EFFECTS OF TOPOSEQUENCE AND SOIL LOSS ON WEED SEED BANK DYNAMICS IN UPLAND MAIZE PRODUCTION

KHWANRAWEE ANUSORN

A Thesis Submitted to the Graduate School of Naresuan University
in Partial Fulfillment of the Requirements
for the Master of Science in (Agricultural Science)
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has been approved by the Graduate School as partial fulfillment of the requirements for the Master of Science in Agricultural Science of Naresuan University

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Title	EFFECTS OF TOPOSEQUENCE AND SOIL LOSS ON WEED SEED BANK DYNAMICS IN UPLAND MAIZE PRODUCTION
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ABSTRACT

Weeds are the major pests in maize production and cause yield loss. Weed seed bank dynamic consists of input and output processes of weed distribution and composition. Some seeds of seed rain are able to remain as soil seed bank while some of which could be dispersed by erosion and runoff water, especially happening at high slope angles and elevation. This study aimed to determine the effects of toposequence and soil loss on soil seed bank dynamics through seed output by seed removal under natural rainfall and seed input by seed rain. Micro plots (1 m^2) were installed on four slope positions (top, upper, middle, and down) in the upland maize production areas. Soil seed bank samples were collected using a soil core. Seed removal by natural rainfall was collected during rainy season in 2018. Seed rain was collected by seed traps for one year in 2019. The results showed that there were 95,095 seedlings/m^2 for soil seed bank, 399 seedlings/m^2 for seed loss, and 481,450 seeds/m^2 for seed rain. A number of seed losses by natural rainfall and seeds of seed rain were accounted for seed output and seed input process, respectively. Seed rain contributed the greatest proportion in the input process of soil seed bank. Soil seed bank was affected by toposequence. Amount of soil seed bank was greatest at down slope position compared to other slope positions ($p<0.05$). Moreover, Shannon’s diversity and evenness indices of soil seedbank were greatest at down slope position compared to other slope positions ($p<0.05$). Seed bank was removed or changed from the upper part to the lower part of slope position resulting in seed accumulation at the down slope position. Seeds from seed removal under natural rainfall and seed rain processes were affected by toposequence. Amount of seed losses were greatest at upper, down, and top slope positions, respectively. The quantity of sediments had positive correlation with quantity of seed losses (R^2=0.96). Thus, seed losses can be removed with sediment due to soil erosion. Seed rain amount was greatest at the upper, down, and top slope positions, respectively. *Ageratum conyzoides* was the dominant species with greatest amount in seed rain process, especially at upper and down slope positions. There was greater amount of seed rain at the upper and down slope positions compared to top and middle slope positions ($p<0.05$). Each slope position had unique pattern of soil seed bank dynamics. Moreover, soil seed bank dynamics can be used to predict weed species composition and quantity of seeds in the next crop season. Weed management should be done differently on slope positions and practiced before the reproductive stages to prevent the large input of seeds into the soil seed bank. In conservation approach, weeds can be used as a soil coverage during no planting period to protect soil surface from erosion.

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CHAPTER I

INTRODUCTION

Maize is the one of important agricultural products in Thailand which is being used for food, feed, and fuel (Edgerton, 2009). The northern region of Thailand contained approximately 800,000 ha of maize in 2014, representing 68% of the total maize acreages of the entire country (OAE, 2015). The maize production in the northern Thailand is mostly found in the upland (Figure 1). Upland maize production is a monoculture cropping in rain-fed areas, which is cultivated early in the rainy season and harvested in early September (DOAE, 2015).

Figure 1 Upland maize production in Nan Province, Thailand.

Weeds are one of major pest problems in maize production because they can compete with maize for sunlight, moisture, and nutrients (Birendra, Ranvir, Suman, & Mizzanul, 2013; Saeed, Khaliq, Cheema, & Ranjha, 2010) (Figure 2). In addition, weeds are host of insect-pest and diseases (Capinera, 2005). Weeds are reducing maize yield depended upon the composition of weed flora, period of crop-weed competition, and its intensity (Rai, Mahata, Lepcha, Nandi, & Mukherjee, 2018). Maize is sensitive to weeds infestation, especially in early stage of growth and development. If maize is heavily infested by weeds, maize yield is reduced ranging from 28 to 100% (Madhavi, Ramprakash, Srinivas, & Yakadri, 2014). However, emerged seedlings can maintain the biodiversity and conserve soil and water in field. In these function, weeds can help in controlling of soil and water losses, especially in the rainy season where surface soils are eroded. Soils and soil seed banks were lesser moved if there were more surface cover (De Rouw, Ribolzi, Douillet, Tjantahosong, & Soulileuth, 2018).

When weeds emerge, grow, and develop to the flowering stage, numerous seeds can disperse into a field and persisted in the soil for several years by many dispersal factors such as water, wind, animals, and human activities (Menalled, 2008). These seeds are depleted by germination, physiological aging, decay, predation, or removing from erosion and runoff (Hemantaranjan, 2008; Menalled, 2008). Seed population dynamics is changing all the time depended on seed inputs and outputs (García-Fayos, Recatalá, Cerdá, & Calvo, 1995; Jiao, Zou, Jia, & Wang, 2009; Menalled & Schonbeck, 2011).

Figure 2 Weed infestation in maize crop.

Nan province is the most growing maize area in the upper northern region and ranks in a second majority of maize production areas in Thailand (OAE, 2018). Farmers usually grow maize on the sloping areas. Along the toposequences, differences in elevations may present different weed species and number of seed banks (Tsubo et al., 2006). Moreover, intensive maize plantation in upland areas is susceptible to erosion (García-Fayos, García-Ventoso, & Cerdà, 2000; García-Fayos et al., 1995; Jones & Esler, 2004). Long-term uses of growing areas and process of weed management are associated with soil properties, soil seed bank, and erosion (Campos & Souza, 2003).

Changes in weed seed banks occur with time and weed management methods. A few of the current studies of weed management in maize in Thailand focused on the relationships between tillage systems on maize production such as the production of maize under no tillage, corn-legume relay cropping system in highland (Intafongkham, 2010), effect of tillage practices on soil properties and maize yield (Prasertsombut, 2011), and influence of maize density and weed-free period on yield under no tillage (Ruangkij, 2005). The information on soil seed bank dynamics in the upland maize in Thailand is needed for improving weed control methods and preventing soil erosion. Bochet (2015) studied on seed fate in overland flow with about 20% slope angle and focused on seed removal by runoff (seed characteristics and plant trapping capacity). The lack of data on seed dynamics including soil seed bank and seed rain was remained. A better understanding of input and output of weed seed bank, and species composition was needed for efficient weed management strategy, suitable land preparation method, and soil conservation. This study was conducted in upland maize production with slope angles of 35 to 45% and focused on weed seed bank species and composition. The objective of this study was to investigate the effects of toposequence and soil losses on weed seed bank composition, weed seed removal under natural rainfall, and weed seed rain in the upland maize production, Nan Province, Thailand.

Purposes of the Study

1. Investigate the effects of toposequence and erosion on weed seed bank composition.
2. Investigate the effects of toposequence and erosion on weed seed removal under the natural rainfall.
3. Investigate the effects of toposequence on weed seed rain.

Statement of the Problems

How do the toposequence and erosion affect weed seed bank dynamics in the upland maize production?

Scope of the Study

The study of weed seed dynamics was included the processes on initial soil seed bank, runoff seeds, and seed rain. Soil seed bank was collected before the growing season in May 2018. Runoff seeds were collected under the natural rainfall of 2018. Seed rain was collected between January and December 2019.

Basic Assumption

There were different seed bank patterns along the toposequence. Erosion affected the composition of weed seed bank, seed loss, and seed rain.

Key Words

Weed seed bank, Species composition, Seed removal, Seed rain, Erosion

Hypotheses of the Study

The down slope had more the number of seeds in soil seed bank than the upper and middle slopes due to seed transportation by runoff water and erosion.

CHAPTER II

LITERATURE REVIEW

Erosion and seed losses

In steep slope area, tillage, burning, and bare land after harvesting are sources of land degradation that lead to soil erosion and sediment loss, especially surface runoff in response to rainfall (Lipper, McCarthy, Zilberman, Asfaw, & Branca, 2017). Tillage makes the soil more erodible and increases the risk for the generation of concentrated flow (gullies). On the other hand, it can increase the roughness of the soil surface and water infiltration capacity. Soil crusting is one of the primary processes that can decrease the infiltration rate during rainfall events, reducing the total amount of water infiltration and increasing surface runoff (Bu, Wu, & Yang, 2014). Crusts form at the surface of unprotected soils due to the raindrops, splashing, detaching soil particles in a thin, and dense surface layer (Lacombe et al., 2018). Splash erosion is the initial detachment of soil particles by surface-hitting raindrops and a major factor controlling soil erosion (Marzen, Iserloh, Casper, & Ries, 2015). The splash erosion and crusting are two inseparable processes (Kukal & Sarkar, 2010). Result on soil erosion depends on many factors such as soil type, preceding fallow type, landscape position, field history, method intensity of soil cultivation, and rainfall characteristics (Turkelboom, Trébuil, & Vejpas, 1996). A strong relationship was found between the magnitude of seed transport by runoff and rainfall and slope characteristics. Under high rainfall concentration and high erosivity conditions, seeds on the soil surface can be exposed to overland flow, especially in bare soil. *Olea europea* seeds in amount of 21 to 61% were translocated to new sites under simulated rainfall within 3 m × 3 m plots placed in restored forested areas in Ethiopia (Aerts et al., 2006). Jiao et al. (2011) and Han et al. (2011) found that in laboratory experimental, seeds were moved 30 to 45, 46.9 and 20.4 % from one site to another site at intensities of 50, 100 and 150 mm/hr, respectively. Seeds transported by overland flow are not lost but seeds are moved from original location through to downslope (Bochet, 2015).

Estimation of seed density and species composition

Methods for soil seed bank and seed transportation by erosion and runoff.

There are numerous methods for investigation the density and composition of soil weed seed bank. Two main techniques used to counting number of seeds from the soil samples are 1) weed seed extraction method, and 2) weed seedling emergence method (Hussain et al., 2017). For extraction method, weed seeds are extracted by washing and floatation and then identified under a binocular microscope. In the weed seedling emergence technique, the soil sample is placed in the greenhouse or controlled environment, watered for seed emergence and these emerged seedlings are identified and counted (Gonzalez & Ghermandi, 2012; Luschei, 2003). Seed extraction methods can separate different seeds size and density from the soil. The residue and soil-material are hand-sorted under a binocular microscope for collecting seeds. Seed extraction method can detect greater seed densities than the seedling emergence method but the smallest-seeds in extraction method are failed in seed detection, which may be lost during processing sample (e.g., through sieving) (Gonzalez & Ghermandi, 2012). Ishikawa-Goto and Tsuyuzaki (2004) found that seed density is higher obtained by flotation method than that of a germination method. In seedling emergence methods, the soil samples are spread in trays under suitable conditions to promote the germination of seed (Gonzalez & Ghermandi, 2012). This method is simple but takes long time period to make seed germination and fail to detect dormant seeds. Some seeds are germinated in specific requirements. Small seeds (< 2 mm) can be found in this method (Price, Wright, Gross, & Whalley, 2010).

Methods for seed rain study.

There are different ways of measuring seed rain and numerous types of seed traps. Funnels traps have often been described as the best trapping method, catching the highest number of seeds (Kollmann & Goetze, 1998). Funnel traps could collect greater seeds depended on trap installing and position. Funnels should be placed 1 to 2 cm above the soil surface because the most height of seed fall and avoid seed decomposition and removal by ground animals (Cottrell, 2004; Kirk, 2018). Kollmann and Goetze (1998) suggested that 8 to 10, 20-diameter funnels are suitable to detect common species. Seed rain collection can identify for 2 methods which are seeds germination and seedlings identification directly from traps. The first method is commonly used because they do not require seed identification skills. The method of direct seed identification from trap can be done under a binocular microscope, and all seeds are removed. Seeds from library can be photographed and images digitally stored to aid lab workers in identifying seeds from trap collections. In addition, seed identification is more accurate count of seed rain than germination which dormancy and germination requirement are problems (Cottrell, 2004; Gonzalez & Ghermandi, 2012).

Maize production in Thailand

Maize (*Zea mays* L.) is one of five major crops in Thailand, among rice, cassava, sugarcane, and rubber. The total quantity of maize production in Thailand was about 4,804,670 tons in 2014 (FAO, 2016). Generally, maize cultivation in this region is classified into two generations. The first generation is cultivated in the rainy season (May to October) and primarily harvested in early September. The second generation is cultivated in the dry season (November to April) and primarily harvested in February (DOAE, 2015). Maize is mainly grown as the first crop in every region of Thailand at the beginning of the rainy season and is harvested after 100 to 120 days. Maize occupies a major portion (about 33%) of Thai upland farmlands and is mainly grown in the upland rain- fed areas in Thailand (Ekasingh, Gypmantasiri, Thong Ngam, & Krudloyma, 2004). The upland maize production in Nan starts once a year between May and November. Maize is cultivated in the uplands successively with fields mechanically ploughed and with herbicide application (i.e. glyphosate and atrazine). General management practices can differ from field to field. In some fields, the growers are not ploughed due to steep land or insufficient financial resources and sprayed with herbicides before sowing and others use either conventional or minimum tillage. Later in the season, herbicides are commonly sprayed at least once during the season (i.e. in June) (Heppa et al., 2017).

