Journal of Natural Resources and Environmental Management
https://doi.org/10.29244/jpsl.16.1.52

RESEARCH ARTICLE

OPEN ACCESS

Check for updates

Evaluation of the Effectiveness of the Manual Hydroseeding Method for Planting Turi (*Sesbania grandiflora* (L.) Pers.)

Zainal Muttaqin[a], T. Yuliana Purba[b], Srikandi[c]

[a] Department of Forestry, Nusa Bangsa University, Bogor, 16166 Indonesia
[b] Department of Master of Development Economics, Nusa Bangsa University , Bogor, 16166, Indonesia
[c] Department of Biology, Nusa Bangsa University, Bogor, 16166, Indonesia

Article History
Received
11 September 2025
Revised
4 November 2025
Accepted 19 Desember 2025

Keywords
hydroseeding, revegetation, *Sesbania grandiflora*, slope area, observed sample plots (osps)

ABSTRACT

As an alternative to conventional reforestation using plant seeds, slightly hilly slopes can be revegetated using no-till and hydroseeding methods. This study aimed to evaluate the effectiveness of hydroseeding mixtures for revegetation on 15–25% slopes in the campus area of Nusa Bangsa University. The research was conducted at a plot scale using Observed Sample Plots (OSPs) measuring 2.0 m × 1.2 m, following slope conditions. Each plot (OSP) consisted of 60 sub-plots using the Templok method, arranged in a checkerboard pattern, with 30 sub-plots treated with hydroseeding mixtures. The treatments included combinations of two planting media of sengon (*Falcataria falcata*) sawdust and chopped jati (*Tectona grandis*) litter (1.1 kg each) and three concentrations of tackifier (0, 3, and 6 g/L water). The result of univariate analysis of variance (ANOVA) and the graphic of germination development that the treatment of M2S2 (media of sawdust and tackifier 6 g/L) showed significant effect on the germination percentage. So, this combination treatment improved germination compared to other treatments. However, splash erosion was observed across all plots, causing considerable loss of planting media. Therefore, large-scale application of hydroseeding on slopes requires additional erosion control, such as bamboo supports, coconet, or geo-jute, to maintain soil stability.

Introduction

Over the past five years, data from the National Disaster Management Agency (*Badan Nasional Penanggulangan Bencana*/BNPB) in 2024 recorded a total of 14,930 disaster events across Indonesia. In 2024, 751 disaster events were reported, with landslides being the most frequent type of disaster (249 events) and volcanic eruptions being the least frequent, with only one recorded occurrence [1]. Natural disasters, such as floods and landslides, have frequently occurred in Indonesia, particularly since early 2020. These disasters have caused extensive land degradation, where erosion and surface runoff are intensified owing to the loss of vegetation cover [2]. As reported in previous studies, landslides often trigger splash erosion and accelerate soil particle loss. In addition, de Ona et al. [3] and Kendarto et al. [4] presented that vegetative methods are among the most recommended techniques for protecting slope areas. These include planting grasses, legume cover crops (LCC), and various fast-growing tree species as ground cover vegetation. One alternative technique that has gained attention is hydroseeding [5]. This method applies a uniform blend of seeds, organic mulch, nutrients, and adhesives (tackifiers) across the soil layer to promote rapid germination and slope stabilization.

Compared to traditional methods, direct seeding is more practical and cost-effective, particularly for large-scale applications, and it bypasses the nursery and transplanting stages [6]. However, its limitations lie in the lack of seed protection during germination, particularly on steep terrain [5]. Subsequently, to further examine the advantages and disadvantages of the direct seeding and hydroseeding methods, research needs to be

Corresponding Author: Zainal Muttaqin muttaqinznl@gmail.com Department of Forestry, Nusa Bangsa University, Bogor, 16166, Indonesia.

conducted on their effectiveness [7,8]. In contrast, hydroseeding improves seed adhesion and growth by creating a more suitable microenvironment for germination.

Hydroseeding can be conducted manually and mechanically using a hydroseeder, whereas community-based hydroseeding planting practices have been carried out for slope stability [9]. Grass seeds obtained from the market, which were mixed with compost, soil conditioner, guar gum, water to form a hydroseeding formula. The formula was then sprayed on landslide soil media at various slope levels in a laboratory-scale study. Moreover, the review suggested that hydroseeding success can be enhanced through various techniques, such as topsoil spreading, using native seeds, and Mycorrhizal or Rhizobium inoculation [10]. Research on hydroseeding in Indonesia is limited. In addition, the technique of planting mixed hydroseeding materials can be done using the term *templok* as hydroseeding method manually. In Indonesia, the *templok* method was developed as a manual adaptation of hydroseeding, designed for small-scale use in rural or degraded areas. Preliminary research on the application of the *templok* method was conducted by a researcher at the scale of the Gunung Walat Educational Forest, IPB, Sukabumi Regency [11]. Meanwhile, researchers have conducted laboratory-scale research on the use of hydroseeding mixtures to stabilize easily eroded road slope soils, including testing the aspects of soil physical and chemical composition [12]. Hence, this research was carried out to build on the results of the previous two studies by determining the types of local plants that are ecologically adaptive and modifying the hydroseeding mixture applied to sloped areas after landslide and erosion disasters. Considering the status of this research as preliminary, the results can be recommended for the implementation of best practices performed by the district, sub-district, village, and community governments, as well as the BNPB. Thus, this study includes a basic research scheme.

