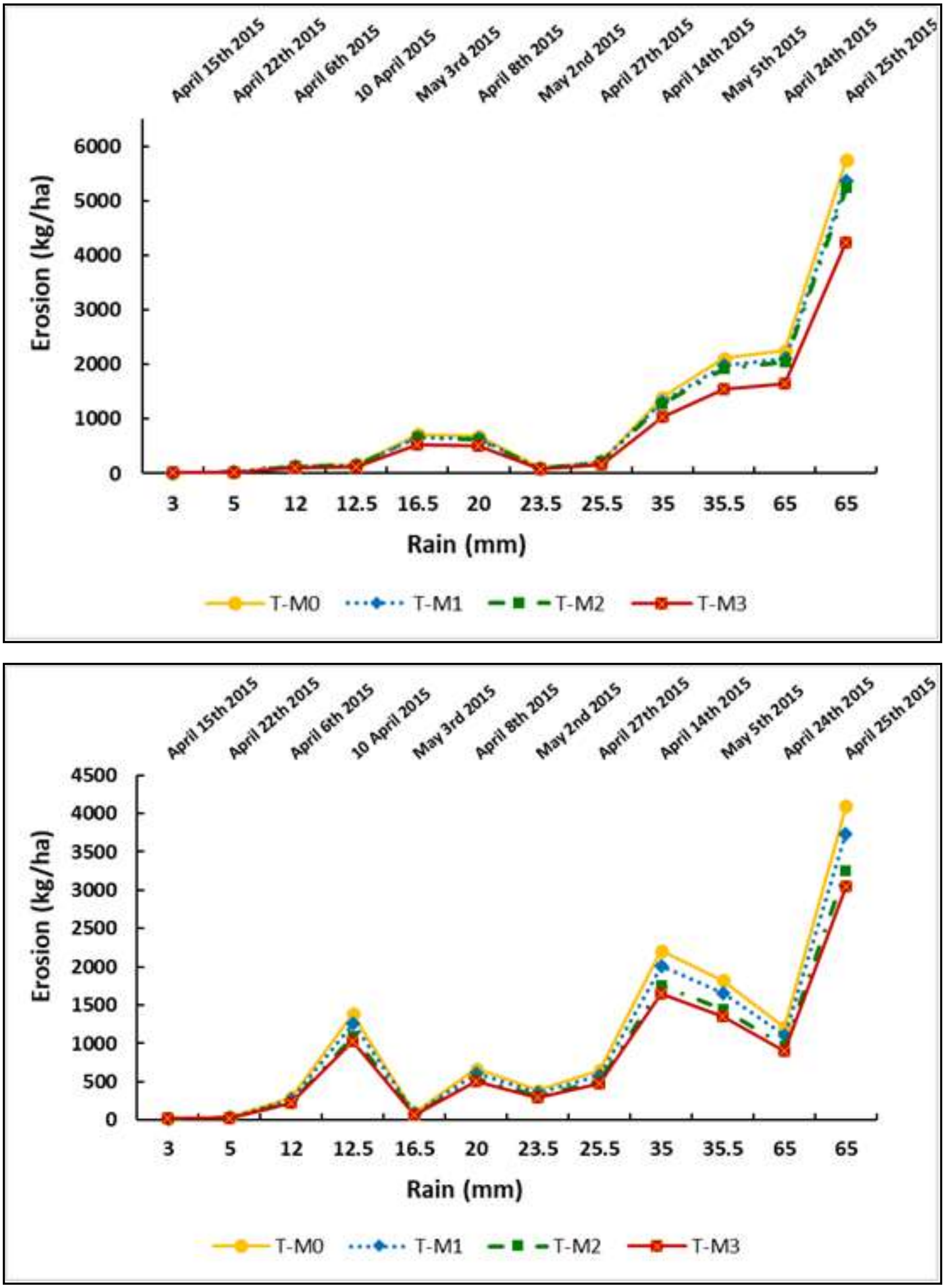


Figure 6. The relationship between rainfall and soil loss in A) cabbage and B) red beans.

