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Soil erosion assessment under different land use types using modified Gerlach trough in North-Western Thailand Highland

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Abstract

Soil erosion is a severe risk on the sloping agricultural land due to improper managements. This study aimed to evaluate and compare the dynamics of soil loss and runoff under different land use types in order to find the best soil erosion control for sustainable land use planning. A field trial was conducted in Bor Krai village, Mea Hong Son Province, North-Western Thai Highlands during 2008–2009. Four land use types were selected for comparative measurement, including i) 4-year-fallow land (FaL), ii) mixed orchard (MixO), iii) maize (M) and iv) upland rice (UR). Surface runoff (SR) and soil loss (SL) were monitored after each effective rainstorm using modified Gerlach troughs (GT). The GT was made of a bamboo and linked to a 50-litre container by a rubber hose. The size of GTs was 0.5–0.7 m long and 0.1–0.2 m diameter. The GTs were installed perpendicular to the contour line at the lower part of each land use. The results showed that, during the 2-yr, monoculture with inappropriate soil water conservation caused the first average highest values of SR and SL (SR=299 $m^3 ha^{-1}$) and (SL=3.4 t ha^{-1}) while FaL yielded the lowest SR (41 $m^3 ha^{-1}$) and SL (0.01 t ha^{-1}) amounts. Moreover, further study is required for long-term prediction to estimate annual soil loss under different land use types.

1. Introduction

The upper Northern Thailand Highland (NTH) is characterized by steep slopes with a slope gradian of more than 20% (Stahr et al., 2013) and these areas have been used for agricultural activity for many years without any proper soil conservation managements. Most of crop production in these regions such as rainfed maize and upland rice have been being practiced on sloping land. Land preparation for maize and upland rice production in NTH typically involves land clearance and burning during the dry season, followed by hoeing the surface soil to prepare the seedbed. The depth of seedbed pit was around 2–5 cm (Turkelboom et al., 1997).This activity leads to less or no soil cover which is induced surface runoff (SR) and associated soil loss (SL), especially at the beginning of the rainy season.

The amount of soil erosion in NTH is dependent on rainfall intensities and distributions, land use types, the development of cultivated crops at various growth stages, cultural practices, and slope gradient. On sloping agricultural land that has little or no ground cover, soil erosion caused by precipitation is excessive in the absence of soil conservation methods (Panomtaranichagul, 2008). As a result, it can lead to a rapid SR and SL. Along the slopes of farmed land, water erosion has caused the loss of fertile topsoil, including the loss of soil organic matter and nutrients, as well as a decline in the number of plant and animal species and soil microbes (Durán Zuazo and Rodríguez Pleguezuelo, 2008). In addition to affecting soil chemical qualities, soil erosion also affects soil physical properties, such as by eroding topsoil, reducing the depth of the soil surface, reducing the soil water retention capacity, and exposing gravel and rocks (Chaplot et al., 2002; Maass et al., 1988; Podwojewski et al., 2008). Continued soil erosion has also gradually led to negative effects on soil quality, agricultural productivity, transportation of soil pollutants to a riverine and downstream, reduction of ecological diversity and flood patterns at the lowland areas (Majoro et al., 2020).

In certain instances, soil conservation and erosion assessment have been implemented in Thailand highlands. According to measurements of soil erosion undertaken in the upper NTH, soil loss amounts differed from location to location based on land use types and soil conservation efforts (Khongdee et al., 2021, 2022; Pansak et al., 2008)

Conventional upland rice cultivation contributed to an annual soil loss of up to 102 t ha^{-1} (Hurni and Nuntapong, 1983). Meanwhile, upland rice cultivation together with soil and water conservation measures created annual soil loss less than 1 t ha^{-1} (Hurni and Nuntapong, 1983; Inthapan et al., 1995; Sombatpanit and Suwangerd, 2013). Furthermore, conventional practices of burning above-ground vegetation at the beginning of the rainy season can increase soil loss by reducing the interception of rainfall, resulting in numerous environmental and health issues in both highland and lowland regions. If agriculture need to be practiced on sloping land, soil and water conservation must be integrated. As pointed out by FAO (2017), conservation agriculture is based on three principles: 1) minimize soil disturbance, as little or no soil tillage is required, during the seedbed preparation or application of fertilizers, which can decrease soil erosion and maintain soil organic matter, 2) permanent topsoil cover with crop residues and/or cover crops which can protect topsoil from extreme weather patterns and conserve soil moisture and avoid soil compaction and 3) crop diversities through a well-designed crop rotation can contribute to good soil structure, protect soil flora and fauna, which contributes to nutrient cycling and improved plant nutrition, including avoiding crops from pests and diseases. Therefore, soil and water conservation need to be implemented.