Weed infestation

Weeds are the one of major pest problems in maize production because weeds can compete with maize for sunlight, moisture and nutrients (Birendra et al., 2013; Saeed et al., 2010). In addition, weeds are host of insect-pests and diseases (Capinera, 2005). Maize is grown as a widely spaced crop that can be infested with a variety of weeds and subjected to a heavy weed infestation. Maize yield decreases due to weed infestation ranging from 28 to 100% (Madhavi et al., 2014). In other crops, crop yield was reduced around 15 to 100 % if presence of weeds in farm and weeds can also reduce product quality (Saeed et al., 2010). Intensity and type of weeds are reducing factors in maize yield by 40 to 60% (Sunitha & Kalyani, 2012). Weeds infestation during germination to 45 days after sowing can reduce maximum maize yield (Das et al., 2016). Travlos, Economou, and Kanatas (2011) found that maximum maize yield are lost by 24 to 34% if barnyard grass (*Echinochloa crus-galli* L.) appears at an early stage, and about 9% if barnyard grass appeared after V4 stage growth. Barnyard grass can be reducing maize seed yield by 15 to 30% or 0.75 to 1.5 tons per hectare (Pasaribu, 2015). The magnitude of losses largely depends upon the composition of weed flora, period of crop and weed competition, and weeds intensity (Rai et al., 2018). The study of weed flora in maize field in West Bengal, India reported that the major weeds were *Polygonum persicaria*, *P. pensylvanicum*, *P. orientale*, *Oldenlandia diffusa*, *O. aquatic*, *Oxalis corniculata*, *Stellaria media*, *S. aquatic*, *Physalis minima*, *Solanum nigrum*, *Hydrocotyl ranunculoides*, *Ageratum conyzoides* (appeared at latter part of crop growth), *Cyperus rotundus*, *Cynodon dactylon*, *Digitaria ciliaris*, *Setaria glauca*, *Echinochloa* sp. and highly aggressive species were *Polygonum* sp., *C. dactylon*, *D. ciliaris*, *S. glauca* (Mukherje & Rai, 2015).

Weed seed bank dynamics

Weed seeds are an important component of the weed life cycle as they are the origin of the future populations, especially annual and simple perennial species (Gulden & Shirtliffe, 2009). Weed seeds can reach the soil surface and become part of the soil seed bank through several processes. High initial population results in a high density of weeds surviving cultivation and competing with the crop. Initial weed population is directly related to the density of seeds in the soil seed bank (Brainard, Bellinder, Hahn, & Shah, 2008; Teasdale, Mangum, Radhakrishnan, & Cavigelli, 2004). Seed population dynamics is changing all the time depended on seed inputs and outputs (Figure 3) (García-Fayos et al., 1995; Jiao et al., 2009; Menalled & Schonbeck, 2011). Seed bank dynamics regulate many of weed species communities (Barberi & Lo Cascio, 2001). Soil seed bank is a critical component of the dynamics, conservation and sustainable management of the ecosystems related to the past, present, and future of soil seed bank (Miao, Li, & Jiang, 2013; Wen-Ming, Xue-Mei, & Ling-Hao, 2004). Weed seed banks are the main source of weed infestation in crops and agricultural soils can contain thousands of weed seeds per square foot (Menalled & Schonbeck, 2011). Of the many seeds in the seed bank, very few actually emerge and produce plants.

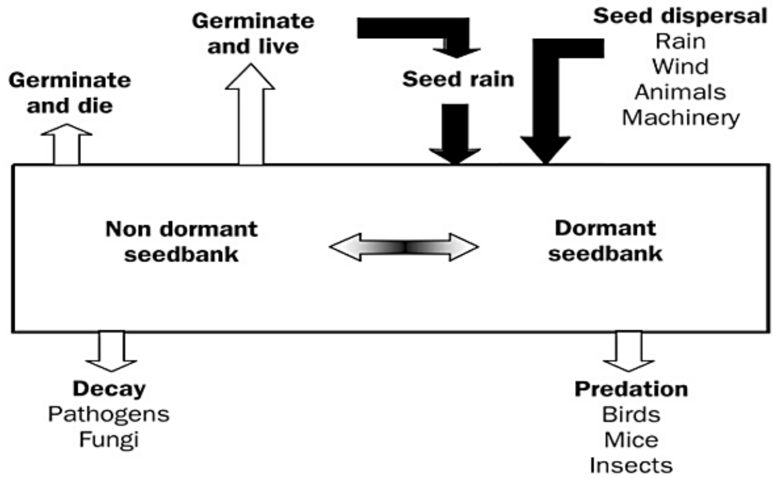

Figure 3 Fate of weed seed bank. Seed inputs to the seed bank are shown with black arrows and losses with white arrows. (Source: Menalled, 2013)

The input of seed refers primarily to a seed rain (García-Fayos et al., 1995). Seeds disperse after ripening and then form a seed rain, which are from mother plants that mature in the area (Renner, 2000). Species dispersal abilities can contribute differentially to local species diversity. The similarity of species composition of seed rain to standing vegetation is an important content of vegetation regeneration (Yu et al., 2015). Agricultural weed seeds can enter to field by many ways such as animals, wind, water, and human activities (Menalled, 2008). After seed disperses, seeds remain on the soil surface until they germinate, emerge, grow, and produce more seeds. But some seed are death, decay in the soil or predations such as insects, birds or mammals. Some seed will die before reaching a maturity stage (Menalled & Schonbeck, 2011). When seeds enter into soil seed bank, some seeds can be buried in the soil (Chambers & MacMahon, 1994). Many weed seeds remain dormant in the soil and not germinate under any sets of environmental conditions. In rainfall intensities area, soils are tend to loss of surface by runoff and seed dispersal by surface wash may alter accumulation pattern (Aerts et al., 2006). The surface runoff is transport of sediments can result in seed output through removal, which reduces the seed in the soil seed bank (García-Fayos et al., 2000; García-Fayos et al., 1995; Jones & Esler, 2004)

Vegetation cover and soil conservation

Vegetation cover shows several positive impacts as it can contribute to water infiltration, soil surface protection, strength and fertility, as well as to biological activity and thus biodiversity in soils. Using vegetation in ecological rehabilitation or restoration projects can promote the recovery of ecosystem structures and functions (Stokes et al., 2014). The development of agricultural activities has especially influenced many processes such as erosion, contamination, decline in organic matter, compaction, salinization resulting in the loss of biodiversity in lands (Pimentel, 2006). In South-East Asia, long-term monitoring of soil erosion has highlighted the necessity to adopt appropriate land use management strategies to mitigate soil degradation (Valentin et al., 2014). The seed stage (through a constitution of a seed bank) may play a more important role in natural recovery of degraded ecosystems in tropical climate. Moreover, soil erosion was not the limiting factor for natural recovery of vegetation. Later vegetation stages, such as germination and seedlings may be more important for vegetation recovery.

CHAPTER III

MATERIALS AND METHODS

Study site

The study was conducted in the upland maize production with the present of gully erosion at Ban Thap Man, Na Noi District, Nan Province, Thailand. (18°19'30.0"N 100°34'17.3" E). In the study site, growers have been produced maize as a monocrop for over 30 years with reduced tillage practice (5-6 years per time). Maize has been grown once a year and relied on natural irrigation from rainfall. Field was plowed in May 2018 for planting preparation. Farmers use glyphosate (48% W/V SL) at 300-500 g ai/rai (1 rai = 0.16 ha) was applied for weed control in late of June 2018 before planting. Maize (*Zea mays* L.) cultivar CP 888 (Charoen Pokphand Produce Co.Ltd (Thai) Limited) was planted in early July 2018 using a planting stick at a spacing of 25 cm along the row and 75 cm between rows. For fertilizer application, NPK 46-0-0 + NPK 16-20-0 were applied on 30 days after planting on August, 4 2018 with the rate of 25 kg/rai. For the second application at the V12 development stage for maize grown, NPK 46-0-0 + NPK 16-20-0 were applied for the second at August, 23 with the rate of 25 kg/rai (Figure 4).

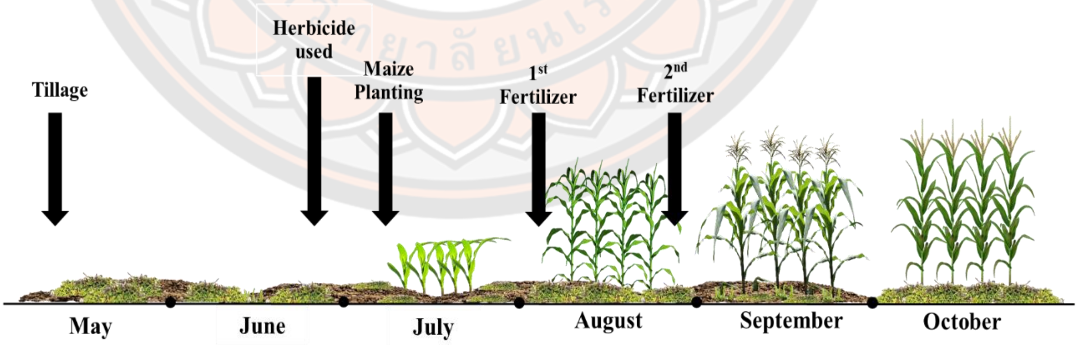

Figure 4 Timeline of maize production and field practices in 2018.

The study area was in a tropical savannah climate. Annual temperatures ranged from a high of 35.1°C to a low of 17.1°C, with an average annual temperature of 26°C in 2018. The total annual rainfall at the experimental site amounted to 1,205.3 mm and rainy season starts in May and ends in October 2018 (Figure 5). There were 12 rainfalls with high intensity caused erosion (at least 25 mm). Runoff volume and sediment data were collected. Accumulation of rainfall volume in each event ranged from 133.8 to 52.4 mm. There were 12 rainfall events during rainy season in 2018 (Table 1).

Table 1 Data of rainfall volume, runoff volume and sediment dried weight for twelve rainfall events lead to soil erosion in rainy season in 2018.

Events	Date	Rainfall volume (mm)
1	5/25/2018	133.8
2	6/12/2018	85.4
3	6/21/2018	63.6
4	7/3/2018	56.8
5	7/17/2018	88.2
6	7/23/2018	80.4
7	7/31/2018	91.4
8	8/18/2018	59.4
9	8/23/2018	69.8
10	9/7/2018	52.4
11	9/12/2018	54
12	10/3/2018	126.2

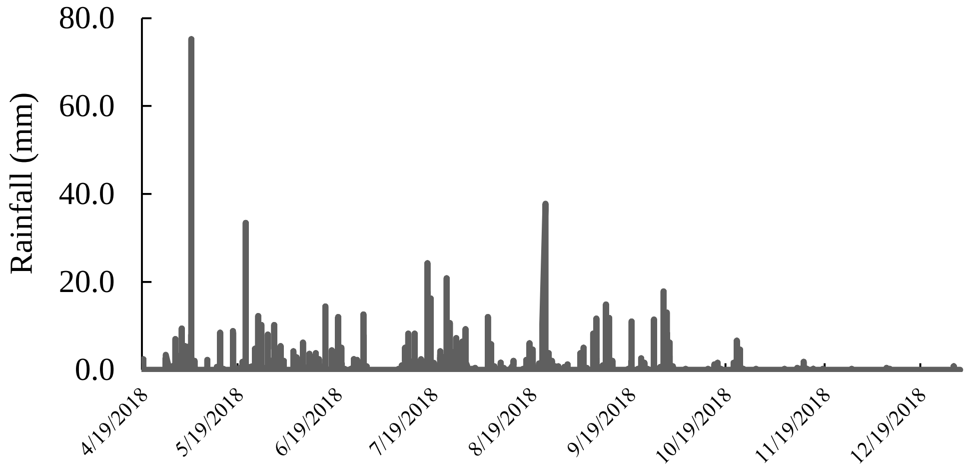

Figure 5 Distribution of daily precipitation in 2018 at study site in Nan province.

Soil on the study site was classified as a Typic Haplustalfs (Wang Saphung series) according to Soil Survey Staff (2018) with a bulk density (BD) of 1.15 g/cm^3. The topsoil (0 to 25 cm.) had a pH (H_2O) of 6, an organic matter content (OM) of 3.57%, a total nitrogen content (N) of 0.18%, an available P (Bray II) content (P) of 21.23 mg/kg and an exchangeable K content (K) of 181.29 mg/kg. Physical and chemical properties of soil profile in each slope position are presented in Table 2. Soil texture was clay at top, upper, and down slope positions while silty clay at middle slope position. Bulk density was not significant difference in each slope position. The study site has slope angle ranged from 35% to 45%.

Table 2 The physical and chemical properties of topsoil samples (0-20 cm) of the study site along with four slope positions.