Effects of maize stalk mulch on sediment enrichment ratio (SER)

The sediment concentrations in runoff and nutrients N, P, K, organic C washed away by erosion regarding the maize stalks mulch treatment on cabbage and red beans are presented in Table 6. Statistically speaking, maize stalks mulch treatment on cabbage plants significantly increased the value of sediment enrichment ration (SER) at doses 4, 8, 12 tons ha^{-1} for nutrients N and P, and at doses 8 and 12 tons ha^{-1} for nutrient K, and at doses of 12 tons ha^{-1} for organic C. However, red bean mulch treatment of maize stalks significantly increases the SER value at dose of 12 tons ha^{-1} for nutrient K. The enormity of SER value is influenced by factors which in turn affect the destruction of some composites inducing them into small particles and runoff (Arsyad, 2010) and the process of selective erosion (Sinukaban, 1981). If runoff becomes slow due to dense crop cover or because of a huge amount of residual plants scattered on the ground, thus, the erosion selectivity will be tremendous as well as the SER value (Arsyad, 2010).

Also, Table 6 shows the SER value for N nutrients amounting 1.06-1.24, with P nutrients of 1.77-3.67, and K nutrients of 1.01-1.58 and with organic C of 1.04-1,24. This corresponds with the results by Cachene *et al*. (1997) from an experiment undertaken at the erosion research station in Faculty of Agriculture and Veterinary Science, University of Nairobi, Kenya which obtained a 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).

The overall results showed that the increase in mulch doses caused sediment concentrations in the runoff to decrease, but on the other hand, the SER values tended to increase (Table 6). This exactly corresponds to the reports of Sinukaban (2007), asserting 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 some 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 dose 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, more addition of mulch dose would eventually trigger an erosion (sediment) that contain higher organic C concentrations and nutrients.

Table 6. Effect of maize stalk mulch on sediment concentration and sediment enrichment ratio (SER) on cabbage and red beans.

Treatment	N	Sediment concentration on cabbage ($g\ l^{-1}$) *	Value of sediment enrichment ratio (SER) on cabbage			
			N *	P *	K *	Organic-C *
T-M0	12	18.03[a]	1.06[a]	1.77[a]	1.01[a]	1.04[a]
T-M1	12	17.16[a]	1.12[b]	3.67[b]	1.03[a]	1.07[a]
T-M2	12	16.62[a]	1.09[ab]	3.65[b]	1.27[b]	1.12[ab]
T-M3	12	13.92[a]	1.11[b]	3.67[b]	1.53[c]	1.21[b]
Average		16.43	1.10	3.19	1.21	1.11
SEM		1.19	0.08	0.23	0.09	0.08
Treatment	N	Sediment concentration on red beans ($g\ l^{-1}$) *	Value of sediment enrichment ratio (SER) on red beans			
			N *	P *	K *	Organic-C *
T-M0	12	25.28[a]	1.11[a]	2.06[a]	1.15[a]	1.09[a]
T-M1	12	23.67[a]	1.15[a]	2.35[a]	1.31[a]	1.07[a]
T-M2	12	20.91[a]	1.18[a]	2.53[a]	1.29[a]	1.24[a]
T-M3	12	19.80[a]	1.24[a]	2.81[a]	1.58[b]	1.22[a]
Average		22.41	1.17	2.44	1.33	1.16
SEM		2.14	0.11	0.23	0.13	0.11