It is essential to understand the status of SR and SL under different land use types to implement the most effective soil conservation measures that can reduce soil degradation and enhance soil health. Therefore, monitoring of soil erosion at the field scale is needed to collect a quantity data for soil loss under different land use types. Soil erosion measurements at the field scale comprise two common methods: bounded and unbounded plot methods. A bounded plot (runoff plot) is frequently used for SR and SL estimation over short-to-medium time periods (Boix-Fayos et al., 2006; McDonald et al., 2002; Sheng, 1990). The runoff plot is a conventional procedure for evaluating field erosion rates and it has been applied greatly to produce information for the Universal Soil Loss Equation (USLE) and the Revised Universal Soil Loss Equation (RULE) (Hsieh et al., 2009). Unlike bounded plots, unbounded plots can determine soil erosion from spatially unrestricted plots down the slopes such as Gerlach Trough (GT; Gerlach, 1967). Using GT to quantify soil loss is an inexpensive and simple technique (Hudson, 1993). The GTs can be used to assess soil loss across a large region and at a large number of randomly selected areas due to no plot boundaries used during the measurement. However, the hardship of using GT has been reported that it is difficult to identify the contributing areas for each GT (Morgan, 2009).

In addition, monitoring of soil erosion on sloping agricultural land is still not well documented, particularly under varying land use types and rainfed conditions. We hypothesized that GTs can provide better spatially resolved information about soil erosion in particular steep slope areas and can be able to provide promising data of soil erosion under different land use types. Therefore, the objective of this study was to evaluate and compare the dynamics of SR and SL across various land use types using unbounded plots like GTs. This work would also suggest for further investigation for long-term soil loss prediction in order to implement the most effective soil erosion control to reduce soil degradation.

2. Materials and methods

2.1 Study area and soil properties

The study sites were located around Bor Krai village (19.33°N and 98.12°E), Pang Ma Pha district, Mae Hong Son Province, North-Western Thai Highlands (Fig. 1a). Annual rainfall in 2007 was 1,642 mm, recorded from April and lasted until October (Fig. 1b). The study was conducted between 2008 and 2009. Four common land use types in the village were selected for comparative measurement from the four small catchments (one field

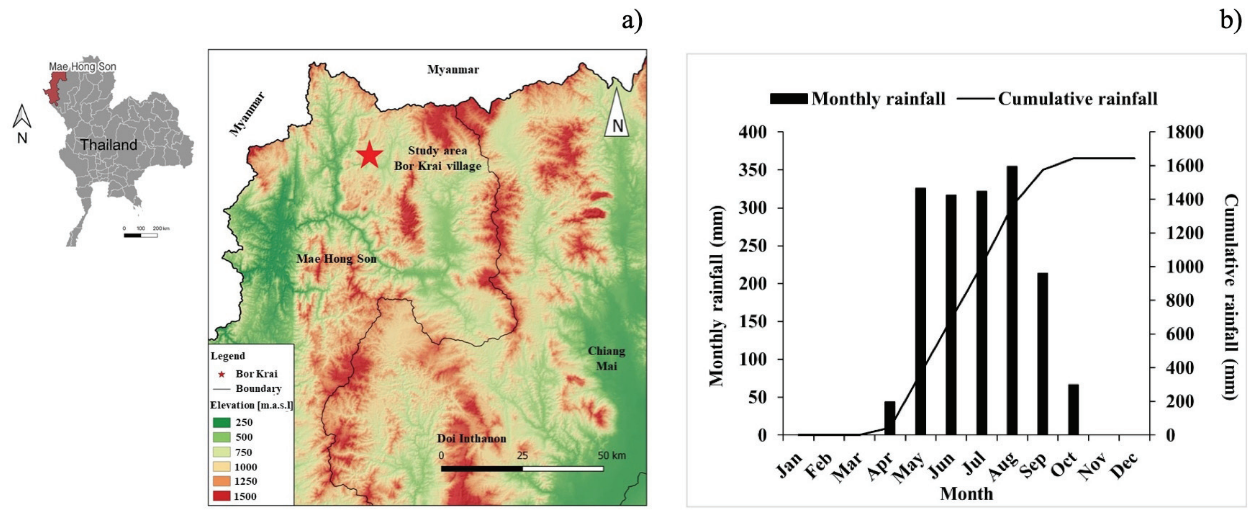

Fig. 1. Location of study areas during 2008–2009 (a) and annual rainfall in 2007 (b) in Pang Ma Pha district, Mae Hong Son Province.

Table 1
Slope inclination, elevation and summary of soil properties of four land use types (data taken from Wicharuck, 2016).