Previous studies have explored the use of various hydroseeding media, such as sawdust, chopped litter, and compost, and have identified several local Leguminosae species suitable for such methods [13]. Among them, *Sesbania grandiflora* (turi) shows promise because of its fast germination and ecological adaptability, and it is a lowland species highly suited to hot and humid environments, as well as seasonally waterlogged conditions. This plant has a low tolerance for cold temperatures (below approximately 10 °C) and is not wind-resistant [14]. However, germination rates remain low when applied to mineral soils using hydroseeding. Therefore, further experimentation is essential to optimize the media composition and adhesive concentration to enhance germination success.

Hydroseeding research with local Leguminosae species on post-mining land was conducted by researchers, which concluded that the perennial *Cajanus cajan*, *Indigofera* sp., and *Sesbania sesban* can also potentially be incorporated into hydroseeding slurries to enhance the vertical structure of vegetation and the species diversity of pioneer plants [5]. Meanwhile, *S. grandiflora* and *Adenanthera pavonina* have a low germination rate (germination percentage <20%) even though they have a fast germination time. Hydroseeding also was favoured by legume species, such as *Onobrychis viciifolia*, *Ononis arvensis*, *Lotus corniculatus*, and *Trifolium medium*, while *Festuca rubra* favoured the regular seeding treatment [15]. On the whole, their findings confirm that legume species that performace more competitive growth traits than grasses and forbs species. The legume speies should be belonged in the seed mixture in worth proportions when hydroseeding is used up. As a comparison, further research is needed on the hydroseeding of local Leguminosae (*S. grandiflora*) on sloping mineral soil within the scope of the present research. The present study sought to evaluate the efficacy of hydroseeding mixtures using chopped jati (*Tectona grandis*) litter and *Falcataria falcata* sawdust, combined with varying concentrations of tackifier, to promote *S. grandiflora* germination on 15–25% sloped areas.

Materials and Methods

Materials & Site Preparation

The source seed turi (*S. grandiflora*) was obtained by purchasing it online. It is considered to have superior quality seeds. They were used directly for mixed hydroseeding. The hydroseeding technique in this study involved the preparation of a slurry mixture composed of planting media (mulch), soil-stabilizing agents, adhesive substances to bind seeds to mulch, fertilizers, and legume seeds [16,17]. In manual applications, hydroseeding can include combinations of cocomesh, polymer materials (e.g., teraglu or kacret as adhesives), water, legume seeds, and organic materials such as compost or litter of uniform size, following a systematic mixing sequence [18]. The field experiment was conducted on a 15–25% slope located within the Nusa Bangsa University campus in Bogor, Indonesia. The initial site preparation included the manual clearing of existing vegetation. The study location was at 6^0 83′ 07″S, 106^0 46′ 36″E; 6^0 33′ 07″S, 106^0 46′ 35″E, at an altitude of 184 m above sea level, and has latosol of reddish brown [19]. The environmental data in the form of weather are presented in Table 1.

Table 1. Data of some elements of weather in study location in April, May, June 2021 during the field study. That table presents daily rainfall in April (low), May (moderate) and June (low), and the annual rainfall in 2021 was 3,786.6 mm. Temperature ranges 25.9–26.9 ^oC in accordance with the tropis area in Indonesia, relative humidity ranges 83.9–86.1 (very high), solar radiation ranges 5.5–6.8 hour/daily. In this source, is climatology station West Java, -6.50000 latitude, 1006.7500 longitude, elevation 207 m a.s.l (above sea level).

Elements of weather	April	May	June
Rainfall (mm)	301.3	479.1	281
Rainfall daily (mm)	11.2±15.9	29.9±25.4	11.7±16.8
Temperature (^{o}C)	26.2±0.6	26.9±0.6	25.9±0.6
Relative humidity (%)	84.2±3.8	83.9±3.5	86.1±2.6
Solar radiation (hour)	5.5±3.1	6.8±2.1	5.7± - 26.9 2.5

The other environmental data based on the results of soil chemical analysis by Laboratorium of ICTB PT Biodiversitas Bioteknologi Indonesia were tested in 2024 and refer to Djaenudin et al. [20]. The study site has soil fertility status parameters such as soil pH (H_2O) ranging from 5.3–6.3 (acid-rather acid), C-organic (0.64–1.90%) (very low-low), N total (0.09–0.22%) (very low-low), P available (1.79–8.88 mg/kg) (very low-low), K^+ exchangable (0.08–0.40 cmo(+)/kg) (very low-moderate), CEC (13.67–20.46 cmol(+)/kg) (low-moderate), base saturation (78–100%) (very high).

Experimental Design and Hydroseeding Application

Sample plots, known as Observation Sample Plots (OSPs), were constructed with modified dimensions of 2.0 m × 1.2 m, adjusted from the original 4.0 m × 1.2 m layout, suit field conditions and space limitations in the Nusa Bangsa University area [11]. Each OSP was arranged using the *templok* method, following a systematic checkerboard pattern composed of 60 subplots (20 cm × 20 cm), 30 of which were treated with the hydroseeding mixture. The experiment used a factorial design with two treatment variables. The first factor was the type of planting medium: chopped teak leaf litter (M1) and *F. falcata* sawdust (M2), each weighing 1.1 kg. The second factor was the concentration of the tackifier used as a binding agent: 0 g/L (S0), 3 g/L (S1), and 6 g/L (S2). Each OSP received 24 g of *S. grandiflora* (turi) seeds. The hydroseeding slurry was prepared by mixing the planting medium (1.1 kg), tackifier at the designated concentration, and 1 L of water in a container until a uniform and homogeneous mixture was formed. The six treatment combinations resulting from 2 media types × 3 tackifier concentrations (2 × 3 = 6) were applied to six OSPs. Each treatment was replicated twice, resulting in 12 OSP units. The placement of each OSP was randomized in the study area. The layout of the six treatments and OSP is shown in Figures 1 and 2.