Positions	Texture (%)			Soil texture	Bulk Density (g/cm^3)
	Clay	Sand	Silt		
Top	61	7.27	31.73	clay	1.20ns[1]
Upper	47.29	13.30	39.41	clay	1.19
Middle	40.13	17.34	42.53	silty clay	1.20
Down	40.94	21.21	37.85	clay	1.33

[1]ns = Non-significant difference

Experimental design

The study plots were installed in four slope positions, down, middle, upper, and top slope positions (Figure 6). The plot of study was built by using a micro-plot size of 1 m² connected with a waterspout and a bucket to collect seeds carried by runoff under natural rainfall (Figure 7). There were three micro-plot per slope position and 12 micro-plots in total.

Figure 6 Micro-plot position for soil sampling and collection of seed transportation from runoff and seed rain.

Figure 7 A micro plot structure consists of two parts; micro-plot and a pipe carrying runoff and sediments.

Soil seed bank experiment

Soil samples were collected randomly around the micro plot using a soil core (8 cm diameter x 10 cm depth). Three soil cores were taken and combined on each of left, right, and top sides of each micro-plot to be three sub-samples for each micro-plot (Figure 8). Soil samples were stored in labelled plastic bag and transported to a greenhouse. Soil was air-dry and sieved through 5 mm size to remove stones and residues. Weed germination method modified from Bhatt and Singh (2007) was used to study a soil seed bank and estimate the viable seeds in soil. Soil volume of 1,125 cm^3 were spread on top of peat moss covered with landscape fabric in a plastic tray size 25x25 cm^2. The soil samples were kept in a greenhouse and watered daily. Seedling were counted every 2 weeks. The seedlings were either identified and removed from the tray or transplanted for later identification. Once the initial germination phase was completed, soil samples were air-dry for a week, soil in the tray was stirred to expose un-germinated seed to favorable conditions of emergence and re-watered to restart the next of germination cycle.

Figure 8 Position of soil samplings (red dots) and groups of sub-replications in each micro-plot for soil seed bank study.

Runoff seed experiment

Runoff water and sediments were collected from the bucket connected with a micro- plot as previously described after each rainfall event of at least 25 mm/ hr between June to November 2018 (Figure 9). Runoff water and sediments were filtered through a cotton fabric 0.15 mm mesh size, which was smaller than the diameter of the presence of smallest seeds in the study area. The sediments were air- dried and transported to laboratory for germination study. Sediments were washed pass through 3 different sieve sizes 0.71, 0.30, and 0.15 mm to separate seeds by size and removed litter. Sediments from each sieve size were used for germination study by spreading on top of germination paper in a petri dish and water as needed. Petri dishes with sediments were kept at 25 °C and 12 hr photoperiod. When seedlings emerged, they were counted and removed from a dish weekly until no seedling emergence. In each month, the sediment was dry at 35°c for 24 hr and remixed to start the next germination cycle. Sediments were watered to continue the emergence method.

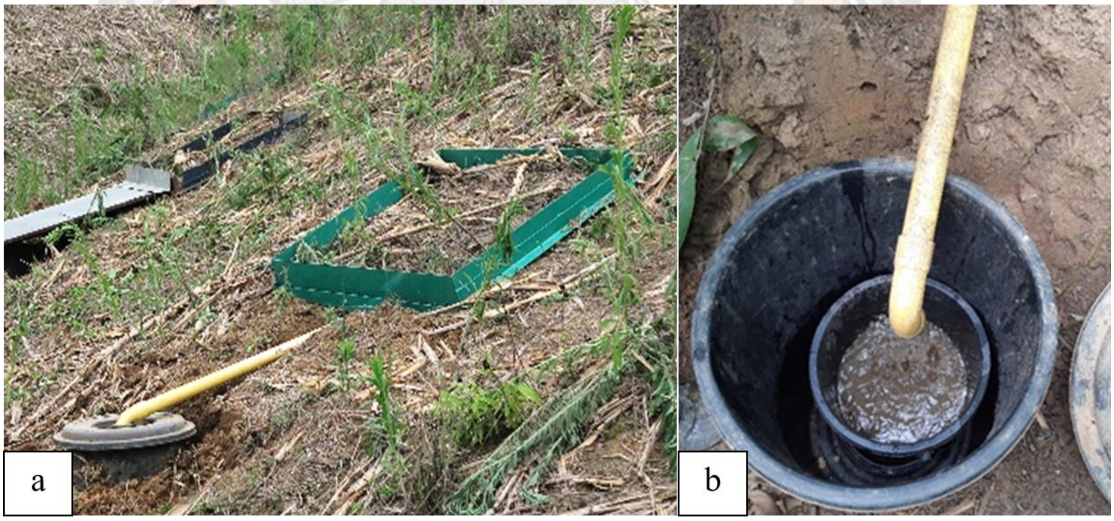

Figure 9 Micro-plot structure. A bucket and tubes are linked with each micro-plot for storage runoff water and sediments. Side view (a) and Top view (b).

Seed rain experiment

Seed rain was collected using seed rain trap in a cone shape which has been described as the best trapping for getting high number of seeds in Kollmann and Goetze (1998) and Zhang and Chu (2015). A seed rain trap consisted of a 20 cm diameter of plastic funnel with a 0.5 mm mesh at the end to protect the bag from predators. Fabric of a 0.15 mesh was attached to the funnel. The funnel was put on a metal frame above soil surface 1 to 2 cm to avoid seed decomposition by runoff and removal by ground animals. Four traps were installed on top of micro plot (Figure 9). The trap was about 25 cm above ground. Weed seeds passing through the funnel and fall into the bags were collected monthly from December 2018 to May 2019. Seeds were identified in the laboratory using a dissecting microscope (Jakobsson, Eriksson, & Bruun, 2006).

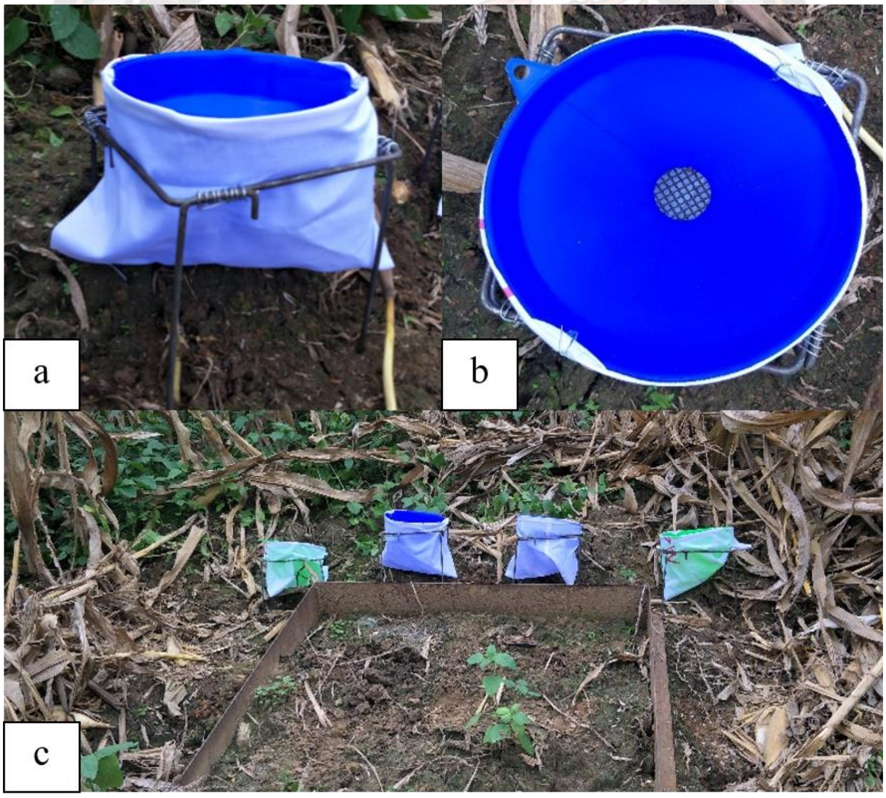

Figure 10 Seed rain trap structure. Side view (a); top view (b) and seed rain traps on top of a micro-plot (c).

Data analyses

Soil seed bank

Number of seed species in soil seed bank across slope positions of top, upper, middle and down slope positions were recorded. Data of seedling numbers from 36 samples (3 samplings x 3 micro-plots x 4 slope positions) of soil surface area were transformed by area of square meter to achieve a number of seedlings per square meter. Total seedlings were analyzed using ANOVA and means were separated by a Least Significant Difference (LSD) at $P \leq 0.05$.

In order to determine weed community structure affected by slope positions, species and number of emerged seedlings across slope positions were used for analysis and measured the species diversity calculate using Microsoft Excel following equations:

Shannon–Wiener index (H') = $-\sum_{i=1}^{s} pi \ln pi$ (1)

Where pi is the number of individuals of one species in relation to the number of individuals in the population and i is the total number of individuals in one species.

Pielou's evenness index (E) = H' / lnS (2)

Where H' is the Shannon diversity index of sample and S is the total number of species in the sample.

Species richness (Dmg) = (S-1)/ ln N (3)

Where S is the total number of species, N is the total number of individuals and ln is the natural logarithm.

Total seedling, Shannon's diversity and evenness index and species richness of seed rain along slope position were analyzed using ANOVA. Means were separated by a Least Significant Difference (LSD) at $P \leq 0.05$.

Soil losses, seed removal by erosion and runoff, and seed rain

Data of soil losses, seed removal amounts, and seed rain along slope positions were analyzed using ANOVA. Means were separated by a Least Significant Difference (LSD) at $P \leq 0.05$. Correlation between sediment dried weight, seedling number and runoff volume were analyzed using linear regression in Microsoft excel. Statistical analyses were performed using R statistical program (RCoreTeam, 2018).

CHAPTER IV

RESULTS AND DISCUSSION

Soil seed bank

Species compositions of soil seed bank along four slope positions were identified and counted using seedling emergence method. After 80 weeks of germination cycle, seed bank species were identified to 40 species (Table 3). Mostly, the recorded species were annual herbaceous. The species were classified in to 19 families which were Asteraceae (Figure 11). Species lists and their families with life cycle and morphology type of emerged seedling of soil seed bank in 2018.

Table 3 Species lists and their families with life cycle and morphology type of emerged seedling of soil seed bank in 2018.

Families	Scientific name	Life cycle[1]	Habit[2]
Asteraceae	*Acmella ciliata* (Kunth) Cass.	Pe	H
	Ageratum conyzoides (L.) L.	An	H
	Blumea balsamifera (L.) DC.	An	H/S
	Blumea sp.	An	H
	Conyza sumatrensis (S.F.Blake) Pruski & G.Sancho	An	H
	Crassocephalum crepidioides (Benth.) S.Moore	An	H
	Cyathocline purpurea (Buch.-Ham. ex D.Don) Kuntze	An	H
	Laggera sp.	An	H
	Vernonia cinerea (L.) H.Rob.	An	H
	Unknown S1	-	H
Acanthaceae	*Andrographis paniculata* (Burm.f.) Nees	An	H
Aizoaceae	*Trianthema portulacastrum* L.	An	H
Araceae	Unknown S5	-	H
Cyperaceae	*Fimbristylis miliacea* (L.) Vahl	An	H
	Kyllinga nemoralis (J.R.Forst. & G.Forst.) Dandy ex Hutch. & Dalziel	Pe	H
Dennstaedtiaceae	*Pteridium aquilium* (L.) Kuhn	Pe	TerF
Fabaceae	*Mimosa pudica* L.	Pe	ExH
	Unknown S4	-	T
Lamiaceae	*Hyptis capitata* Jacq.	An	H/S
Lygodiaceae	*Lygodium flexuosum* (L.) Sw.	Pe	CF

Families	**Scientific name**	**Life cycle**[1]	**Habit**[2]
Onagraceae	*Ludwigia hyssopifolia* (G.Don) Exell	An	H
Orobanchaceae	*Lindenbergia philippensis* (Cham. & Schltdl.) Benth.	Pe	H
Oxalidaceae	*Oxalis corniculata*	An	H
Pteridaceae	*Pteris vittata* L.	Pe	F
Poaceae	*Echinochloa colona* (L.) Link	An	H
	Eleusine indica (L.) Gaertn	An	H
	Leptochloa chinensis (L.) Nees	An	H
	Paspalum conjugatum P.J.Bergius	An	H
	Thysanolaena latifolia **(**Roxb. ex Hornem.) Honda	An	H
Rubiaceae	*Spermacoce alata* Aubl.	Pe	H
	Spermacoce exilis (L.O.Williams) C.D.Adams ex W.C.Burger & C.M.Taylor	An	H
	Oldenlandia diffusa (Willd.) Roxb.	An	H
	Oldenlandia ovatifolia (Cav.) DC.	An	H
	Unknown S2	-	H
	Unknown S3	-	T
Salicaceae	*Flacourtia rukam* Zoll. & Moritzi	Pe	T
Selaginellaceae	*Selaginella helferi* Warb.	Pe	F
Urticaceae	*Elatostema* sp.	An	H
Others	Unknown S6	-	H
	Unknown S7	-	H