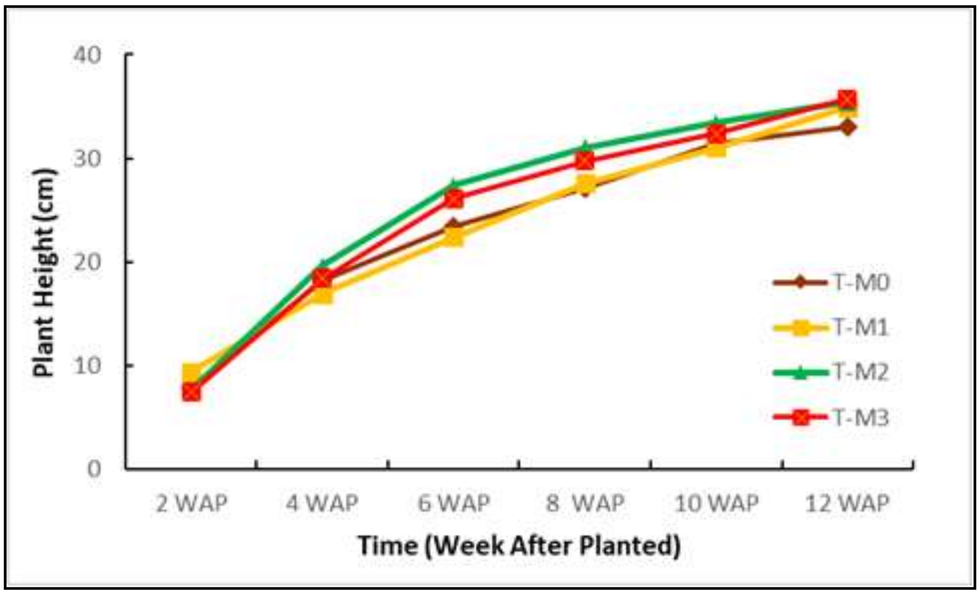
SER: Comparison of concentration between elements in sediments and concentration of these elements obtained from their origin soil.
* The numbers in the same column followed by the same letters had no significant difference in DMRT (Duncan's multiple range test) standards of 5%.

Effects of Maize Stalk Mulch on Plant Growth and Yields

Effects of maize stalk mulch on plant growth

The plant growth rates from maize stalk mulch treatment on cabbage and red bean plants are presented in Figure 7 and 8. The results showed that the increase of dosage in maize stalk mulch increased the height and canopy cover during the 2-weeks period. This finding corresponds to the report of Goldman *et al*. (1986) saying that the treatment of straw mulch cut into size 15 cm with a dose of 4.5-9.0 tons ha^{-1} can increase plant growth while maintaining soil temperature and preserving soil moisture. Mulumba and Lal (2008) also argued that the increased dose of wheat straw mulch would increase the available water capacity (AWC) underground and moisture content at field moisture capacity. Mulch protects soil surface serving as a block which is meant to avoid moisture loss from the soil, and as a result, water would remain longer under the soil and which can be transformed into soil moisture available for plant growth (Sinukaban *et al*., 2007; Shaver *et al*., 2013).

A)



B)