Figure 1. The layout of hydroseeding treatment combination code of each OSP in the field study in campus area of Nusa Bangsa University. That figure illustrated a treatment combination consisting of: M1S0Bt: 1.1 kg chopped teak litter media + 0 g stickifier + 1 L of water; M1S1Bt: teak litter media chopped 1.1 kg + 3 g tackifier + 1 L water; M1S2Bt: teak litter media chopped 1.1 kg + 6 g tackifier + 1 L water; M2S0Bt: 1.1 kg sengon (Paraserianthes falcata) sawdust media + 0 g tackifier + 1 L water; M2S1Bt: media of sawn sengon 1.1 kg + tackifier 3 g + 1 L water; and M2S2Bt: media of sawn sengon 1.1 kg + tackifier 6 g + 1 L water.

Figure 2. The experimental plots were conducted on a slope of 15-25%. Sample plot unit (OSPs) were constructed with modified dimensions of 2.0 m × 1.2 m, adjusted from the original 4.0 m × 1.2 m layout in campus area of Nusa Bangsa University. Those plots were adapted to the condition and limitations of the land.

Measurement of Parameters

In the germination process of turi, divided into four stages as follows modification of criteria for this study [21], especially for this study, consists of Stage 1: cotyledon was divided, forming a hypocotyl (prospective stem under the cotyledon); Stage 2: cotyledon was elevated, forming an epicotyl (candidate stem above the cotyledon); Stage 3a: cotyledon was present, forming hypocotyls, epicotyls, and one pair of leaves; Stage 3b: cotyledon fell off, forming stems, two pairs of leaves, and further growth. The measured parameters included the percentage of germination (%K), germination value (NK_1 and NK_2), and the sum of leaves in the final germination. The sum of leaves as vegetative growth is considered to represent the parameter of diameter and height of sprouts that are measured technically in hydroseeding media. The parameter measurements were performed every week for 8 weeks, or approximately 2 months. Observation sheet of turi seed germination data.

Data Processing and Analysis

The data of the germination parameters were processed by means of tabulation and graphically. The parameter of seed physiology quality was used in the Czabazor formula, that is, %K (percentage of germination), NK (germination value) differentiated of NK (1) and NK (2), and added the sum of sprouts leaves in the sighting finally [22,23]. The data analysis carried out includes the percentage phase of germination, germination value, with the following formula:

$$\% K = \frac{the\ sum\ of\ seed\ germinated}{the\ sum\ of\ seed\ sowed} \times 100\% \quad (1)$$

where %K, is the percentage fase of germination, this is calculated from the number of seeds that germinate divided by the total number of seeds sown, then multiplied by 100 or expressed as a percentage.

in addition, the formula of germination value (NK) is divided into 2 formulas. The first formula is shown in Equations 2, 3, and 4. Meanwhile, the second formula can be seen in Equations 5 and 6.

$$NK_1 = PV \times MDG \quad (2)$$

where NK_1, is calculation between the peak of germination value (the highest PV value) multipled by the average of germination daily (MDG).

$$PV = \frac{\%\ germination\ in\ the\ day\ to{-}i}{the\ sum\ of\ day\ needed} \quad (3)$$

$$MDG = \frac{\%\ germination\ of\ observed\ finally}{duration\ of\ observation} \quad (4)$$

for formula 2, where NK_2, is the average number of days to germination divided by the sum of seed sowed then multiplied by the germination percentage and 10 subplots.

$$NK_2 = \frac{\sum RH}{N} \text{ x } \% \text{ K x } 10 \quad (5)$$

where RH, is the average number of days to germination obtained from hi or ∑ seed sowed in the day to-, n_i = the day to-i.

$$RH = \frac{(n_1 \text{x } h_1) + (n_2 \text{x } h_2) + \cdots + (n_i \text{x } h_i)}{n_1 + n_2 + \cdots + n_i} \quad (6)$$

Statistical analysis using univariate ANOVA with IBM SPSS Statistics 23 revealed that either a single factor, such as the first treatment of the type of media (M) consisting of [chopped litter of teak] and [sawdust of sengon] or the second treatment of the tackifier (S) content, or a combination of media and tackifier content showed a significant difference (Sig. <0.05) among several treatment combinations of six OSPs [M1S0, M1S1, M1S2, M2S0; M2S1; M2S2). A 2 × 3 factorial experimental design was used to examine the differences in parameters between the treatments.

Result

The Value of the Germination Parameter

The tabulation results of the recapitulation of the turi seed germination process by hydroseeding are summarized in Table 2. In that table, the single treatment (M1, M2), the treatment of SO versus S2, and the treatment of the combination of M and S had very significant and significant effects on percentage germination (%K). In addition, for germinate value (NK_2), the treatment of M (M1, M2) effect significant to (%K). However, for germination value (NK_1) and the sum of leaves, the treatment of single M, S, and combination of M and S were not significantly affected. The results suggest that sengon sawdust in M2 medium and S2 tackifier provided better support for the percentage germination of *S. grandiflora* seeds.