Land use types	Slope inclination (°)	Elevation (m a.s.l.)	Soil properties[1]						
			Sand (%)	Silt (%)	Clay (%)	Texture	BD[2] (Mg m^{-3})	IR[2] (cm h^{-1})	OM[2] (%)
FaL	27	680–700	24	35	41	Clay	1.23±0.03	57±10	4.60±0.73
MixO	26	710–750	26	33	41	Clay	1.26±0.05	63±3	3.46±0.37
M	25	700–750	19	37	44	Clay	1.23±0.05	45±1	3.62±0.35
UR	25	720–760	32	33	35	Clay loam	1.31±0.06	36±4	2.7±0.35

[1] Standard methods were used to analyse soil properties. Soil particle analysis according to International Classification: sand (2.0–0.2 mm) – silt (0.2–0.002 mm) – clay (≤0.002 mm) (hydrometer method; Gee and Bauder, 1986), BD (bulk density; McIntyre and Loveday, 1974), IR (steady infiltration rate; White et al., 1992) and organic matter (OM, wet oxidation, %; Black, 1965).
[2] Average values ± standard deviation

per each land use type). Four land use types comprised of i) the 4-year-fallow land that the land has been left fallowed since 2004 (FaL), ii) mixed orchard – peach, banana and mango- (MixO), iii) maize (M) and iv) upland rice (UR). The slope inclination ranged from 25° to 27° with an elevation of 680–760 m a.s.l (Table 1). Soil properties of topsoil (0–0.2 m) for each land use type in the village of Bor Krai were in Table 1 (Wicharuck, 2016). A common reference soil group in the study area is Alisols according to World Reference Base for Soil Resources (WRB) (Schuler, 2008; Schuler et al., 2010).

2.2. Gerlach trough installation, sample collection and data analysis

Modified Gerlach Troughs (GT) were employed to assess SR and SL at spatially unrestricted plots of different types of land use. The bamboo was used for making of the GT. The GT was linked to a 50-litre container by a rubber hose. The dimensions of GTs were 0.5–0.7 m long and 0.1–0.2 m diameter. On the upslope side, a quarter of the bamboo internode was taken out, while the two-thirds of the lower tubes of bamboo were installed in the soil. Four GTs per land use type were located at the same contour line in the lower part of each field (Fig. 2). Soil suspensions (mixture of surface runoff and soil sediment) were collected by the GTs and the samples were transferred into sedimentation tanks. The sampling interval was conducted after each effective rainfall event (cumulative rainfall amounts) and was defined by the time interval from the previous data collection to the sampling date. The level of suspension in the sedimentation container was measured by a one-meter length of ruler after every effective rainfall event. Then, the suspension in each sedimentation container was strongly stirred and 500 cm^3 of sample was collected. The sedimentation container was cleared. The suspension samples were dried at 105°C for 24 hours (Mutchler, 1963) in the laboratory of the Faculty of Agriculture, Chiang Mai University, Thailand.

Simple ground cover was estimated as the non-vegetated surface was evaluated based on the dark space uncovered (Barry, 1996).

For comparative measurement, the standardization of SR and SL quantities into units of area is suggested (Morgan, 2009). The calculated SR and SL amounts were then converted to m^3 ha^{-1} and t ha^{-1}, respectively. The average of SR and SL amounts from each land use type at each effective rainfall event were

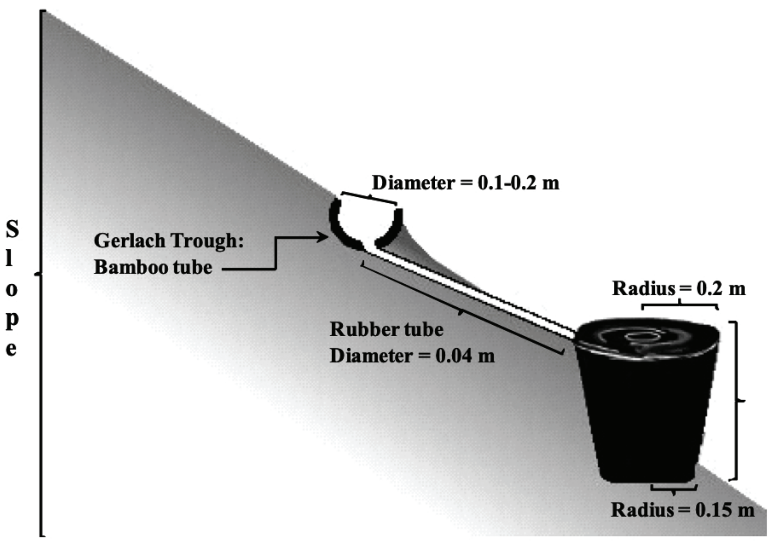

Fig. 2. Dimension and installation of Gerlach Trough.

calculated and the average values were then summed up over the year to present cumulative SR and SL amounts.