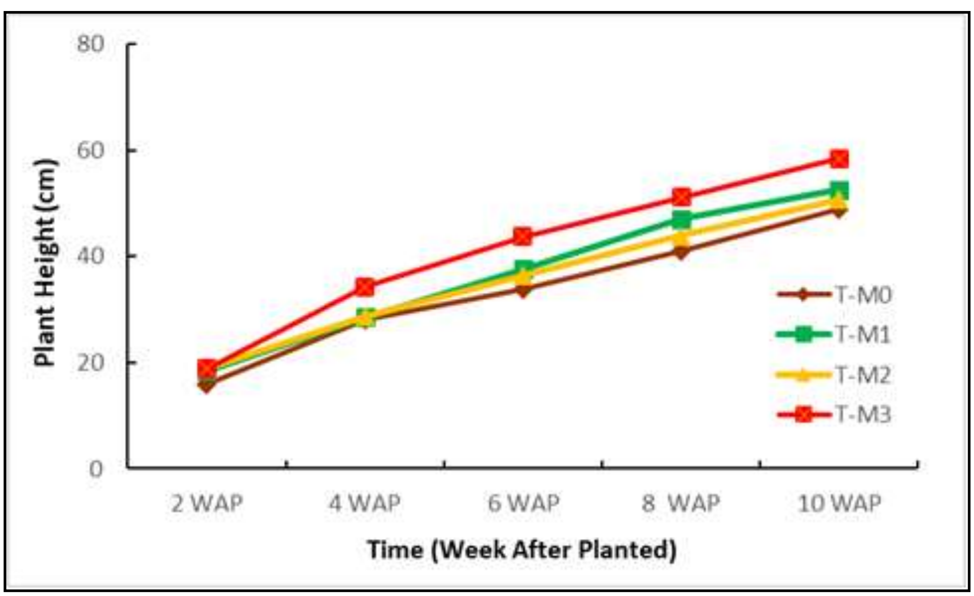
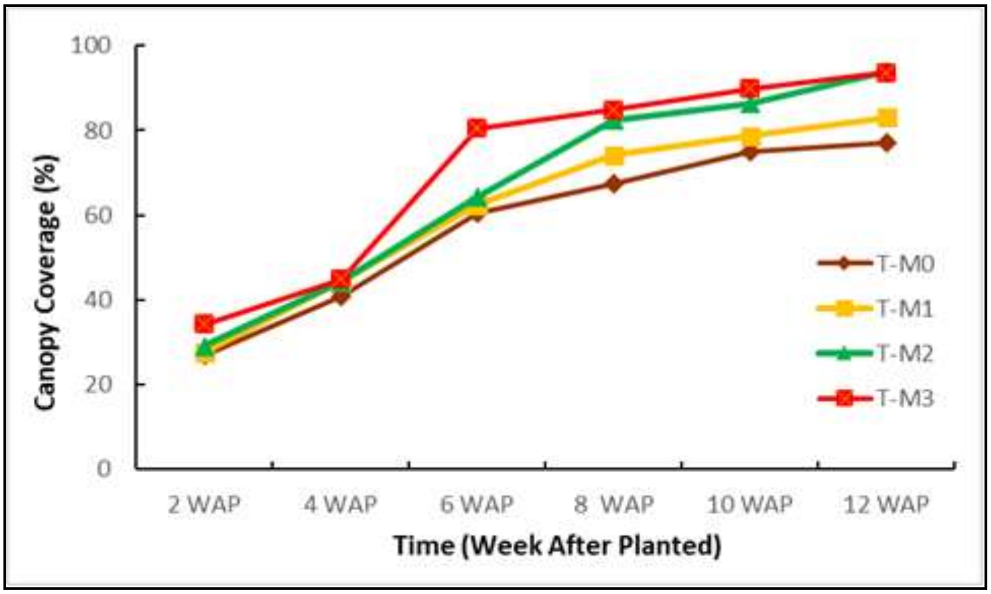


Figure 7. Effect of maize stalk mulch on the height of A) cabbage and B) red bean plants.

A)



B)

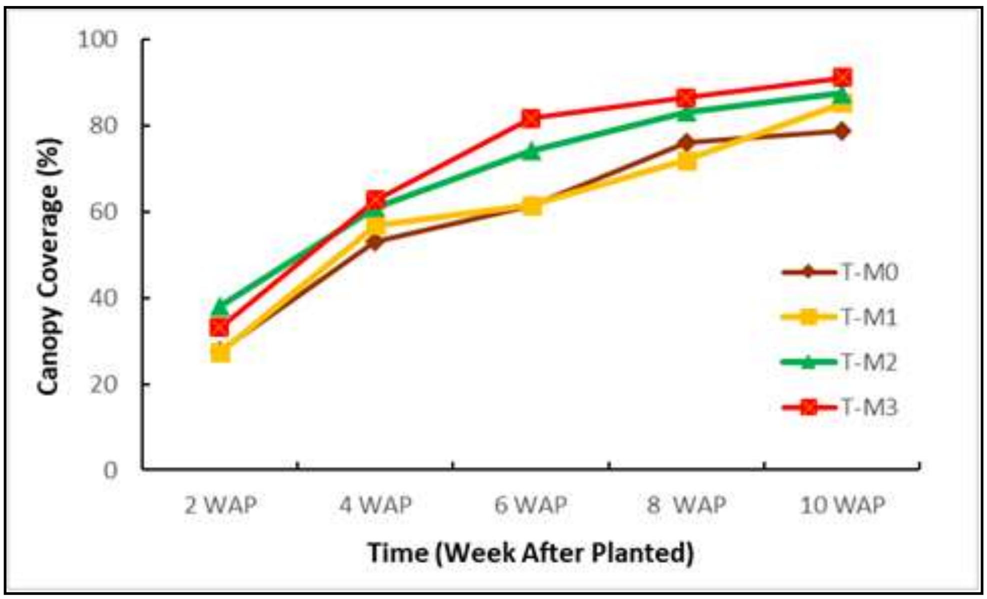


Figure 8. Effect of maize stalk mulch on canopy cover of A) cabbage and B) red bean plants.