Table 2. The result of recapitulation of ANOVA for germination parameters of turi (*S. grandiflora*) by hydroseeding manually on slope 15–25% , among significantly different treatments. That table presents a summary of parameter of germination percentage (%K), germination value (NK_1, NK_2), and the sum of leaves. In that table, both the single treatment (media), and the combination of M (media) and S (tackfier) have very significant (**), whereas the treatment of SO versus S2 was significant (*) on percentage germination (%K).

Parameter	On ANOVA		Source
	F	P	
% Germinate (% K)	109.621	0.000**	Media
	19.047	0.003**	media + tackfier
	0.037	0.028*	S0 x S2
Germinate value (NK_1)	1.727	0.237	Media
	0.635	0.562	media + tackfier
Germinate value (NK_2)	16.002	0.007**	Media
	0.188	0.833	media + tackfier
The sum of leaves	1.534	0.262	Media
	1.731	0.255	media + tackfier

The development of the seed germination process of turi was analyzed step by step by hydroseeding fromsix treatments over eight weeks of observation and measurement, as shown in Figures 3 and 4. The following selected only for parameter of percentage germination (%K) and germination value (NK_2) have respond significant, there were the effect of treatment significant of its M (media), S (tackfier) and its combination of M and S.

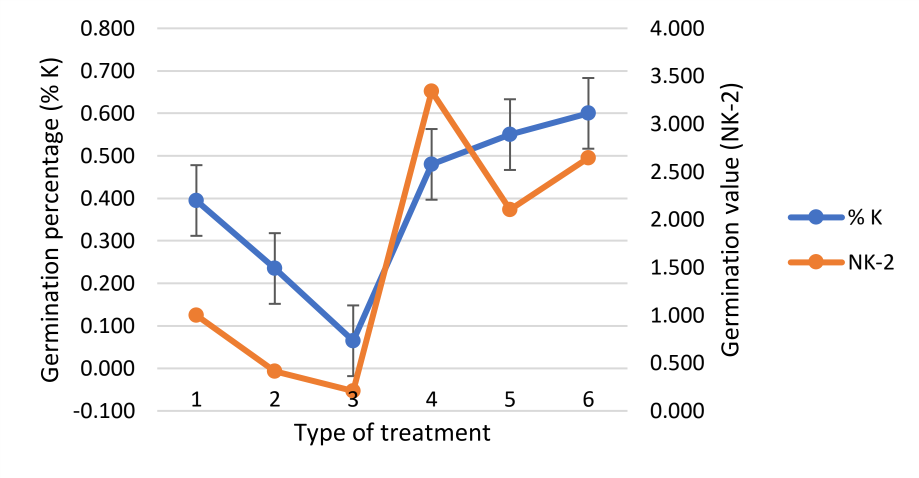

Figure 3. Respond of type of treatment to germination percentage (% K) and germination value (NK_2) for hydroseeding manually of turi (*S. grandiflora*) on slope 15–25%. Type of treatment consist of 1=M1S0, 2=M1S2, 3=M1S2, 4=M2S0, 5=M2S1, 6=M2S2. That figure presented that treatment of 6 (M2S2) was consists of media of sawn sengon 1.1 kg + tackifier 6 g + 1 L water, it gave the highest of %K. Besides that treatment of 4 (M2S0) was consists of media of sawn sengon 1.1 kg + tackifier 0 g + 1 L water, it gave the highest value (NK_2).

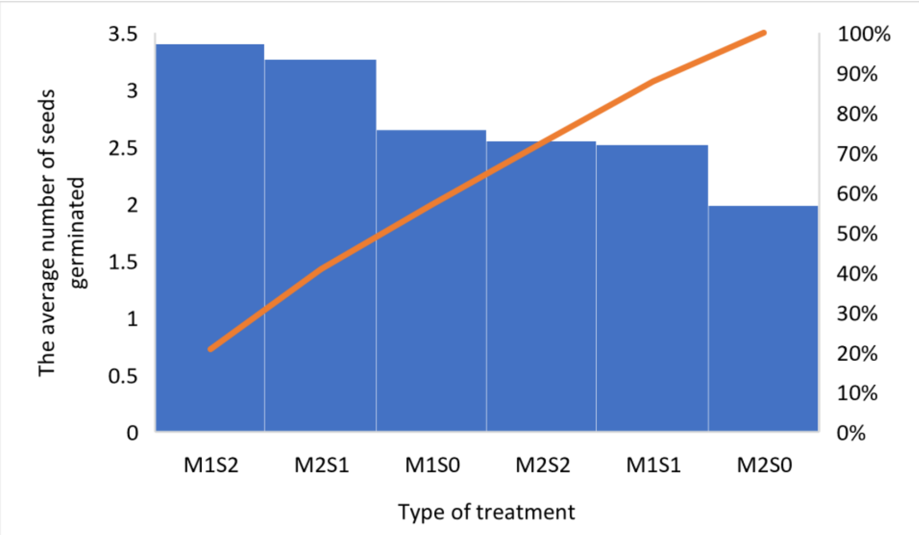

Figure 4. The average number of seeds germinated by six treatments at the finally germination stage of turi (*S. grandiflora*) by hydroseeding manually on slope 15–25%. In that table, the two highest average number of germinated seeds was in the M1S2 and M2S1 media. The M1S2 treatment consists of media of jati litter chopped 1.1 kg + tackifier 6 g + 1 L water, and the M2S1 treatment consists of media of sawn sengon 1.1 kg + tackifier 3 g + 1 L water.