[1]Life cycle: An = Annual, Pe = Perennial

[2]Habit: CF = Climbing fern,

H = Herbaceous,

Exh = Exotic herb,

F = Fern,

S = Shrub,

T= Tree,

TerF = Terrestrial fern

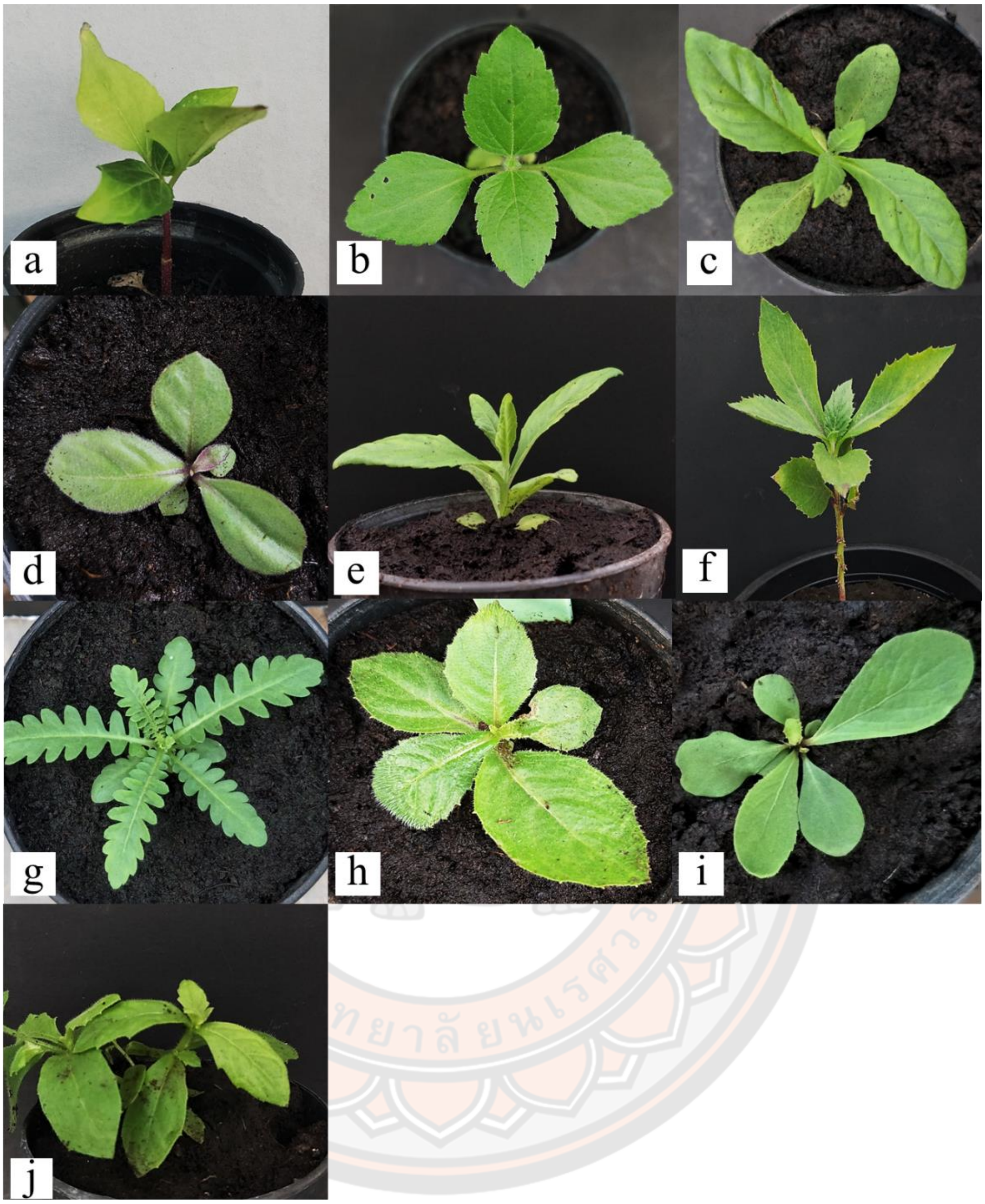

Figure 11 Seedling of seed bank in Asteraceae family. *Acmella ciliata* (a), *Ageratum conyzoides* (b), *Blumea balsamifera* (c), *Laggera* sp. (d), *Conyza sumatraensis* (e), *Crassocephalum crepidioides* (f), *Cyathocline purpurea* (g), *Blumea* sp. (h), *Vernonia cinerea* (i), and unknown S1 (j).

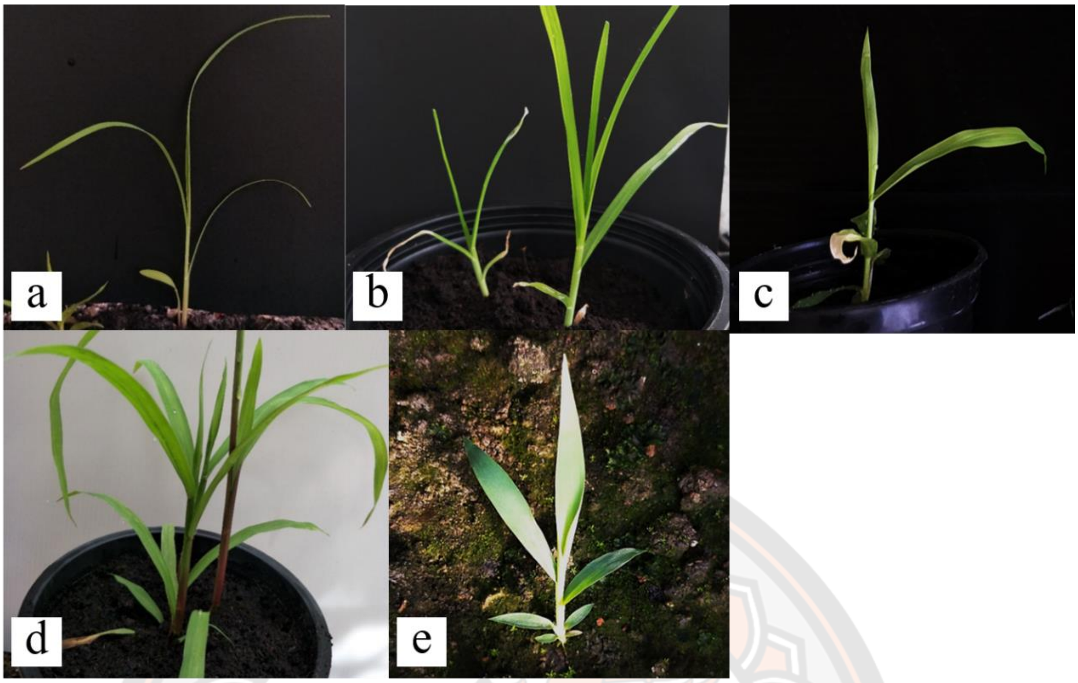

Figure 12 Seedling of seed bank in Poaceae family. *Echinochloa colona* (a), *Eleusine indica* (b), *Leptochloa chinensis* (c), *Paspalum conjugatum* (d), and *Thysanolaena latifolia* (e).

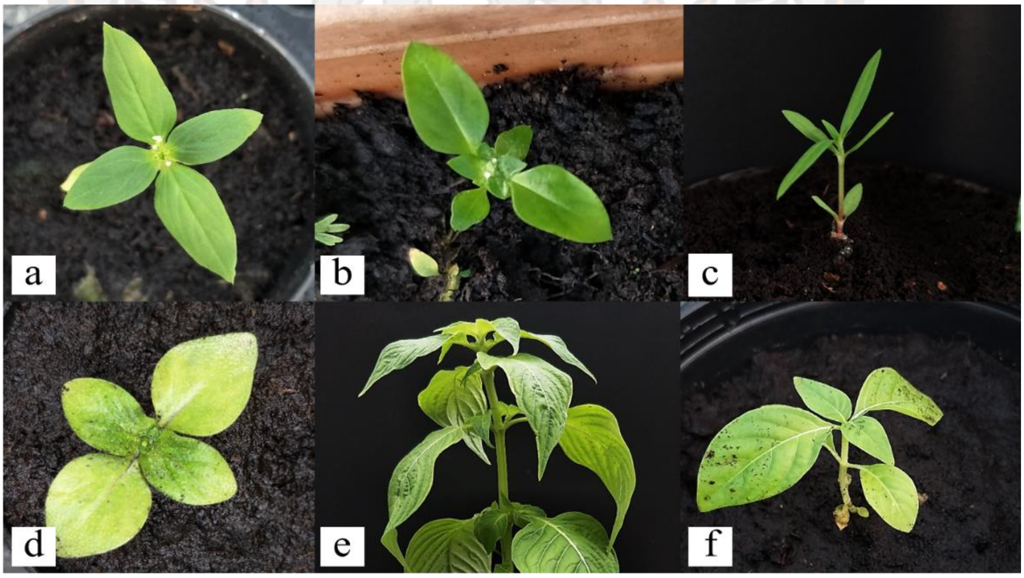

Figure 13 Seedling of seed bank in Rubiaceae. *Spermacoce alata* (a), *Spermacoce exilis* (b), *Oldenlandia diffusa* (c), *Oldenlandia ovatifolia* (d), Unknown S2 (e), and Unknown S3 (f).

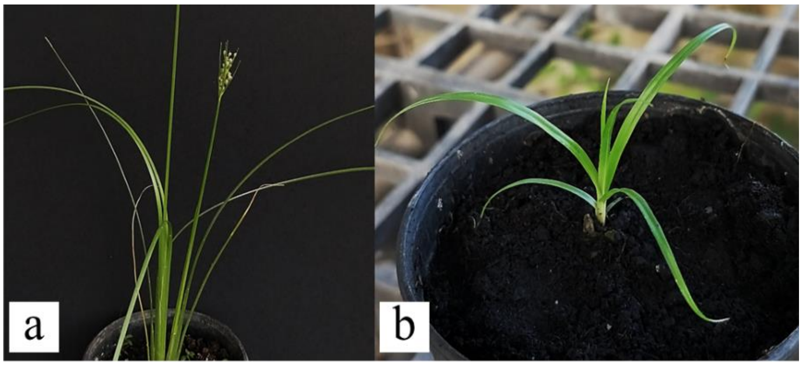

Figure 14 Seedling of seed bank in Cyperaceae family. *Fimbristylis miliacea* (a) and *Kyllinga nemoralis* (b).

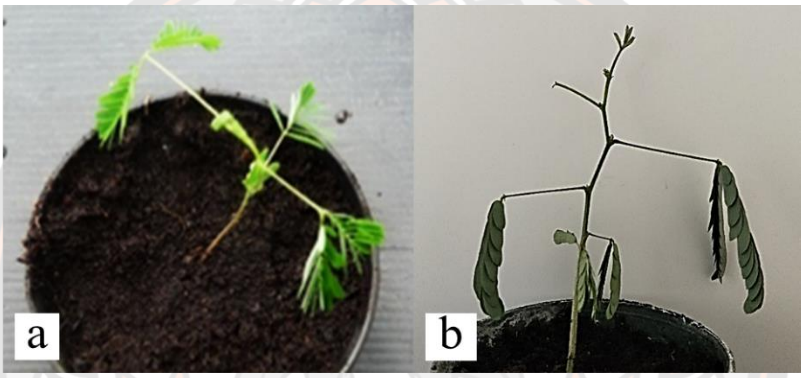

Figure 15 Seedling of seed bank in Fabaceae family. *Mimosa pudica* (a) and unknown S4.