Figure 8, also shows that during the 2-weeks period, the canopy cover of red bean plants is relatively higher than in cabbage plants. This is thought to have been caused by a spacing system on red beans (30cmx40cm) which is more tightly than the spacing of cabbage (50cm x70cm). The percentage of canopy cover in red beans which is relatively higher than that of cabbage is the main cause of erosion rates as implied by the daily rainfall and the total amount of rainfall obtained from April to June 2015 on red bean (925.98 kg ha^{-1} and 11.11 tons ha^{-1}) which was lower compared to cabbage (1011.36 kg ha^{-1} and 12.14 tons ha^{-1}) (Table 4 and 5). Plants canopy cover protects the soil from the destructive raindrops and prevents them because it blocks them to drop directly on the ground and help increase the plant's interception capacity (Suyana, 2012).

Effect of maize stalks mulch on weeds

The effect of maize stalks mulch treatment on weeds that may hinder the cabbage and red beans are presented in Table 7. Statistically speaking, maize stalk mulch treatment in cabbage was not significantly able to hold back the growth of weeds, but maize stalks mulch treatment dose 8 tons ha^{-1} and 12 tons ha^{-1} in red beans has significantly hampered the weeds dry weight. In general (Table 7), describes the increasing dose of maize stalk mulch which is positively correlated with the decreasing growth of weeds or increasing the percentage of weeds reduction. This finding corresponds to the research results found by Suwardjo (1981), who observed that an increased dose of plant residual mulch seemed to have thwarted the growth of weeds. Plant residual mulch would provide a surface cover and as a result, there would be less open space left for sun rays to penetrate on the soil which is useful for weeds growth.

Effects of maize stalk mulch treatments on crop yields

The effect of maize stalks mulch treatment on cabbage and red beans are presented in Table 8 and Table 9. Statistically speaking, maize stalks mulch treatment in cabbage (Table 8) has significantly increased cabbage dry weight, and at a dose of 12 tons ha^{-1} which noticeably increased the cabbage fresh weight. The T-M3 treatment compared to T-M0 (without mulch) was able to increase the cabbage fresh weight (33.5%) and the cabbage dry weight (53.9%), followed by the treatment of T-M2 could increase the cabbage fresh weight (9.9%) and cabbage dry weight (10.8%), and T-M1 treatment was able to increase the cabbage fresh weight (1.7%) and cabbage dry weight (6.4%). The treatment of maize stalks mulch at 12 tons ha^{-1} in red beans (Table 9) has significantly increased the plant stems dry weight, pod dry weight, and bean dry weight. T-M3 treatment compared to T-M0 (without mulch) was able to increase the bean dry weight (41.4%), followed by T-M2 treatment able to increase the bean dry weight (18.9%), and T-M1 treatment was able to increase the bean dry weight (17.2%). Mulumba and Lal (2008) emphasized that the treatment of wheat straw mulch at a dose of 8 tons ha^{-1} would significantly increase the available water capacity (AWC) and moisture content at field moisture capacity so that more water was available for plants. Likewise, Goldman *et al*. (1986) asserted that plant growth has increased when treatment with the straw mulch of a dose of 4.5-9.0 tons ha^{-1}.

Table 7. Effect of maize stalks mulch treatment on the weeds dry weight.

Treatment	N	Cabbage		Red Beans	
		Weeds dry weight (g 2m^{-2}) *	Rw (%)	Weeds dry weight (g 2m^{-2}) *	Rw (%)
T-M0	7	17.45^{a}	0	17.70^{a}	0
T-M1	7	16.28^{a}	6.7	17.29^{ab}	2.3
T-M2	7	16.74^{a}	4.1	15.76^{b}	10.9
T-M3	7	15.66^{a}	10.3	14.45^{b}	18.4
Average		16.53		16.30	
SEM		2.24		2.20	

Rw: % reduction in weeds: decrease of weeds value compared to T-M0 (without mulch)
* The numbers of the same column followed by the same letters showed no significant difference from the DMRT (Duncan's multiple range test) standards of 5%.