Review of Value of Soil Erodibility and Eroded of OSPs

Based on the results of the soil test at three sampling points, the estimated soil erodibility (K) and the amount of erosion that occurred (E) at the study site were determined. It obtained K value ranges of 0.06–0.10 (very low) [24]. The amount of erosion was obtained based on the USLE formula, USLE ranges from to 144.174–246.270 ton/ha/year. This means that although soil erodibility is very low, it is based on the review of the erosion hazard level of the soil solum to the sum of maximum erosion [25]. This was compared with solum thickness (>90 cm) so that it was obtained from erosion, including moderate to heavy.

Table 3. Percentage of media eroded on OSPs of Hydroseeding manually on slope 15–25%. That table presented average percentage of media eroded and its standard deviation (SD) in each subplot in the PCP of each or all treatments. Also, that table presented that the highest of % average of media eroded was M2S1 dan M2S2 (90%), respectively. That treatment of M2S1 was consists of media of sawn sengon 1.1 kg + tackifier 3 g + 1 L water, and that treatment of M2S2) was consists of media of sawn sengon 1.1 kg + tackifier 6 g + 1 L water.

Treatment	% average of media eroded on every subplot in OSPs	The sum of subplots in OSP with media eroded completely		Average
		repetition 1 (n=30)	repetition 2 (n=30)	
M1S0	75	18	8	13
M1S1	50	3	1	2
M1S2	50	10	0	5
M2S0	75	1	1	1
M2S1	90	24	22	23
M2S2	90	4	4	4
Average±SD	71.7±18.1	10.0±9.2	6.0±8.4	8.5±7.7

Discussion

In Figure 3, the treatment of M2S2 (media sawdust of sengon 1.1 kg + tackfier 6 g/L) has the hydroseeding manually the highest germination percentage (K%) (0.60±0.04) also strengthened by considered that tendency line the more increasing withdrawn starting from the treatment of M1S0 until M2S2. As shown in Table 2, stated there ws the different significant treatment of S0 and S2 means gave tackfier 2x concentration affected the increase in germination percentage. Actually the other result The treatment with M2S0 (saw dust of sengon 1.1 kg + tackifier 0 g/L) or even without tackifier had the highest germination value (NK_2) (3.34±2.13), followed by M2S2 and others. However, the tendency line kept increasing from the treatment of M1S0 to M2S2. As the support of comparisons of the average number of turi seed germination among treatments are shown in Figures 4.

At the final process of the germination stage, the highest number of germinated seeds was in the M1S2 treatment using chopped teak leaf litter media with a 6 g/L stickifier. It was also revealed that a higher concentration of tackifier as a seed adhesive, from 3 to 6 g per L with chopped teak leaf litter media, resulted in a higher average number of germinated seeds. In addition, the final process of the germination stage was indicated by loose cotyledons, formed stems, and two or more pairs of leaves. This condition indicates that the stickier materials increased cohesively and added adhesion of soil aggregates and the adhesive of the seed surface to the media surface. The increase in cohesion strengthens the bond between soil particles and seeds, forming a more stable protective layer against raindrop impact and surface runoff [26,27]. This combination has been proven effective in reducing the rate of soil erosion and maintaining seeds in optimal planting positions, thereby supporting early seedling establishment and uniform germination [28–30].

Hydroseeding mulch used as a seed germination medium consists of a tackifier agent, water, compost, and fiber [31]. *S. sesban* had the highest germination rate (67%) in M2 medium with twice the tackifier content than its M1, in accordance with the results of this study (Figure 3), and the lowest was shown by *T. arundinaceae* (2%) in both media. The earliest germination was observed in *C. pallida* and *S. sesban*, which germinated as early as 2 days after sowing (DAS). Meanwhile, *S. timorense* and *T. arundinaceae* exhibited the lowest germination rates, reaching their maximum at 11 days after sowing (DAS). The fluid M1 medium was optimal for the germination of *S. sesban* (50%) and *S. grandiflora* (35%), whereas the denser M2 medium favored *S. sesban* (67%) and *S. timorense* (50%).

Similarly, a study by Azalia et al. [32] on post-mining soils demonstrated that all tested species were able to germinate and grow successfully in hydroseeding mulch treatments. Mulches two, three, four, and five consisted of galam bark, cocopeat, humic acid, local microorganisms (LMO), and water, but differed in the adhesive used for preparation. In contrast, mulches six and seven were prepared using sawdust, cocopeat, LMO, goat compost, leaf compost, water, and adhesive. The control mulch was prepared using buffalo feces mixed with water. The species tested were *Crotalaria pallida, Cajanus cajan, Kyllinga monocephala, Paspalum conjugatum, Digitaria sanguinalis*, and *Eleusine indica*. Among these, *K. monocephala* failed to grow on mulches two, four, and five, whereas *D. sanguinalis* did not grow on mulch four. The highest germination percentages were observed in *C. cajan* (56.7%) and *C. pallida* (39.4%) on mulch two, with germination occurring at eight and three DAS, respectively. Conversely, *K. monocephala* exhibited the lowest germination across all mulch treatments, persisting until 30 DAS. Based on these findings, mulch two (pH 7.06 and 59% organic matter) was identified as the most suitable formulation for accelerating revegetation using hydroseeding, particularly for Leguminosae, whereas mulch seven (pH 6.8 and 47% organic matter) was recommended for Poaceae and polyculture systems.