Rainfall data was obtained from a research institute close to the village (distance of 6 km, approximately). In addition, a land use history survey under each land use type was conducted by an individual interview with the owner of the fields.

2.3. Statistical analysis

Descriptive statistics were calculated as the average and standard deviation. Pearson's correlation coefficient and linear regression were calculated for i) cumulative SR and rainfall and ii) cumulative SL and rainfall.

3. Results

3.1. Land use history, percentage of dark area covered and variations of rainfall

The land use history from 1980 to 2010 in all land use types was displayed in Fig. 3a. Under FaL, weeds and shrubs, including in large and small plantations, were naturally formed after the field was left fallow in 2004. Before the field abandoned, the field was used to cultivate maize for two years during 2002–2003. Meanwhile, MixO was a mixture of different fruit tree varieties such as mango (the main fruit), peach, banana and tea. The topsoil was always covered by grass because the farmer did only one time of weeding per year and no chemical fertilizer application. Under M and UR, farmers started the weeding in March and the dried vegetation was burned in April. The herbicide was applied before crop cultivation. The sowing periods of maize and upland rice were in May and June, respectively. Weeds control was performed two times under M and three times under UR during the crop production.

The Fig. 3b shows the percentage of dark areas covered during 2008–2009. This was implied for the non-vegetated area. The highest vegetation cover was detected under permanent vegetation such as FaL and MixO. Meanwhile, annual crops like M and UR showed different dynamics. Lower vegetation cover was found at the beginning of the rainy season and decreasing trends were observed after sowing periods in May (for maize) and June (for upland rice).

Furthermore, rainfall distribution in the study areas occurred more frequently between May and October (Fig. 3c). The amount of annual rainfall was 1,717 mm and 1,579 mm in 2008