Table 8. Effects of maize stalk mulch treatments on results of cabbage plants.

Treatment	N	Cabbage fresh weight		Cabbage dry weight	
		(g plants^{-1}) *	IY (%)	(g plants^{-1}) *	IY (%)
T-M0	10	792.2^{a}	0	62.1^{a}	0
T-M1	10	806.0^{a}	1.7	66.1^{b}	6.4
T-M2	10	870.8^{a}	9.9	68.8^{c}	10.8
T-M3	10	1057.6^{b}	33.5	95.6^{d}	53.9
Average		881.7		73.2	
SEM		70.2		5.8	

IY: Increased yield compared to T-M0 (without mulch)
* The numbers of the same column followed by the same letters showed no significant difference from the DMRT (Duncan's multiple range test) standards of 5%.

Table 9. Effects of maize stalk mulch treatments on results of red bean plants.

Treatment	N	Plants stem dry weight (g plants^{-1}) *	Pod dry weight (g plants^{-1}) *	Bean dry weight	
				(g plants^{-1}) *	IY (%)
T-M0	10	3.9[a]	8.3[a]	5.8[a]	0
T-M1	10	4.5[a]	9.5[a]	6.8[a]	17.2
T-M2	10	4.3[a]	9.5[a]	6.8[a]	18.9
T-M3	10	5.2[b]	11.4[b]	8.2[b]	41.4
Average		4.5	9.7	6.9	
SEM		1.4	3.4	2.6	

IY: Increased yield compared to T-M0 (without mulch)
* The numbers of the same column followed by the same letters showed no significant difference from the DMRT (Duncan's multiple range test) standards of 5%.

In general, Tables 8 and Tables 9 show that increasing doses of maize stalk mulch would increase cabbage yield (cabbage fresh and dry weight) and red bean yield (plants stems dry weight, pods, and bean). This finding corresponds to the research results which have been widely published. The practice of mulch treatment of plant residues can increase plant growth (Goldman *et al*., 1986) and tends to increase crop yields (Suwardjo, 1981; Sinukaban, 2007) through increased infiltration, reduced evaporation of soil surface and loss of nutrients (Baptista *et al*., 2015), and the use of green water (the part of rainwater that can be used for biomass production) is more efficient (Stroosnijder, 2003). Mulumba and Lal (2008) observed that supplying mulch would help conserve more water remain in the soil during the period of plant growth, while stabilizing soil temperature and soil mechanical resistance, causing better root growth and higher crop yields. Shaver *et al*. (2013) also argued that mulching will increase the accumulation of plant residues which have an indirect effect on increasing water absorption and storage by improving soil aggregation, bulk density, and porosity that is conducive to water infiltration. Land management practices meant to restore plant residues to the soil system would lead to soil beneficial physical properties that increase soil sorptivity and water availability, and which would greatly reduce the potential for runoff and erosion but would increase the efficiency of energy use from the agricultural system.

CONCLUSIONS

The data presented support the following conclusions: Provision of maize stalk mulch to a dose of 12 tons ha^{-1} has not significantly reduced runoff and erosion. Mulch dose of 12 tons ha^{-1} could decrease runoff and erosion by 5.1-5.2% and 25.6-26.5%, mulch dose of 8 tons ha^{-1} decreased runoff and erosion by 2.3-3.1% and 8.6-20.7%, and mulch dose of 4 tons ha^{-1} decreased runoff and erosion of 2.1-2.8% and 6.5-8.9% compared to soil without mulch. Provision of maize stalk mulch tends to reduce sediment concentration but increases nutrient concentration in sediments (SER value). Provision of maize stalk mulch could increase the growth and yield of cabbage and red beans. With a dose of 12 tons ha^{-1} increase the cabbage fresh weight and red beans dry weight by 33.5% and 41.4%.