In contrast, another study showed that hydroseeding significantly increased ecosystem nitrogen storage during the initial stages of post-fire succession, but this occurred at the expense of native shrub regeneration and species richness [33]. Similarly, the other research reported that the application of organic mulch in coastal sage scrub restoration enhanced microbial nitrogen immobilization and improved the survival rates of replanted native shrubs [34]. In addition, the main cause was the large amount of planting media (hydroseeding mixture) being eroded in each sub-OSPs in the OSP unit, which is explained in the next paragraph.

According to field observations, the number of individuals that germinated was low due to some seeds having low viability, fungal attacks, and predation by ants in a coal post-mining land. It was also explained that seed quality and dormancy, inhibitor presence, and predation might serve as limiting factors [35]. Fungal attack occurred if the medium was highly acidic and moist. In addition, immature seed germination stimulates fungal growth [36]. In this study, it was observed that many turi (*S. grandiflora*) seeds did not germinate, potentially due to the decomposition rate of the hydroseeding mixture and the physical resistance of the hydroseeding mulch that was not optimal for seed germination. Seeds that do not germinate can be influenced by internal factors such as seed quality and external factors such as temperature, air availability, and physical barriers (mulch) [37–39].

The other researcher have highlighted that seed germination is determined by factors including species selection, genetic material, inherent germination rate, applied treatments, environmental conditions, germination timing, and rainfall amount and intensity [40]. One strategy to overcome low germination involves increasing seed quantity and improving selection criteria. Furthermore, hot-water soaking at specific temperatures and exposure times can substantially improve germination, particularly in seeds of the Leguminosae family [41]. As described in studies, germination is a complex biological process involving multiple regulatory mechanisms that drive embryo development and plant establishment [42,31]. The other evidence demonstrated that Leguminosae species possess superior germination performance, characterized by higher rates and faster germination times than those of Poaceae and Cyperaceae [32].

Seed Germination Characteristics of *Sesbania grandiflora*

This supports the success of hydroseeding, which requires large amounts of seeds for its application [43]. As compared with the other study results, based on availability, *S. grandiflora* (broadleaf plans) can be found in large quantities in the market, both direct buying and marketplace. Based on vegetative growth, this species can grow quickly [5]. It has been reported that *S. grandiflora* has a germination rate (6%), with lower 1st day germination (lower), high seed availability (high), fast vegetative growth (fast), moderate seed production (moderate), a perennial life cycle (perennial), and a sapling life form (sapling). Also, they presented of their result that percentage of leguminosae include *S. grandiflora* of seeds germination, was higher than that of Cyperaceae and Poaceae seeds [44].

Factors Influencing Germination Stages

Environmental factors, the occurrence of splash erosion and small surface runoff in each OSP indicated the presence of environmental factors. Subsequently, most subplots in the OSPs, previously cleared of vegetation cover, lost the hydroseeding planting media mixed with tackifier. The intensity of splash erosion was triggered by the number of rainy days during the research period (approximately 3.0 months) in April, May, and June of 2022. The intensity of splash erosion was triggered by the number of rainy days during the research period (approximately 3.0 months) in April, May, and June 2021 (Table 1). Splash erosion was also triggered by soil aggregates in the OSPs, which were easily susceptible to decomposition by falling raindrops because of the small amount of adhesive organic matter. Coconet and geo-jute mesh materials were spread to strengthen the soil aggregates and the media used [45]. Bioengineering techniques such as hydroseeding and coconet application can accelerate vegetation growth while reducing soil erosion and enhancing soil stability, with coconets made from coconut fiber serving as effective soil conditioners [46].

The use of various media, based on the use of hydroseeding media, the mulch inhibited the growth of weeds, protected soil particles from erosion and being carried away by surface runoff, and maintained the stability of soil structure and moisture [47]. A higher average percentage of germinated seeds was identified in the M2S2 treatment than in the other five treatments. The treatment used sengon sawdust media with 6 g/L of tackifier at germination stages finally A, which was marked by the appearance of cotyledons, the formation of hypocotyls and epicotyls, and had a minimum of two pair of leaves. Furthermore, at the final germination stage, a higher average number of germinated seeds was found in the M2S2 treatment using sengon sawdust media with 6 g/L of tackifier that were marked by loose cotyledons, formed stems, and two pairs of leaves or more, compared with the other five treatments. Sawdust media had a relatively smaller particle size than chopped litter, so it could bind or attach more strongly and compactly to mixed turi seeds, producing a higher number of germinated seeds. Moreover, the chopped litter media had a larger particle size to support the development of germinated seeds. The data on the eroded hydroseeding media in each plot (OSP) at the end of the observation period are presented in Table 3.

Table 3 shows that the treatment of a combination of the media type and tackifier content resulted in an average of 50–90% of every subplot eroded media in the OSPs. In other words, each OSP area had its media eroded by a minimum of 50% and a maximum of 90%. A large amount of eroded media was mainly due to the direct fall of raindrops on the sloping OSP soil surface (15–25%) without vegetation cover or given shield of coconut and geo-jute at the start of the hydroseeding method, which caused initial splash erosion. This condition caused the aggregate media and soil particles to reduce or become brittle, so that the adhesion of the seeds to the media decreased, and the media and soil particles were washed away by small surface flows following the slope. Hydroseeding treatments significantly enhanced vegetation cover, with wood fibers exhibiting the highest effectiveness [48].