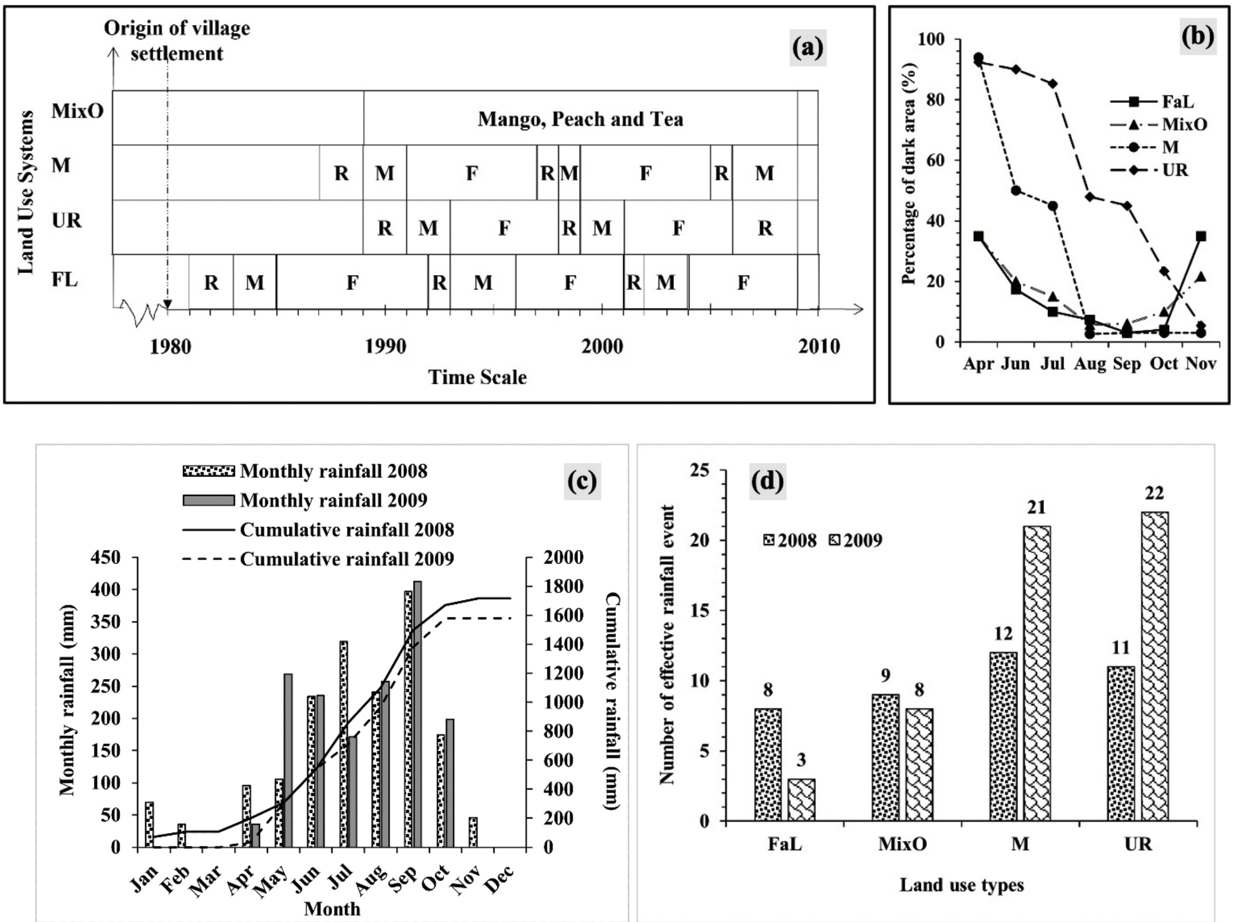

Fig. 3. Land use history of the field since the settlement of the village from 1980 to 2010 (a). M, R and F letters were maize cultivation, upland rice production and fallow period, respectively. Percentage of dark area covered the surface soil (b), annual rainfall distribution (c) and effective rainfall events under different land use types (d) in Pang Ma Pha district, Mae Hong Son Province during the measurement period from 2008 to 2009.

and 2009, respectively. The highest rainfall events to contribute to SR and SL were observed in the land uses of M and UR, with the number of effective rainfall events of 33 for both study years (Fig. 3d). More than 40 mm of rainfall amounts at each effective event generated SR and SL under FaL meanwhile more than 19 mm of rainfall amounts at each effective event generated SR and SL in the land use of M and UR.

3.2. Variations of surface runoff and soil loss under different land use types

Different land use types had different effect on values of SR and SL during the measurement periods. Cumulative values of SR and SL ranged from one rainfall event to another and from year to year under all land use types. Average values of cumulative SR and SL values for each effective rainfall event were plotted versus time under different land use types during the measurement periods (Fig. 4a and b). The effective rainfall events were different in each land use type and the same rainfall amount generated the SR and SL in one land use it might not be generated in the other land use types. Therefore, it can be clearly noticed that FaL had the lowest values of both the cumulative SR and SL values for the two study years due to the lowest rainfall events. Intermediate of the cumulative SR and SL values were observed on the site of MixO between 2008 and 2009. The first and second highest of cumulative SR and SL were found under UR and M in comparison to FaL and MixO. Moreover, the variations of cumulative SR and SL over the year showed the same trends under M and UR. The SR and SL values considerably increased between May and June/or July due to low topsoil protection under M and UR. However, a slight reduction in SR and SL was discovered because of a subsequent change in crop development a few months after sowing.

3.3. Relationship of cumulative rainfall, surface runoff and soil loss

Pearson's correlations (R) were calculated between i) cumulative SR and rainfall and ii) cumulative SL and rainfall (Table 2). The results showed that there were highly significant correlations between cumulative SR, SL and rainfall under all land use types during the measurement periods, with the exception under MixO. In addition, the values of coefficient of determinations (R^2) showed that the R^2 values between cumulative rainfall vs SR varied from 0.91 to 0.99 (Fig. 5a) while the values of R^2 between cumulative rainfall vs SL ranged from 0.60 to 0.90 (Fig. 5b).