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REFERENCES

Abdurrachman, A. 2008. Technology and Strategy for Soil Conservation in the Agricultural Revitalization Framework. Agricultural Innovation Development. 1(2): 105-124. (In Indonesian).

Arsyad, S. 2010. Soil and Water Conservation (Second Edition). Bogor (ID): IPB Press. p. 470. (In Indonesian).

Baptista, I., Ritsema, C., Querido, A., Ferreira, A. D., Geissen, V. 2015. Improving rainwater-use in Cabo Verde drylands by reducing runoff and erosion. Geoderma. 237: 283-297. http://doi.org/https://doi.org/10.1016/j.geoderma.2014.09.015

Bogor Soil Research Center. 2005. Criteria for Assessing the Results of Soil Analysis. (In Indonesian).

Cachene, C. K. K., Narvis, N. J., Linner, H., Mbuvi, J. P. 1997. Soil erosion effects on soil properties in highland area of Central Kenya. Soil Science Society of America Journal. 61(2): 559-564.

Díaz-Ravina, M., Martín, A., Barreiro, A., Lombao, A., Iglesias, L., Díaz-Fierros, F., Carballas, T. 2012. Mulching and seeding treatments for post-fire soil stabilization in NW Spain: short-term effects and effectiveness. Geoderma. 191: 31-39. http://doi.org/https://doi.org/10.1016/j.geoderma.2012.01.003

Dlamini, P., Chivenge, P., Manson, A., Chaplot, V. 2014. Land degradation impact on soil organic and nitrogen stocks of sub-tropical humid grassland in South Africa. Geoderma. 235: 372-381. http://doi.org/https://doi.org/10.1016/j.geoderma.2014.07.016

Gao, X., Wu, P., Zhao, X., Wang, J., Shi, Y. 2014. Effects of land use on soil moisture variation in a semi-arid catchment: implications for land and agricultural water management. Land Degradation Development. 25(2): 163-172. http://doi.org/http://dx.doi.org/10.1002/ldr.1156

Goldman, S. J., Jackson, K., T.A Bursztynsky, P. E. 1986. Erosion and Sediment Control Handbook. New York (USA): McGraw-Hill Book Company, Inc. p. 369.

Magrath, W.B., Arens, P. 1989. The cost of soil erosion on Java: a natural resource accounting approach.Environment Department Working Paper 18. World Bank Policy Planning and Research Staff, World Bank, Washington, DC.

Morgan, R. P. C. 2005. Soil erosion and conservation (Third Edit). Malden (USA): Blackwell Publishing Company. p. 304.

Mulumba, L. N., Lal, R. 2008. Mulching effects on selected soil physical properties. Soil & Tillage Research. 98(1): 106-111.

Pimental, D., Allen, J., Beers, A., Guinand, L., Hawkins, A., Linder, R., McLaughlin, P., Meer, B., Musonda, D., Perdue, D., Poisson, S., Salazar, R., Siebert, S., Stoner, K. 1993. Soil erosion and agricultural productivity. *In*: Pimental, D. (ed.), World soil erosion and conservation.Cambridge University Press, Cambridge. pp: 277-292.

Sadeghi, S. H. R., Gholami, L., Homaee, M., Darvishan, A. K. 2015a. Reducing sediment concentration and soil loss using organic and inorganic amendments at the plot scale. Solid Earth. 6(2): 445-455. http://doi.org/https://doi:10.5194/se-6-445-2015

Sadeghi, S. H. R., Gholami, L., Sharifi, E., Darvishan, A. K., Homaee, M. 2015b. Scale effect on runoff and soil loss control using rice straw mulch under laboratory conditions. Solid Earth. 6(1): 1-8. http://doi.org/https://doi:10.5194/se-6-1-2015

Shaver, T. M., Peterson, G. A., Ahuja, L. R., Westfall, D. G. 2013. Soil sorptivity enhancement with crop residue accumulation in semiarid dryland no-till agroecosystems. Geoderma. 192: 254-258. http://doi.org/https://doi.org/10.1016/j.geoderma.2012.08.014

Sinukaban, N. 1981. Erosion Selectivity as Affected by Tillage Planting System. Ph.D. Thesis. University of Wisconsin, Madison.