Comparatively, paper mulch was a more economical but less efficient option on gentle slopes, whereas a combination of paper mulch and blankets was more suitable for steep slopes with a high erosion risk. Consistent with these findings, the use of chopped teak leaf litter and *F. moluccana* sawdust as germination media for *S. grandiflora* seeds can likewise be classified as an effective wood fiber–based material. Similarly, the number of subplots in the OSPs with eroded media completely ranged from 1–24 subplots in OSP of replication 1 and 0–22 subplots in OSP of replication 2. Notably, there were 10 subplots with an average of 33.3% eroded media completely in the first OSP replication, whereas the second replication ran into six subplots with an average of 20%.

The OSP was run into 26.7% eroded media in the subplots on average. In comparison, that demonstrated that the hydroseeding formula, along with the interaction between slope gradient and hydroseeding treatment, significantly influenced the germination rate of *Cyperus brevifolius* and *Pueraria javanica* [49]. However, this interaction had no significant effect on plant height or leaf number. The highest germination rates were recorded in plots with a 100% slope for both species. These findings suggest that both species possess strong potential as pioneer plants for post-landslide reclamation on slopes of 100%, compared with 60% and 140%.

There were several shortcomings in the evaluation of the research results, including the following: 1) The observation sample plot (OSPs) was 2 m by 1.2 m. Based on previous research (4 m × 1.2 m) [11], it was made larger to obtain valid observation results. 2) The design of this study was a two-factorial treatment consisting of media types (two sub-treatments) and tackifier concentrations (three sub-treatments). Each treatment factor had the same number of sub-treatments to obtain an accurate statistical analysis; 3) Each row of *templok* was given bamboo support to prevent or reduce erosion and surface runoff in the plotted area (OSPs) or will give coconet and geo-jute [50]. The *templok* method represents a viable and improved vegetative technique for erosion control and rehabilitation on steep terrain, offering a practical solution to increase the success rate of legume cover crop (LCC) establishment in challenging environments [14]. PT ANTAM UBPE Pongkor placed a cocomesh on the land surface before applying hydroseeding manually (*templok*) [18]. 4) On relatively flat land, cover crop planting can be done manually, whereas on land with a slightly steep slope, cover crops can be planted using hydroseeding to reduce the rate of erosion [51]. Thus, in the final germination stage (3b), early turi seeds were formed and indicated by loose cotyledons, a formed stem, and at least two pairs of leaves in the planting media or hydroseeding with a mixture of chopped teak litter (1.1 kg) and tackifier (6 g) in one liter of water, has the height number of seed turi germinated. The use of tackifier concentrations, twice as much as 6 g/L, increased the percentage of germinated turi seeds.

Conclusions

The results of the univariate analysis of variance (ANOVA) and the graphic of germination development showed that the treatment of M2S2 (media of sawdust and tackifier 6 g/L) had a significant effect on the germination percentage. Besides that, this study concludes that the combination of chopped teak leaf litter with 6 g/L tackifier enhanced the average number of seeds germinated of Sesbania grandiflora on 15–25% sloped land. These findings underscore the importance of selecting appropriate organic mulch materials and optimizing tackifier concentrations. Furthermore, to ensure success in sloped areas, erosion control strategies, such as the use of coconets and geo-jute, should be integrated into the hydroseeding system.

Author Contributions

ZM: Conceptualization, Methodology, Writing-review & Editing; **TYP**: Methodology, Writing-review & Editing; **S**: Methodology, Writing-review & Editing.

AI Writing Statement

During the preparation of this work, the authors used CHATGPT and CONSENSUS to search for a few references. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Conflicts of interest

The authors declare no conflict of interest.

Acknowledgments

The author gratefully acknowledges the support of Nusa Bangsa University and the staff of the technical nursery, who supported this research through the Institutional Research Scheme 2021.

References

1. (BNPB) *Badan Nasional Penanggulangan Bencana*/National Disaster Management Authority. Terkini! Perbandingan Jumlah Bencana Alam di Indonesia 2020-2024. Available online: https://data.goodstats.id/statistic/terkini-perbandingan-jumlah-bencana-alam-di-indonesia-2020-2024-lWikM (accessed on 01 November 2025).
2. Thomas, C.; Sexstone, A.; Skousen, J. Soil Biochemical Properties in Brown and Gray Mine Soils with and Without Hydroseeding. *Soil* **2015**, *1*, 621–629, doi:10.5194/soil-1-621-2015.
3. de Ona, J.; Ferrer, A.; Osorio, F. Erosion and Vegetation Cover in Road Slopes Hydroseeded with Sewage Sludge. *Transp. Res. Part D.* **2011**, *16*, 465–468, doi:10.1016/j.trd.2011.04.002.
4. Kendarto, D.R.; Aliyah, F.; Bafdal, N.; Dwiratna, S.N.P.; Herwanto, T. Study of the Addition of Guar Gum and Bermuda Grass Seeds in Hydroseeding Applications on Erosion Rates. *e-Journal BPPT* **2018**, *11*(1), 25–30,
5. Anshari, M.F.; Fernandes, A.A.R.; Leksono, A.S.; Arisoesilaningsih, E. Screening Potential Local Seed Species for Hydroseeding of Post-Coal Mining Land Multilayering Revegetation. *J. Degrad. Min. Lands Manag.* **2023**, *11*(1), 4969–4977, doi:10.15243/jdmlm.2023.111.4969.
6. Parsakhoo, A.; Jajouzadeh, M.; Motlagh, A.R. Effect of Hydroseeding on Grass Yield and Water Use Efficiency on Forest Road Artificial Soil Slopes. *Journal of Forest Science* **2018**, *64*(4), 157–163, doi:10.17221/2/2018-JFS.
7. Gonzalez-Alday, J.; Marrs, R.H.; Martinez-Ruiz, C. The Influence of Aspect on the Early Growth Dynamics of Hydroseeded Species in Coal Reclamation Areas. *Appl. Veg. Sci.* **2008**, *11*, 405–412, doi:10.3170/2008-7-18497.
8. Emeka, O.J.; Nahazanan, H.; Kalantar, B.; Khuzaimah, Z.; Sani, O.S. Evaluation of the Effect of Hydroseeded Vegetation for Slope Reinforcement. *Land* **2021**, *10*(10), 995, doi: 10.3390/land10100995.