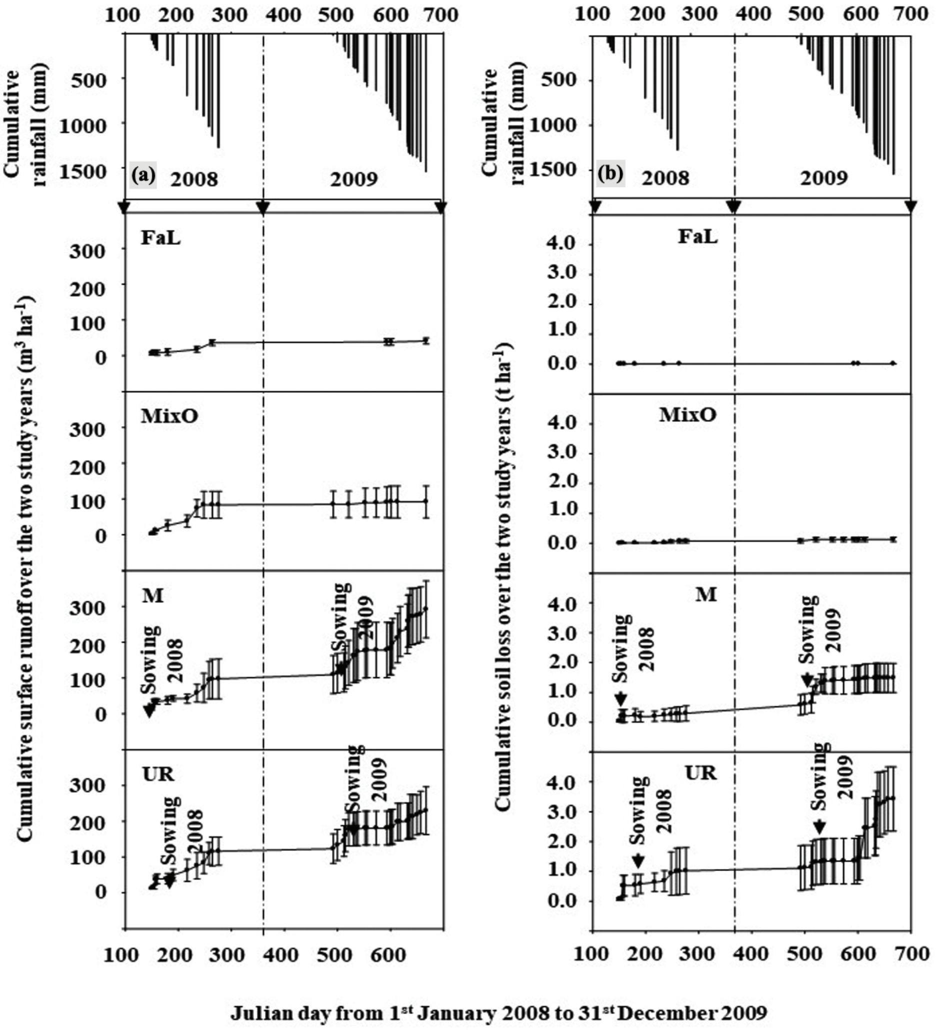

Fig. 4. Cumulative rainfall and SR (a) and cumulative rainfall and SL (b) over the two study year under different land use types between 2008 and 2009.

Table 2
Pearson's correlation coefficients between cumulative rainfall vs SR and cumulative rainfall vs SL under different land use types during the measurement periods.

	FaL		MixO		M		UR	
	SR[1]	SL[2]	SR[1]	SL[2]	SR[1]	SL[2]	SR[1]	SL[2]
Cumulative rainfall (mm)	0.928**	0.898**	0.843**	0.945**	0.987**	0.930**	0.974**	0.910**

** referred to significant correlation at 0.01 level (2-tailed).
[1] and [2] indicated to cumulative SR and cumulative SL over two years.