Sinukaban, N. 2007. Effect of Conservation Tillages and Straw Mulch Application on Food Crop Production and Nutrient Loss Trough Erosion. *In*: Soil and Water Conservation Key to Sustainable Development. Jakarta (ID): Publisher of the Directorate General of Land Rehabilitation and Social Forestry, Ministry of Forestry. pp. 1-14. (In Indonesian).

Sinukaban, N., Sudarmo., Murtilaksono, K. 2007. Effects of Mulch Application and Tillage System on Erosion, Runoff, Erosion Selectivity on Reddish Brown Latosol Darmaga. *In*: Soil and Water Conservation Key to Sustainable Development. Jakarta (ID): Publisher of the Directorate General of Land Rehabilitation and Social Forestry, Ministry of Forestry. pp. 32-46. (In Indonesian).

Stroosnijder, L. 2003. Technologies for improving Green Water use efficiency in West Africa. *In*: Water Conservation Technologies for Sustainable Dryland Agriculture in Sub-Saharan Africa. Symposium and Workshop. Bloemfontein (South Africa): IWMI Conference Proceedings.

Suwardjo. 1981. The Role of Plant Residues in Soil and Water Conservation in Seasonal Crop Farming. Dissertation. Bogor Agricultural University. (In Indonesian).

Suyana, J. 2012. The Development of Tobacco Based Sustainable Upland Farming in Progo Hulu Sub-watershed (Temanggung Regency, Central Java Province). Dissertation. Bogor Agricultural University. (In Indonesian).

Suyana, J. 2014. The Planning of Tobacco Based Sustainable Upland Farming in Progo Hulu Sub-watershed (Temanggung Regency, Central Java Province). Tobacco, Fiber, and Oil Industry Bulletin. 6(1): 32-49. (In Indonesian).

Suyana, J., Komariah., Senge, M. 2010. Conservation Techniques for Soil Erosion Control in Tobacco-Based Farming System at Steep Land Areas of Progo Hulu Subwatershed, Central Java, Indonesia. International Journal of Agricultural and Biosystems Engineering. 4(5): 287-294.

Suyana, J., Muliawati, E. S. 2014. Land Capability Analysis of Agricultural Systems in Serang Subwatershed of Kedung Ombo Reservoir. Sains Tanah, Journal of Soil Science and Agro-Climatology. 11(2): 139-148. (In Indonesian).

Tesfa, A., Mekuriaw, S. 2014. The Effect of Land Degradation on Farm Size Dynamics and Crop-Livestock Farming System in Ethiopia: A Review. Journal of Soil Science. 4: 1-5. http://doi.org/http://dx.doi.org/10.4236/ojss.2014.41001

Traorea, S., Ouattara, K., Ilstedt, U., Schmidt, M., Thiombiano, A., Malmer, A., Nyberg, G. 2015. Effect of land degradation on carbon and nitrogen pools in two soil types of a semi-arid landscape in West Africa. Geoderma. 241: 330-338. http://doi.org/https://doi.org/10.1016/j.geoderma.2014.11.027

Uri, N.D., Lewis, J.A. 1998. The dynamics of soil erosion in US Agriculture. Science of the Total Environment. 218: 45-58.

Wahyunto; Dariah, A. 2014. Land Degradation in Indonesia: Existing Conditions, Characteristics, and Uniformity of Definitions Supporting Movement Towards One Map. Journal of Land Resources. 8(2): 81-93. (In Indonesian).

WOCAT. 2007. Where the land is greener : case studies and analysis of soil and water conservation initiatives worldwide. (H. Liniger & W. Critchley, Eds.). Wageningen, Netherlands: CTA (co-publishers FAO, UNEP, CDE).

Zougmore, R., Mando, A., Ringersma, J., Stroosnijder, L. 2003. Effect of combined water and nutrient management on runoff and sorghum yield in Semiarid Burkina Faso. Soil Use and Management. 19(3): 257-264. http://doi.org/10.1111/j.1475-2743.2003.tb00312.x