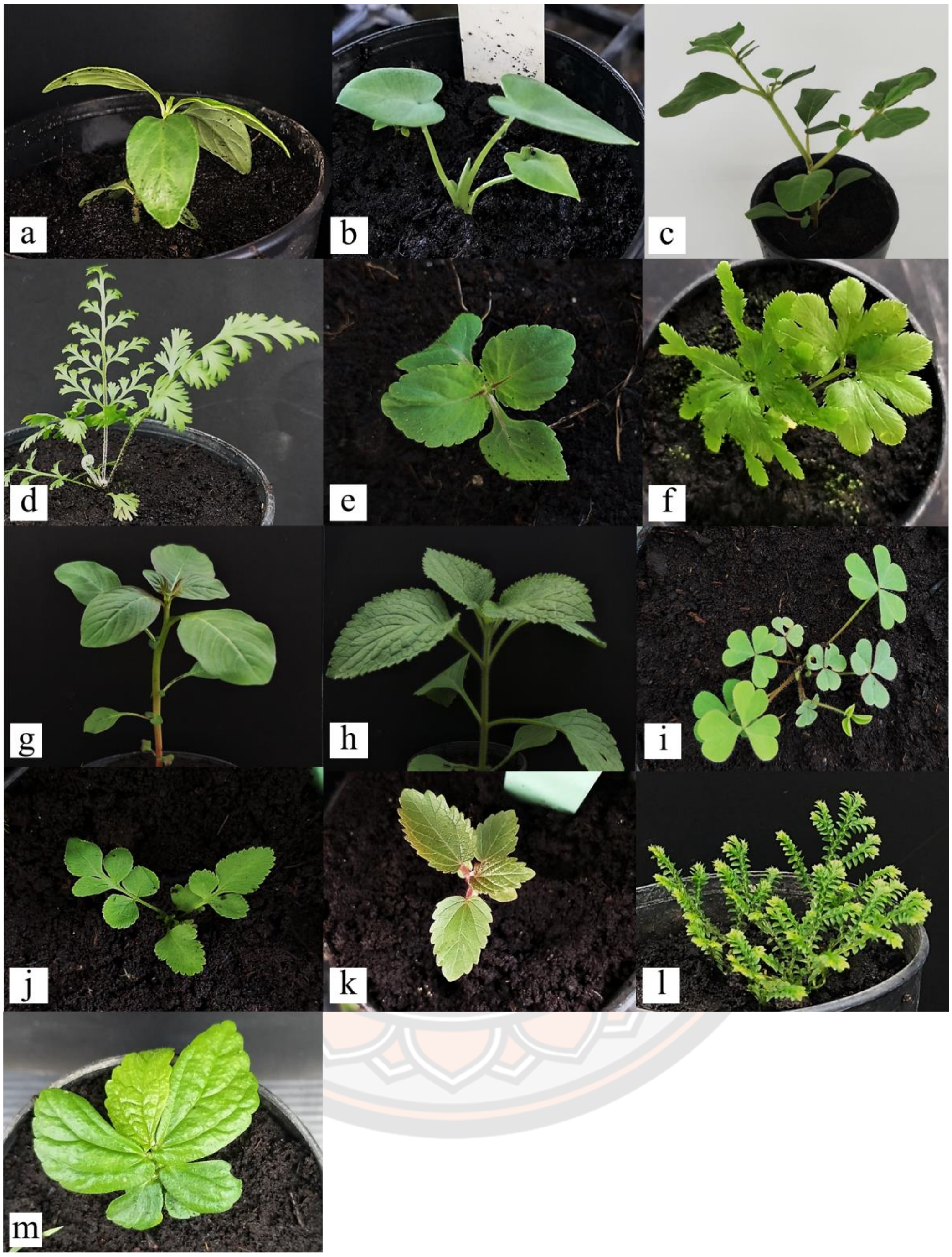

Figure 16 Acanthaceae; *Andrographis paniculata* (a), Araceae; unknown S5 (b), Aizoaceae; *Trianthema portulacastrum* (c), Dennstaedtiaceae; *Pteridium aquilium* (d), Lamiaceae; *Hyptis capitata* (e), Lygodiaceae; *Lygodium flexuosum* (f), Onagraceae; *Ludwigia hyssopifolia* (g), Orobanchaceae; *Lindenbergia philippensis* (h), Oxalidaceae; *Oxalis corniculata* (i), Pteridaceae; *Pteris vittata* (j), Salicaceae; *Flacourtia rukam* (k), Selaginellaceae; *Selaginella helferi* (l), Urticaceae; *Elatostema* sp. (m).

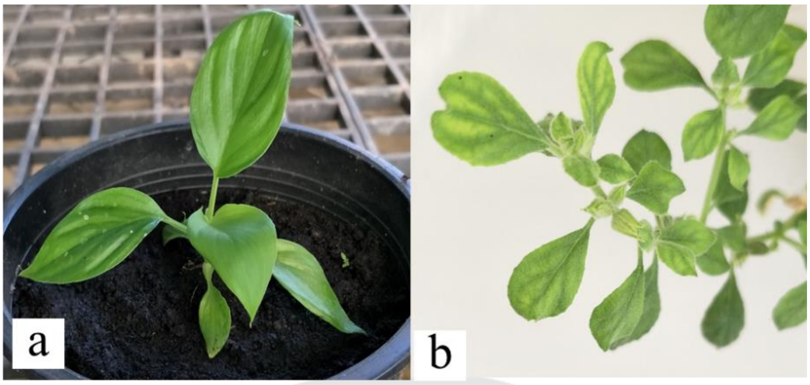

Figure 17 Seedling of seed bank of unknown species.
Unknown S6 (a), and unknown S7 (b).

There were significant differences in emerged seedlings of soil seed bank along difference slope positions ($P < 0.05$) (Figure 18). The number of emerged seedlings was accounting for 12.6, 12.9, 30.8 and 43.7% of total soil seedlings emergence from soil seed bank for top, upper, middle and down slope positions, respectively. The number of emerged seedlings was greatest at down slope position (41,140 seeds/m^2) and lowest at top and upper slope positions (11,853 and 12,121 seeds/m^2, respectively). The down slope position had the greatest amount of soil seed bank. Seeds were dispersed and accumulated at down slope due to many factor such as seed morphology of dominant species, wind, water, animal or machinery. Moreover, seeds at the top and upper slope positions had a greater opportunity to expose to the solar radiation than the lower slope position resulting in the low viability of seed bank. Havrdová, Douda, and Doudová (2015) reported that the large accumulation was probably a result of unsuitable light condition for germination. This result agreed with our hypothesis that the down slope had more the number of seeds in soil seed bank than the upper and middle slope positions.

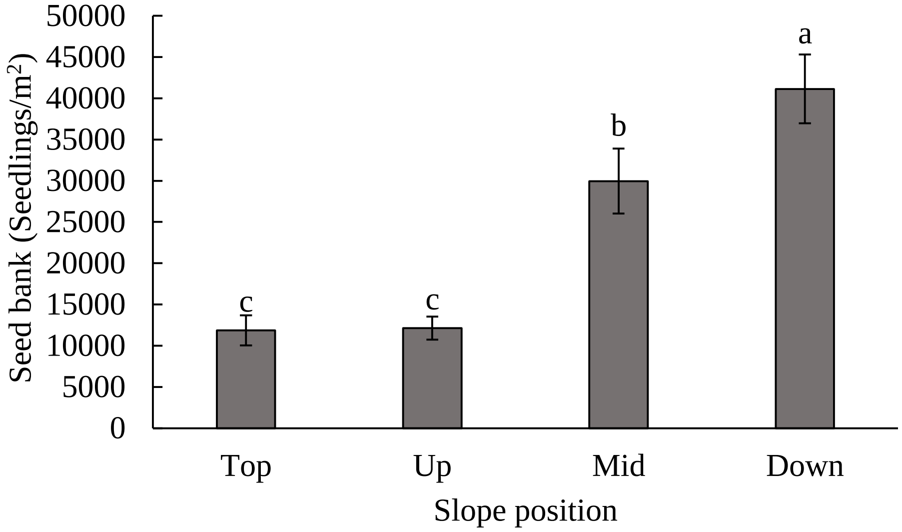

Figure 18 The number of emerged seedlings of soil seed bank along slope positions.

According to soil seed bank data, emerged plants were mostly in Asteraceae followed by Poaceae, Rubiaceae, and Cyperaceae with frequency of 22.5, 12.5, 10 and 5% of all presence species, respectively. Dominant species were herbaceous, broadleaf weeds (Table 3). The results showed that all slope positions similarity shared 14 species (Table 4). The total number of similar species in each position were 19, 23, 33, and 25 for top, upper, middle, and down slope positions, respectively. The most abundant weed species were *Ageratum conyzoides*, *Lindenbergia philippensis*, *Pteridium aquilium*, *Spermacoce exilis*, and *Lygodium flexuosum*, respectively. The greatest seed bank species, *A. conyzoides* dominantly accounted for 56.7% of total emerged seedlings in all slope positions. *A. conyzoides* was found the greatest at middle slope position. *L. philippensis*, *P. aquilium*, *S. exilis*, and *L. flexuosum* were mostly found at the down slope position (Table 4).

Table 4 Species composition of emerged seedlings from soil seed bank study in 2018.

Scientific name	**Frequency (%)**	**Seed bank (seedlings/m^2)**				**Sig.**[1]
		Top	**Upper**	**Middle**	**Down**	
Acmella ciliata	0.15	0	69	20	49	ns
Ageratum conyzoides	56.66	10,019	8,204	21,260	14,377	***
Andrographis paniculata	0.61	118	256	138	69	**
Blumea sp.	0.15	0	59	39	39	ns
Blumea balsamifera	1.05	404	79	227	286	ns
Cyathocline purpurea	0.03	10	0	0	20	ns
Conyza sumatrensis	0.49	168	89	89	118	ns
Echinochloa colona	0.37	20	0	207	128	*
Eleusine indica	0.09	30	20	30	10	ns
Flacourtia rukam	0.03	0	0	10	20	ns
Hyptis capitata	0.19	0	49	59	69	ns
Laggera sp.	0.23	20	59	49	89	ns
Leptochloa chinensis	0.08	10	20	30	20	ns
Lindenbergia philippensis	22.61	355	1,676	4,418	15,048	***
Lygodium flexuosum	1.31	59	79	434	671	**

Scientific name	Frequency (%)	Seed bank (seedlings/m^2)				Sig.[1]
		Top	Upper	Middle	Down	
Oldenlandia diffusa	0.26	69	99	59	20	ns
Oldenlandia. ovatifolia	0.13	0	99	0	30	**
Oxalis corniculata	0.33	30	89	128	69	ns
Paspalum conjugatum	0.03	0	10	20	0	ns
Pteridium aquilium	12.25	355	937	2,199	8,175	***
Pteris vittata	0.52	49	0	20	424	**
Selaginella helferi	0.49	79	99	237	49	ns
Spermacoce alata	0.04	0	0	0	39	ns
Spermacoce exilis	1.38	0	10	10	1,292	***
Thysanolaena latifolia	0.25	59	89	79	10	ns
Vernonia cinerea	0.05	0	0	49	0	ns
Others	0.02	20	30	140	20	ns
Total species		8	11	13	13	**
Total families		6	8	9	9	*

[1] * Significant difference across slope positions at $p \leq 0.05$, ** Significant at $p \leq 0.01$, *** Significant at $p \leq 0.001$ and ns = not significant.

The emerged species in soil seed bank were mostly herbaceous (Table 3). For plant characteristic group, herbaceous were greatest seedling number of soil seed bank. Olaloye and Oke (2016) found that herbaceous species had the highest number of seedlings from the seed bank of riparian forest and upland vegetation in Nigeria. Asteraceae and Poaceae were the commonly found families in our study which had similar to study of soil seed bank in the upland crops (rice, maize, and rubber tree) in Chiang Rai Province, northern part of Thailand of Neyret (2016). Plant families which reported the commonly found weed species in Asteraceae and Poaceae from the weed survey. Many weed species in upland rice in Thailand such as *A. conyzoides*, *A. paniculata*, and *E. indica* in Asteraceae and Poaceae were serious weeds (Nam-Matra, 2017). There were other important factors affected the presence of weed species such as climate, topography characteristic, edaphic factors, human activities, diversity index, and plant life forms (Lazarina et al., 2019; Neyret, 2016).

Weed species composition on each slope position differed. A number of plant species were found the greatest at the upper, middle, and down slope positions and lowest at top slope position ($p<0.05$) (Table 4). *A. conyzoides*, *L. philippensis*, and *P. aquilium* were commonly found species at all slope positions. Meanwhile *S. exilis* was abundant at down slope while *Andrographis panuculata* was frequently at upper slope position compared to other slope positions ($p<0.05$). *S. exilis* has been presented in disturbed areas, especially at low elevation (FloraFaunaWeb, 2019). Dominant species mostly found at middle and down slope positions supported why the lower slopes (middle and down) were found the amount of soil seed bank and species higher than upper slope positions (upper and top).

Diversity indices of different slope aspects was showed in Figure 19. The Shannon’s diversity and evenness indices were greatest at down slope while these indices were lowest at the top slope. The greatest of diversity and evenness at down slope position was possibly because seeds were removed by runoff or wind and can be accumulated in soil at down slope. Similarly, Mota, Rezende, da Silva Mota, Fernandes, and Nunes (2016) reported the highest species diversity at lower elevation and a pattern of decreasing species richness and abundance with increasing elevation. Erosion and runoff affected seed removal through lower part (Menalled, 2008). Furthermore, Zeng et al, (2014) found that slope position significantly influenced species diversity by the positions with higher species richness had higher diversity. Their dominance is lower. There were effects of slope and aspect on vegetation (Austrheim, 2002; Lovett, Marshall, & Carr, 2006; Zhang and Zhang, 2015). Changes in slope and aspect may lead to changes in hours of sunshine, humidity, and temperature, all of which affect community development (Virtanen et al., 2010; Wu, 1980).