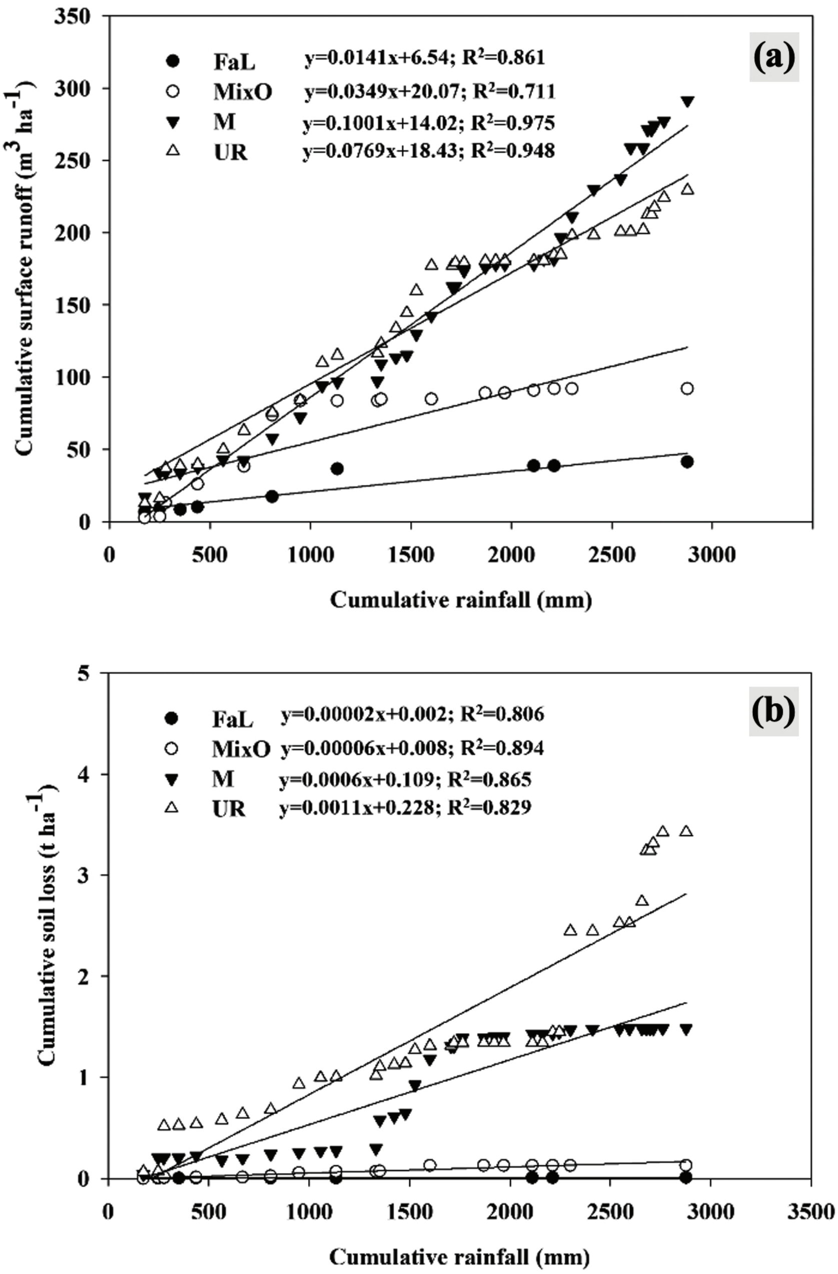

Fig. 5. Linear regression (a) between cumulative rainfall and SR and (b) between cumulative rainfall and SL under different types of land use.

According to the equation in linear regression between cumulative rainfall and SR and between cumulative rainfall and SL, the lower slope value was observed under FaL and MixO than under M and UR.

4. Discussion

The purpose of this study was to contribute the vital information regarding soil erosion quantities in various land use types on sloping agriculture under rainfed conditions using unbounded plots like the "Gerlach trough (GT)" technique. Therefore, the main topics to be discussed comprised of i) difficulties of using the Gerlach trough to measure SR and SL, ii) outlook of SR and SL under different land use types and iii) sustainable traditional agricultural practices (M and UR) on sloping land in NTH.

4.1. Difficulties of using the Gerlach trough to measure SR and SL

The difficulties of employing the GT to measure SR and SL offer advantages and disadvantages as described by Hudson (1993) and Morgan (2009). During the investigation, both positive and negative aspects of employing GT to quantify SR and SL were observed as well. The benefits of using GT were that it could be used in an open system, including in spatially unrestricted plots along with the slope under natural conditions. In addition, the restrictions of applying GT were identified as the surface soil spatial and temporal variations from one to another rainfall event were difficult to identify (Vigiak et al., 2008), which was resulted in SR and SL measurement errors.

Moreover, further limitations of using GT for soil erosion measurements under M and

UR production were identified. The first limitation was the high rainfall intensities incorporated with less vegetation cover and incomplete development of crops at the beginning of the rainy season, leading to a full sedimentation tank. The second restriction was the development of rill attributes during the initial stages of crop cultivation. The rills were discontinuously established. Later on, these rills were connected to each other, leading to the transport of eroded materials along the slope nearby the through. However, rills were no longer recognized when the crops were fully covered the ground. Heavy rainstorms had caused outlet blocking of GT by eroded particles from the upper part during heavy rainstorms. Finally, intensive labour was required for GT management and maintenance. In the same GT, each effective rainfall event did not constantly produce both SR and SL under different types of land use due to their soil physical properties, ground vegetation cover, and the spatial rainfall distribution variability between one and another event. As a resulted, one or two GTs received no or few eroded particles, while the other GTs received highly amount of eroded particles.

4.2. Outlook of SR and SL under different land use types

Different land use types showed different values of SR and SL during the study. When grouped four land use types into two groups as undisturbed (MixO and FaL) and disturbed (UR and M) land uses. It could be seen that the lower SR and SL were in undisturbed group (MixO and FaL) in comparison to disturbed group (UR and M) over the two study years. This was consistent with the findings of Maass et al. (1988) in Mexico and Rudiarto and Dopper (2013) in Indonesia, who determined that soil erosion in the forest was considerably less than in maize production.