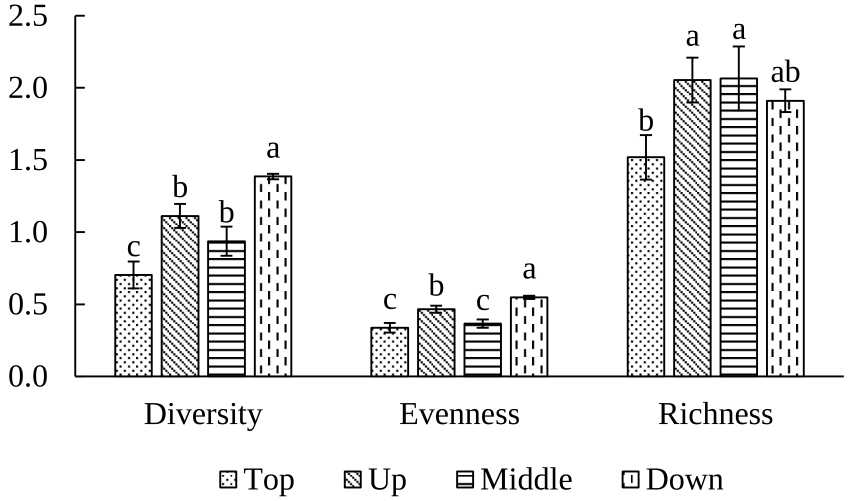

Figure 19 Diversity indices of plant species composition on different slope positions. Different letters above the error bar in the same index show significant difference between slope positions.

Seed losses by erosion and runoff water

There were twelve events with enough rainfall intensity (at least 25 mm) causing erosion in rainy season from May to October 2018. The number of seed removals and soil losses by erosion and runoff water were range 44 to 1 55 seeds/m^2 and 447.07 to 2,045.32 g/total runoff volume (L), respectively (Figure 20; 21). Sediment losses had a strong positive correlation with total amount of seed losses compared to runoff volume (R^2=0.97) (Figure 22). Amount of seed losses was greatest at upper, down and top slope positions while lowest at middle slope position (Figure 20). Amount of sediment losses was greatest at top slope position and lowest at middle slope position (Figure 21).

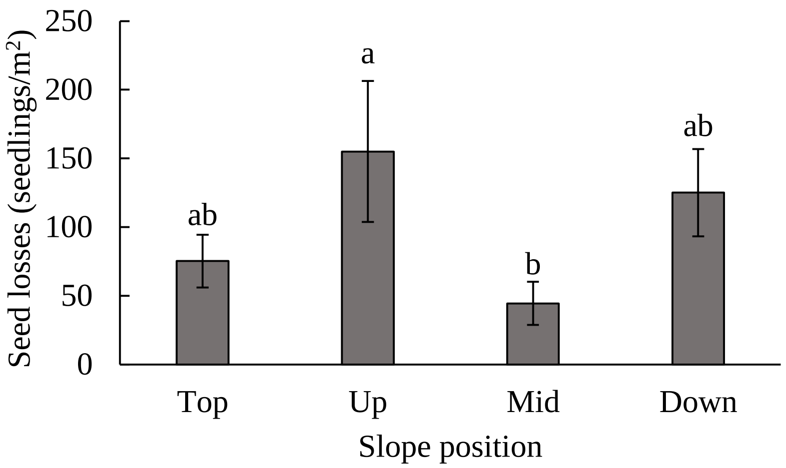

Figure 20 Amount of seed losses by natural rainfall along slope positions.

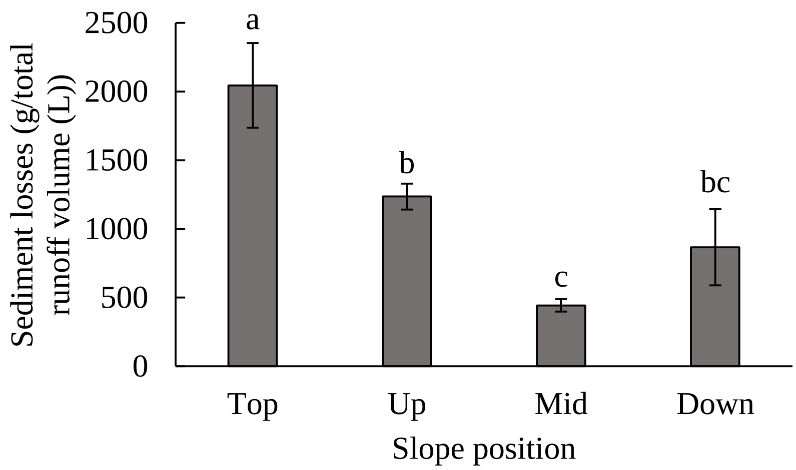

Figure 21 Amount of sediment losses by natural rainfall along slope positions.

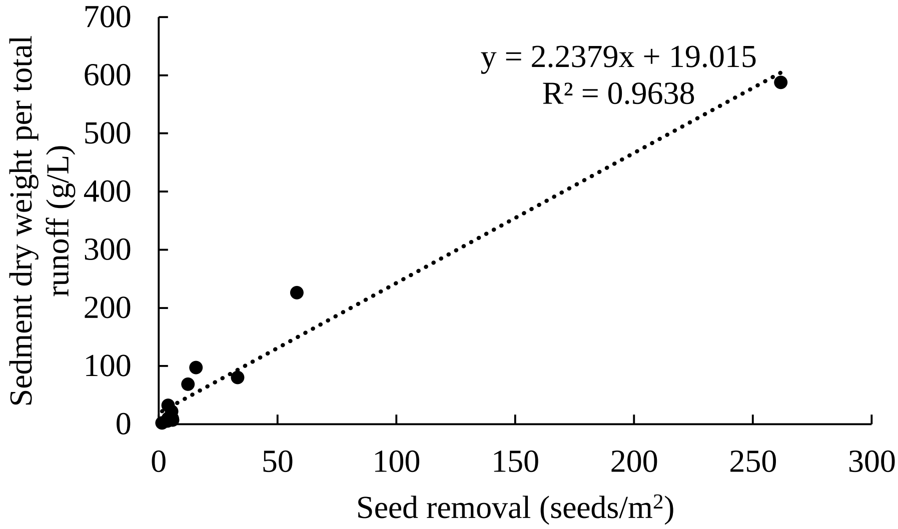

Figure 22 Correlation between number of seedlings emergence and amount of sediments from runoff of 12 rainfall events during rainy season in 2018.

Slope positions was affected amount of sediment and the number of seed losses. The lowest of sediment and seed losses at down slope position due to concave shape. Many studies have reported a relationship between soil erosion and slope shape. Meyer and Kramer (1969) reported that less sediment exportation occurs on concave slopes compared with other shapes (i.e. linear, convex or S-shape). Moreover, Wang, Jiao, Lei, Chen, and Wang (2013) reported that hoof print or hoof print and vegetation can reduce seed loss on the slope area. Although slope shape affected seed losses, the different conditions may be changing patterns of seed removal. García-Fayos et al. (1995) reported that number of seed losses increased as the slope angle increased on badland slopes in southeastern Spain. In contrast, Aerts et al. (2006) found that seed loss was not related to slope gradient in a regenerating semiarid woodland in northern Ethiopia.

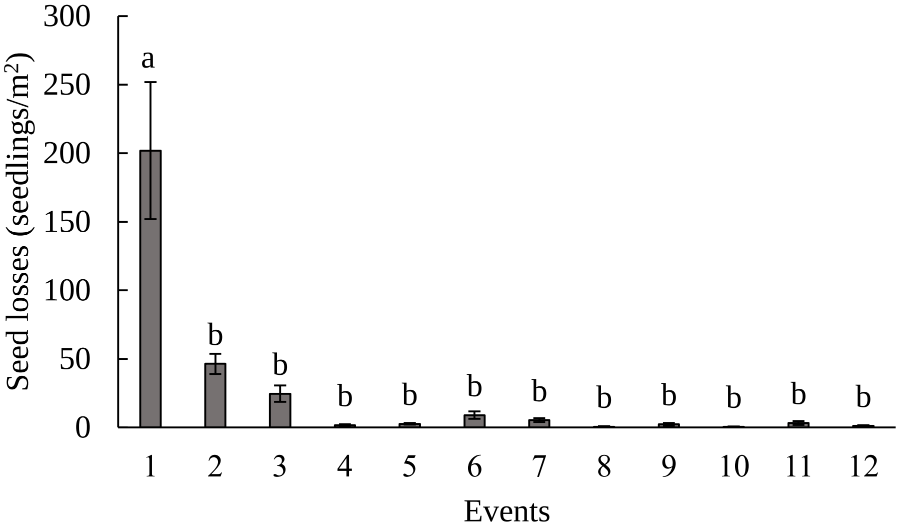

Figure 23 Amount of seed losses by 12 rainfall events by natural rainfall in 2018.

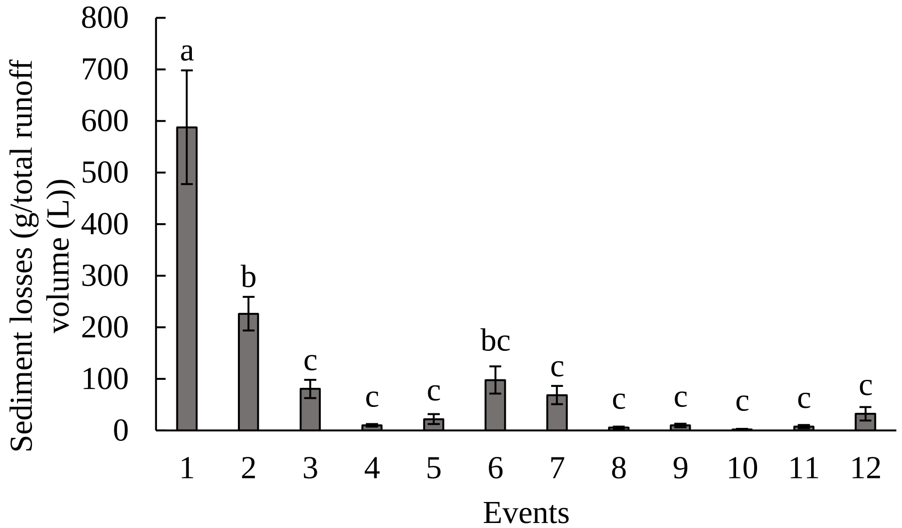

Figure 24 Amount of sediment losses by 12 rainfall events by natural rainfall in 2018.

Among 12 rainfall events, sediment and seeds were eroded (Figure 23; 24). At the first rainfall event in May 2018, soil bed was bared due to the land preparation before starting season (Table 5) and influenced soil and seed losses by erosion and runoff water (Figure 25 and 26a). At the first rainfall, there was the greater sediment losses compared to the following rain because soil surface was without vegetation cover. The amount of sediment and seed losses were lesser after May when soil surface had been covered with emerged maize. On the second and third erosion events in June 2018, the number of seed losses was decreased. The number of seed losses increased in the fourth erosion event because farmers applied pre-emergence herbicide to control weeds in the field and no vegetation covered soil surface. Maize was planted in July. During July to October, soil surface was covered with maize resulting in the reduction of sediment and seed losses (Figure 26c-f). The last rainfall event occurred in October which provided the runoff volume similar to the first rainfall event (Table 5). Although, a number of seed losses was lower compared to the first rainfall event, the surface covered by maize can help to protect and cover soil surface from runoff (Figure 26a; 26f). Maize at different growth stages can reduce force of soil detachment which was the first step of soil erosion (Lacombe et al., 2018). Similarly, Bochet, Rubio, and Poesen (1998) and Zuazo et al. (2008) mentioned that plant canopy can help to reduce the energy of raindrops, soil and seed losses by erosion and runoff water. Soil and seed losses by erosion and runoff water depended on many factors such as amount of runoff water, rain intensity, and rainfall duration (Wang et al., 2013). Total of seed losses were highly related to runoff volume and sediment yield (Bochet, 2015).

Table 5 Erosive events, field activities, maize growth stage, and vegetation cover in the field survey of 2018.

Events date	Field activities	Maize growth stage	Vegetation cover[1] (%)	Runoff volume (L)	Sediment weight per total runoff (g/L)	Seed losses (seeds/m^2)
5/25/18	Field unmanaged	-	3.58	33.49	587.53	202
6/12/18	Field unmanaged	-	41.5	19.37	226.05	46
6/21/18	Herbicide application	-	41.5	17.81	80.42	25
7/3/18	Soil Preparation	-	21.75	7.01	9.66	2
7/17/18	Maize sowing	V0	21.75	7.44	21.80	3
7/23/18	None	V2	21.75	24.37	97.57	9
7/31/18	Maize seedling transplanted	V5	21.75	24.30	68.51	5
8/18/18	1st fertilizer application	V8	35.92	3.22	5.61	1
8/23/18	2nd fertilizer application	V9	35.92	15.14	9.60	2
9/7/18	None	V14	31.75	2.51	1.88	1
9/12/18	None	VT	31.75	12.61	7.29	3
10/3/18	None	R3	39.08	20.34	32.22	1

[1] Vegetative coverage was evaluated monthly in 2018.