On undisturbed group, low amounts of SR and SL under FaL and MixO were attributable to dense ground cover. This helped to protect the surface soil from SR and SL generation by decreasing the size and terminal velocity of raindrop impact or intercepted drops. Moreover, high root density resulted in i) a reduction of soil erosion because plant roots contributed to soil stabilization and topsoil resistance from water erosion by physical binding between soil particles and ii) surface soil pores formed by plant roots can also reduce surface runoff due to their ability to absorb water into the soil profile (Tefera et al., 2002). In addition, the absorbed water by plant roots can decrease the initial soil water content and increase infiltration water (Tefera et al., 2002). In addition, the factor contributing to SR and SL in mountainous areas is rainfall as it is the most important an erosive agent contributing to severe SR and SL (Toy et al., 2002). As shown in Fig. 5, the slope of linear regression was lower for FaL and MixO treatments than for M and UR, demonstrating that FaL and MixO might reduce SR and SL rates caused by rainfall. In general, runoff on a hillslope follows two processes (Favis-Mortlock and Mullan, 2011). The first process is "infiltration-excess overland flow" or "Hortonian overland flow" and the second process is "saturation-excess overland flow". Each of these processes or their combined consequences occurred; these resulted in soil erosion. However, if precipitation and surface runoff are infiltrated into the soil profile, erosion should not occur. In the study, the intensity of precipitation did not always surpass the infiltration capacity; however, surface runoff still existed (Table 1). This revealed that, under FaL and MixO, the most critical component limiting surface runoff was antecedent soil moisture content (Morgan, 2009). Under prolonged conditions of heavy precipitation, the soil profile became saturated; then, the infiltration capacity of the soil was reduced, leading to SR and SL in the areas. This was the reason why soil erosion occurred under FaL and MiO, even though the fields were covered by massive ground vegetation. As pointed out by (Liu et al., 2018) who stated that rubber plantation can enhance detachment of soil rather than protect the topsoil.

In addition, high volumes of translocated soil were discovered in the land use group of disturbed (M and UR), especially at the initial stage of crop production. This was a result of physical soil disturbance, i.e., land clearing, burning and digging topsoil for seedbed preparation, which led to low ground vegetation cover at the beginning of the rainy season (Maass et al., 1988; Tuan et al., 2014; Wicharuck, 2016). These activities influenced the change of the soil's surface due to the fact that the preparation of the seedbed broke down the soil aggregates and reduced soil pore connectivity. Subsequently, soil particles began to fill the soil pores through continuous rainfall, causing soil materials to erode down the slope. Nevertheless, crop development after seeding one to two months helped to decrease runoff and soil transportation. The formation of rills was also noticed during this period; however, the rills were filled by eroded material from the upper portion or nearby splashing material. This resulted in less translocated soil when maize and upland rice ground cover had fully established. In addition, the values of SR and SL were greater under UR than those values under M cultivation. This was due to maize sowing one month earlier than upland rice, leading to an advanced development of ground covered and decreasing the raindrop impact.

4.3. Sustainable traditional agricultural practices (M and UR) on sloping land in NTH

Due to the results mentioned above, M and UR production on sloping areas has led to remarkable soil erosion. However, M and UR are the main crops in the study area because these products are essential for home consumption and livestock, for example, maize grains for animals (mainly pigs and chickens) and rice for villager consumption. M and UR production with typical agricultural practices of land clearing-and-burning in highland areas should be incorporated with proper soil erosion control i.e., contour furrow construction for storing soil water in the soil profile. Burning of above-ground vegetation should be limited. Crop residues should be left in the fields for topsoil protection after harvesting and topsoil mulching should be employed. These activities can increase infiltration capacity and decrease the terminal velocity of raindrops. Natural erosion barriers, such as hedgerows of small trees or vetiver grass strips, should be established on the middle and lower slopes to reduce soil translocation down the slope. Relay cropping which was integrated between the main crop and additional crops, i.e., coriander, kidney bean and lablab bean, should be effectively introduced to the areas, especially under rainfed upland areas. Nevertheless, this advice must be steadily introduced since the farmers would be worried about losing a piece of land for crop plantation and yields.

Soil erosion prevention, control and mapping are the most important aspects of improved sustainable land management, including natural resource conservation (Buttafuoco et al., 2012; Nearing, 2013). Soil erosion estimation will allow for the development of appropriate soil conservation strategies (Ali and Hagos, 2016). It is essential to predict soil erosion in order to implement effective soil conservation measures in a specific area (Bagarello et al., 2012) because this will aid in the development of effective strategies for soil erosion protection, rehabilitation planning, and achieving long-term sustainable productivity as mentioned by Abdulkareem et al. (2019); Hajkowicz et al. (2005) and Lu et al. (2006). Therefore, long-term prediction of annual soil erosion should be introduced in order to find a better way to cultivate crops on sloping land with proper soil conservation, especially in the study areas.

5. Conclusion

Monoculture, M and UR cultivation, in NTH tended to generate a remarkable amount of SR and SL due to less or no ground cover protecting topsoil from the direct raindrop impact at the beginning of the rainy season. UR generated a much higher loss of SR and SL amounts when compared to M due to the earlier sowing date of M, leading to the higher ground covered. Therefore, the monoculture of M and UR (land clearing and burning practice) in highland areas should be integrated with soil and water conservation in order to control soil erosion, especially at the beginning of the rainy season.

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