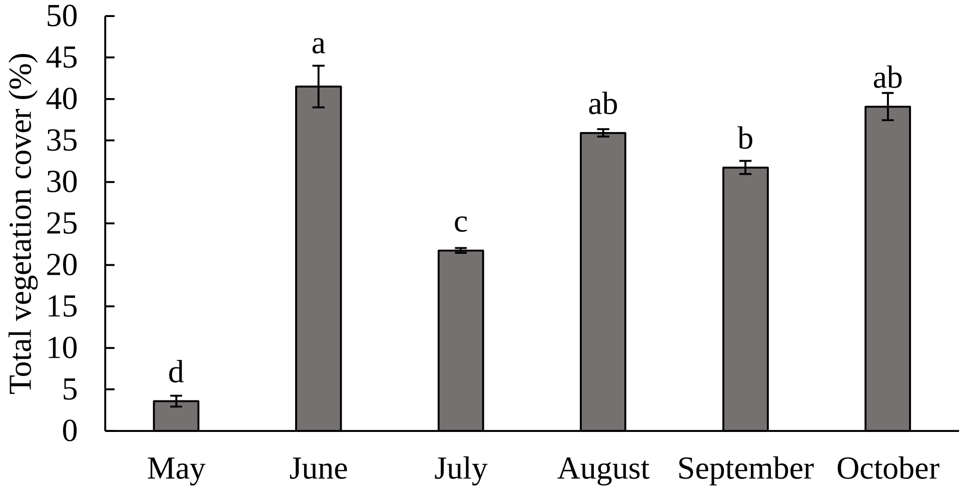

Figure 25 Percentage of vegetative coverage include maize and weed in each month during rainy season in 2018.

Figure 26 Soil surface coverd by vegetationin in different months in 2018. May (a), June (b), July (c), August (d), September (e), and October (f).

Prediction of seed losses from vegetation survey

The number of seed losses from erosion and runoff water was observed using seedling emergence method in a petri-dish. Sediments and seeds were separated by size at 0.15, 0.30 and 0.71 mm sieve to remove residues and rocks from field. The greatest number of seeds were found at 0.3 mm sieve size compared to other sieve sizes ($p<0.05$) (Figure 27). Seedlings were not identified to species due to the rapid emergence of seedling in sediment samples and high quantity of sediment losses at the beginning of rainy season (1,227 g of sediment for the first rainfall event).

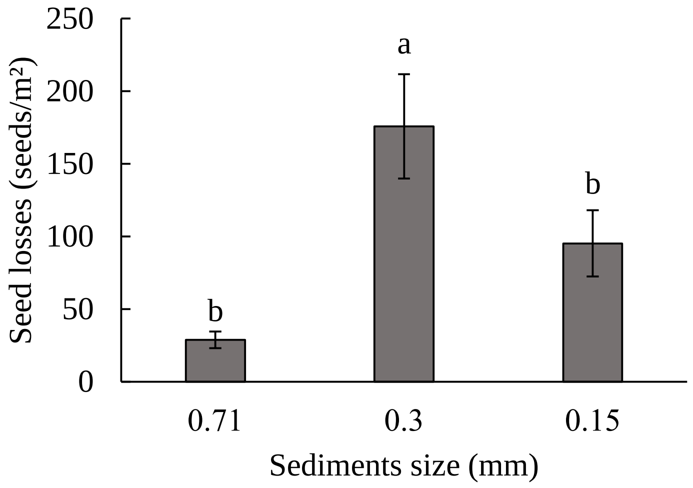

Figure 27 Amount of seed losses by erosion and runoff classified by sediment size.

Seed losses by erosion and runoff water caused by many factors such as slope angle, rainfall intensity, surface roughness and vegetation cover (Cerdà & Garcıa-Fayos, 2002). In addition, seed size can influence the losses. The results showed that a number of seeds with height between 0.70 to 0.30 mm were greater than those with the height of 0.29-0.15 mm and more than 0.71 mm (Figure 27). Large seed size may not be removed or had slightly displacement by erosion and runoff water. Seed weight and shape were mainly affected seed removal rate in rainfall simulation (Jiao et al., 2011). Cerdà and Garcıa-Fayos (2002) reported that seed weight increased the removal rate when seed weight was less than 50 mg, however, seeds greater than 50 mg with spherical shape increased removal rate greater than plate shape.

Seed rain

Weed seeds dispersed by wind were collected using seed traps every month for 12 months in 2019. There were 481,489 seeds found in the seed rain experiment. Plants were identified to 15 species belong to 9 families along slope positions. Species in Asteraceae (*Ageratum conyzoides*, *Conyza sumatrensis*, *Crassocephalum crepidioides*, *Praxelis clematidea*, and Unknown R2) was the greatest found following by Poaceae (*Pennisetum polystachyon*, *Thysanolaena latifolia*, and Unknown R5) family. Species in Asteraceae can produce more seeds and their seeds dispersed by wind due to appendages (pappus). Two dominated species, *Ageratum conyzoides* and *Conyza sumatrensis* were presented in different slope positions account for 85.78 and 13.27% of all seed numbers, respectively (Table 6).

Table 6 Frequency and amount of seed rain species along slope positions.

Species	Frequency (%)	Seed rain (seeds/m^2)			
		Top	Upper	Middle	Down
Ageratum conyzoides	85.780	68,323	138,587	63,542	142,566
Amaranthus viridis	0.018	46	3	15	21
Conyza sumatrensis	13.286	29,624	11,229	22,919	198
Crassocephalum crepidioides	0.406	1,644	289	13	10
Hyptis capitata	0.019	3	8	8	72
Oxalis corniculata	0.067	0	88	222	15
Pennisetum polystachyon	0.018	5	59	21	3
Praxelis clematidea	0.004	0	3	8	10
Spermacoce alata	0.007	8	21	0	8
Thysanolaena latifolia	0.003	5	3	5	0
Unknown R1	0.007	3	8	10	13
Unknown R2	0.077	232	108	10	21
Unknown R3	0.002	0	3	3	5
Unknown R4	0.001	0	3	0	0
Unknown R5	0.304	353	343	340	430

Amount of seed rain was compared along slope positions. Seed rain density was different along slope positions (Figure 28). The greater amount of seed rain was found at the upper and down slope positions compared to the middle slope position (Figure 28). *Crassocephalum crepidioides* and *Oxalis corniculata* were found greater number of seeds at top and middle slope positions, respectively while *A. conyzoides* was found lowest number of seeds at the top and middle slope positions. Moreover, *Hyptis capitata* was greater at down slope position.

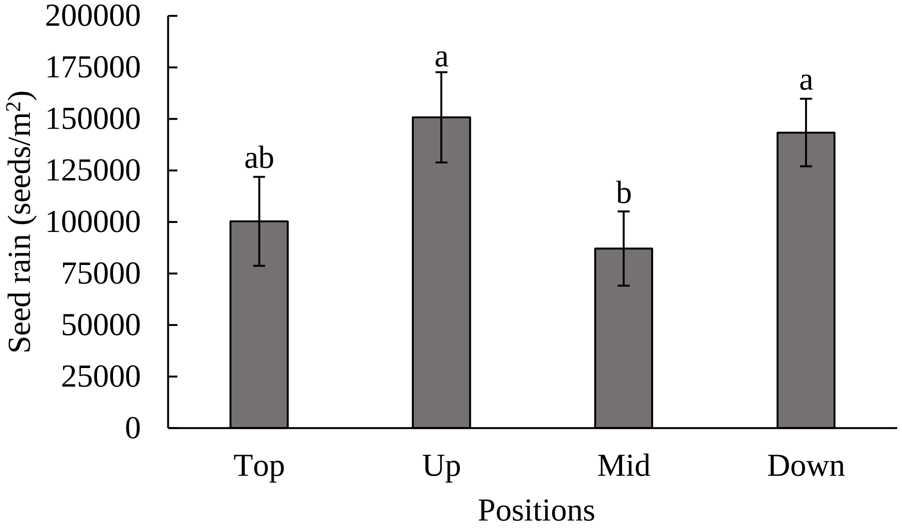

Figure 28 Amount of seed rain along slope positions in 2019.

Total amount of seed rain among 12 month periods was compared (Figure 29). The lesser amount of seed rain between March and September was possibly due to the land management for maize production. In addition, the canopy of maize can cover the soil resulting in the lesser weed growth due to the limitation of light. The seed quantities were greater in January, October, and December compared to other months in 2019. This was possibly due to no land disturbance during maize season. In October to December, maize was in harvesting stage and there was no land management during those time. Without management and less shedding from dry maize plant, weeds were able to grow and reproduce seed. It was possible that weed seeds from adjacent areas could disperse by wind and added up the total amount of seed rain.

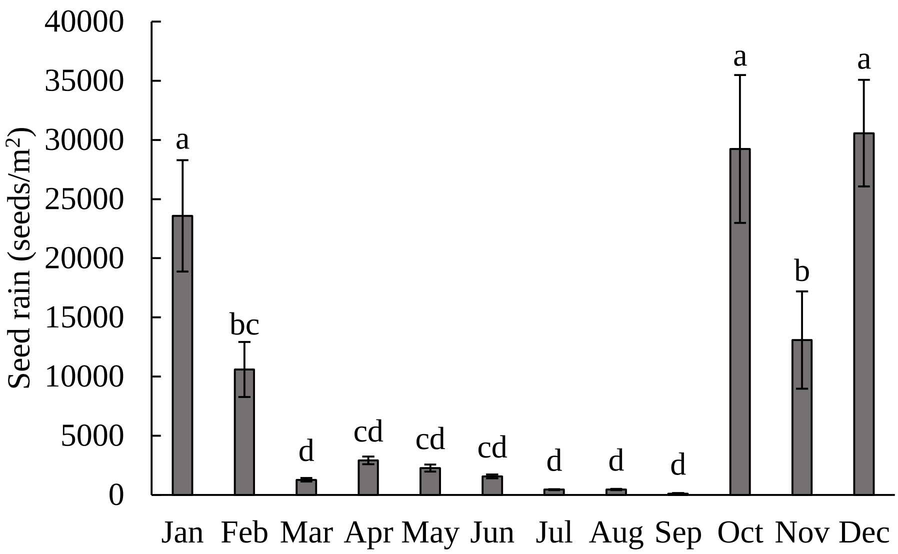

Figure 29 Amount of seed rain in each month during the survey of maize field in 2019.

Amount of seed rain in each month was presented in figure 29. The results showed that seed rain was present in on all slope positions in monthly. Seed were identified to species and counted. Most seed rain species has been presented in soil seed bank (Table 4 and 6). Abundant species in seed rain were *A. conyzoides* and *C. sumatrensis* because they can produce many seeds with appendages (pappus) (Figure 30). Species which were abundant in the regional species pool were also abundant in the local community (Marteinsdottir, 2014). However, some species was not found in soil seed bank. It was possible that some species might disperse from other or nearby areas. The new species which was dispersed long distance to the sites and under the right establishment conditions, might colonize, and change the community dynamics (Marteinsdottir, 2014). In contrast, some seeds might be lost due to possible predation and dispersal before falling into the trap (Du, Guo, Gao, & Ma, 2007). Seed rain was usually related to seed production (Martínez-Duro, Ferrandis, & Herranz, 2009; Zhai et al., 2010). Although, *A. conyzoides* had more weight compare to *C. sumatrensis*, *A. conyzoides* had greater disperse than *C. sumatrensis* and other species (Table 7). Öster, Ask, Cousins, and Eriksson (2009) and Schamp, Chau, and Aarssen (2008) concluded that in the forest, colonization abilities of plants were unlinked to seed mass. The small seed mass with low weight to surface area has a slow descent rate (Meyer & Carlson, 2001). In contrast, Wang et al. (2013) reported that small seed species have increased their opportunities to long-dispersal.

Table 7 Seed sizes and weight of seed rain species.

Species	Width (mm)	Length (mm)	Weight (mg/seed)
Ageratum conyzoides	0.49	2.03	0. 1
Amaranthus viridis	1.03	1.03	0.12
Conyza sumatrensis	0.44	1.68	0.03
Crassocephalum crepidioides	0.57	2.59	0.2
Hyptis capitata	0.93	1.49	0. 4
Oxalis corniculata	1.11	1.72	0. 2
Pennisetum polystachyon	0.95	2.48	0. 6
Praxelis clematidea	0.64	3.20	0. 2
Spermacoce alata	0.83	1.20	0.15
Thysanolaena latifolia	0.48	1.48	0.01
Unknown R1	1.30	1.84	-
Unknown R2	0.39	1.39	0.05
Unknown R3	0.46	2.07	-
Unknown R4	1.09	1.98	0. 5
Unknown R5	0.45	0.65	0.04

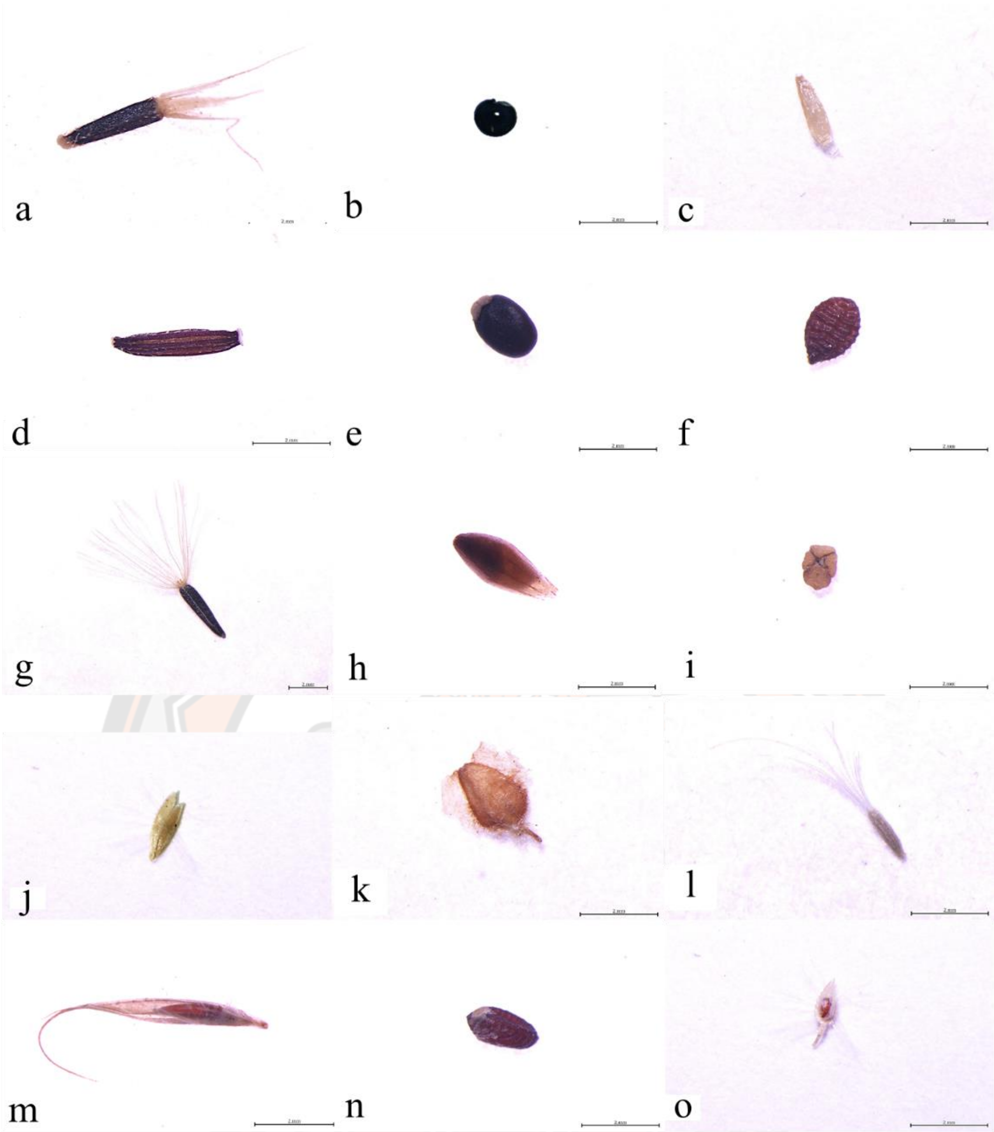

Figure 30 Seed morphology of seed rain species. *Ageratum conyzoides* (a), *Amaranthus viridis* (b), *Conyza sumatrensis* (c), *Crassocephalum crepidioides* (d), *Hyptis capitata* (e), *Oxalis corniculata* (f), *Praxelis clematidea* (g), *Pennisetum polystachyon* (h), *Spermacoce alata* (i), *Thysanolaena latifolia* (j), unknown R1 (k), unknown R2 (l), unknown R3 (m), unknown R4 (n), unknown R5 (o).

Soil seed bank dynamics

Herbaceous species are mostly sources of plant seeds in soil seed bank. Soil seed bank dynamics compose of seed input and seed output process (Menalled, 2008). Soil seed bank, seed losses by runoff (output), and seed rain (input) were parts of processes of soil seed bank dynamics. Seed species in soil represented species communities and they were changed by seed input and output. Based on the result from three experiments, there were total 94,060 seedlings/m^2 of soil seed bank, 399 seedlings/m^2 for seed losses and 481,450 seeds/m^2 for seed rain. The seed rain showed greatest number of seeds (83.60%) followed by soil seed bank (16.33%) and seed losses (0.07%).

The total seedling and seeds from three experiments were 112,172 seeds at top slope, 163,025 seeds at upper slope, 116,097 seeds at middle slope, and 184,641 seeds at down slope positions. Proportion of amount of soil seed bank, seed losses, and seed rain along slope positions showed in Figure 31. Seed rain amount was greatest in all slope positions. Proportion of seed losses was the lowest along slope positions.

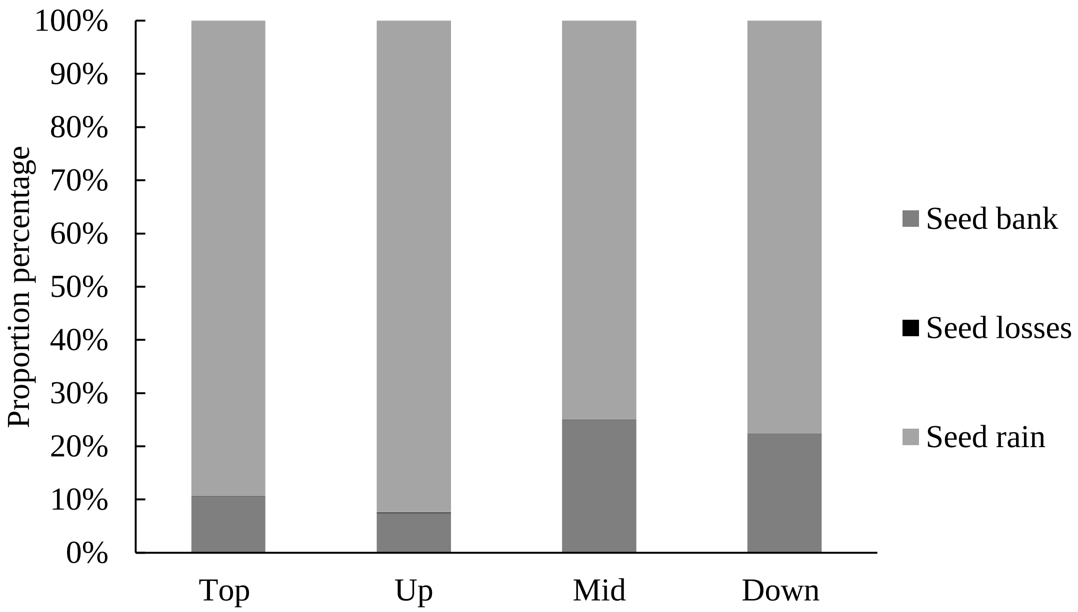

Figure 31 Proportion of soil seed bank, seed losses, and seed rain number along slope positions.

The number of seeds in soil seed bank and seed rain between top and upper differed from middle and down slope positions (Figure 31). The number of seed rain was greater at top and upper than middle and down slope positions. In contrast, the number of soil seed bank was greater at middle and down than top and upper slope positions. By the composition of dominant species which mostly found at the lower slope. It was possible that their seeds could be dispersed and accumulated near the mother plants. On the other hand, the lesser seed bank of seed bank from the upper part was possibly due to more intensive management of emerged vegetation by the grower. For the upland vegetation, the complex factors involved with community composition and structure, and diversity of related species, (Kessler, 2001; Schmidt, Zerbe, Betzin, & Weckesser, 2006). Elevation has a strong influence on the structure of the vegetation in the mountain areas (Brown, 2001; Hawkins & Diniz-Filho, 2004; McVicar & Körner, 2013; Rahbek, 2005; Zhang, Ru, & Li, 2006).

Total 47 plant species were found in all experiments. There were 40 species in soil seed bank, 12 species in seed rain and 21 species in standing vegetation species (Table 8). Some species were found in all processes of soil seed bank dynamics such as *A. conyzoides*, *C. sumatrensis*, *C. crepidioides*, *H. capitate*, *S. alata*, and *O. corniculata*. while other species were overlapped in some processes. Although many species in soil seed bank dynamics were found along slope positions, *A. conyzoides* was the greatest number of species in soil seed bank and seed rain in all slope positions. However, other species affected the numbers of seeds in the system. At down slope position, there were greater numbers of *L. philippensis* than *A. conyzoides* seeds in soil seed bank (Table 4). A number of species was an important key role that drove the seed input and output in the soil seed bank dynamics.

Amount of seed output from erosion and runoff water was lower than seed input from seed dispersal. Seeds can be lost from the system due to many processes such as seed germination, seed decayed by animals, seed death from pathogen and insect, seed decay, and burial depth. Although seed output was lost by many processes, a large number of seeds input were added to the system via seed rain (Yu et al., 2015). Soil seed bank in each slope position was related to spatial factors such as elevation, distribution of diversity, and dominant weed species (Zhang, Xu, & Li, 2013). Although patterns of weeds community were unique, main species have been overlapped among habitats. Weed seeds were easily dispersed in upland by slope angles, runoff, and erosion (Bochet, 2015; Menalled, 2008). Along the toposequences, the differences in elevations may differently have weed species and numbers of weed seed banks (Tsubo et al., 2006).

Table 8 Species of soil seed bank in 2018, seed rain and standing vegetation in 2019.

Scientific name	**Soil seed bank**	**Seed rain**	**Standing vegetation**
Acmella ciliate	✓		✓
Ageratum conyzoides	✓	✓	✓
Andrographis paniculata	✓		
Amaranthus viridis		✓	✓
Blumea balsamifera	✓		
Blumea sp.	✓		✓
Crassocephalum crepidioides	✓	✓	✓
Cyathocline purpurea	✓		✓
Conyza sumatrensis	✓	✓	✓
Echinochloa colona	✓		✓
Eleusine indica	✓		✓
Flacourtia rukam	✓		
Hyptis capitata	✓	✓	✓
Lygodium flexuosum	✓		✓
Lindenbergia philippensis	✓		✓
Leptochloa chinensis	✓		✓
Laggera sp.	✓	✓	
Oxalis corniculata	✓	✓	✓
Oldenlandia diffusa	✓		
Oldenlandia ovatifolia	✓		
Pteridium aquilium	✓		✓
Praxelis clematidea		✓	✓
Paspalum conjugatum	✓		
Pennisetum polystachyon		✓	✓

Scientific name	**Soil seed bank**	**Seed rain**	**Standing vegetation**
Pteris vittata	✓		
Spermacoce alata	✓	✓	✓
Spermacoce exilis	✓		✓
Selaginella helferi	✓		✓
Thysanolaena latifolia	✓	✓	
Vernonia cinerea	✓		✓
Unknown R5		✓	

CHAPTER V

CONCLUSION

Weed seed bank dynamics are changing all the time. Species composition and amount of seed bank also changed followed by land use and cropping systems. This study showed the obvious effects of toposequence on soil seed bank dynamic. A number of seed bank was greatest at the down slope position. Shannon's diversity and evenness index were greater at the down slope position compared to other slope positions. The greatest amount of soil seed bank at down slope position was possibly due to the seed accumulation from seed rain process. Weed species, *Ageratum conyzoides*, *Lindenbergia philippensis*, *Pteridium aquilium*, *Spermacoce exili*s, and *Blumea balsamifera*, were the most commonly found in soil seed bank. *A. conyzoides* was the greatest species in soil seed bank because it can produce more seeds and instantly germinate without dormancy.

Seed losses via seed removal by natural rainfall affected by toposequence. Samples of sediment losses were from 12 rainfall events leading to erosion in rainy season in 2018. The number of seed losses were greatest at upper, down, and top slope positions and lowest at middle slope position possibly due to the concave slope shape at the middle slope position. The major size of seeds in the sediment ranged between 0.3 and 0.7 mm height. There was a positive correlation between sediment and seed loss (R^2=0.96). Amount of sediment and seed losses were greatest at the first rainfall event compared to other events possibly due to the bare soil bed before starting the growing season.

Seed rain via seed dispersal by wind was affected by toposequence. Seed rain samples were collected for one year in 2019. The number of seeds in seed rain were greater at upper, down, and top slope positions than at middle slope position. Amount of seed rain in January, October, and December was greatest compared to other months possibly due to the unmanaged land and flowering interval of local plant. Amount of seed rain was lower between April and September possibly due to the intensive land management during the growing season and the canopy coverage of maize to outcompete other plants. Other months between April to September, amount of seed rain was lower because field was disturbed by the land preparation and maize plantation. *A. conyzoides* was the commonly found species followed by *Conyza sumatraensis*. *A. conyzoides*. *C. sumatrensis* in Asteraceae family produced numerous seeds with pappi resulting in increasing rate of dispersal.

In the study areas, the proportions of soil seedbank, seed output via seed loss, and seed input via seed rain were 16.33, 0.07, 83.6%, respectively. The number of seeds in seed rain accounted for the greatest seed proportion in soil seed bank dynamics. Therefore, seed rain should be managed to prevent the accumulation of seeds in soil seed bank.

To the best of our knowledge, weed management practice should be done differently on different slope positions. The greatest weed seeds deposited at down slope. Therefore, species and number of weed seeds can be used to predict weed species composition in the next cropping systems and design appropriate management practices. Weed seedling can be used as a soil coverage for conservation propose during no planting periods. The further study should be done in evaluation of seed output via seed germination. It is necessary to have a better understanding of biology and ecology of frequently found species and their roles in soil seed bank dynamics.

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