9. Nada, I.M.; Suryatmaja, I.B.; Darmayasa, I.G.O. Kestabilan Lereng Model Tri Datu berkolaborasi dengan Hydroseeding berbasis Masyarakat (Studi Kasus: Desa Songan A dan B Kintamani). *Jurnal Ecocentrism* **2022**, *2*(1), 16-23, doi:10.36733/jeco.v2i1.3697.
10. Sulastri, S.; Zairina, A.; Sukarno, A. Pertumbuhan Rumput Jepang (*Zoysia japonica*) pada berbagai Tingkat Kemiringan Dengan Aplikasi Hydroseeding. *Biosaintropis* **2022**, doi:10.33474/e-jbst.v7i2.477.
11. Indina, L.A. Planting Cover Crop Legumes on Sloping Land Using the Templok Method in the Gunung Walat Educational Forest, Sukabumi Regency. Thesis, IPB University, Bogor, 2011.
12. Sunandar, A.; Mulyani, S.Y. Effect of Wood Shavings and Polyacrylamide Mulch in Hydroseeding Mixtures on Changes in the Chemical Properties of Inceptisol Soil. *Indones. Agrotech J.* **2018**, *3*(1), 6–16.
13. Karmakar, P.; Singh, V.; Yadava, R.B.; Singh, B.; Singh, R.; Kushwaha, M. Agathi [*Sesbania grandiflora* L.(Agast)]: Current Status of Production, Protection and Genetic Improvement. In National Symposium on Vegetable Legumes For Soil and Human Health, Varanasi, India, 12–14 February 2016**.**
14. Vallone, M.; Pipitone, F.; Alleri, M.; Febo, P.; Catania, P. Hydroseeding Application on Degraded Slopes in the Southern Mediterranean Area (Sicily). *Appl. Eng. Agric.* **2013**, *29*(3), 309–319.
15. Vilma, G.; Juzenas, S.; Stukonis, V.; Norkeviciene, E. Sowing Mixtures of Native Plant Species: Are There Any Differences between Hydroseeding and Regular Seeding?. *Plants* **2021**, *10*(2507), doi: 10.3390/plants10112507.
16. Setiadi, Y. Templok Method (Alternative for Hydroseeding). 2010. Available online: http://elti.fesprojects.net/2012%20Course%20Mining%20Reg%20Indonesia/setiadi_templok_methods.pdf (accessed on 31 January 2026).
17. Sunandar, A. *Penanganan Erosi Permukaan Lereng Jalan Secara Vegetatif Melalui Teknologi Hydroseeding*; Adika: Bandung, ID, 2013, ISBN: 978-602-264-043-1.
18. ANTAM UBPE Pongkor. *General lecture materials*. Presented at Nusa Bangsa University, Bogor, ID, 2 June 2018.
19. (BPS) *Badan Pusat Statistik Kota Bogor*/Statistics Indonesia. Kota Bogor dalam Angka 2024. Available online: https://bogorkota.bps.go.id/id/publication/2024/02/28/aa94a4b5d6662971ebe2d881/kota-bogor-dalam-angka-2024.html (accessed on 31 January 2026)
20. Djaenudin, D.; Marwan, H.; Subagyo, H.; Hidayat, A. *Petunjuk Teknis untuk Komoditas Pertanian*. Balai Penelitian Tanah, Pusat Penelitian dan Pengembangan Tanah dan Agroklimat: Bogor, ID, 2003, ISBN 979-9474-25-6.
21. Metz, M.R.; Allen, D.; Banin, L.F.; Lu, X.; Sack, L. Functional Traits of Young Seedlings Predict Trade-offs in Seedling Performance in Three Neotropical Forests. *Journal of Ecology* **2023***, 111*(5), 1055–1070, doi: 10.1111/1365-2745.14186.
22. Gairola, K.C.; Nautiyal, A.L.; Dwivedi, A.K. Effect of Temperatures and Germination Media on Seed Germination of *Jatropha curcas* Linn. *Adv. Biores*. **2011,** *2*(2), 66–71.
23. Caliskan, S. Germination and Seedling Growth of Holm Oak (*Quercus ilex* L.): Effects of Provenance, Temperature, and Radicle Pruning. *iForest* **2014**, *7*, 103-109, doi: 10.3832/ifor0967-007.
24. Arsyat, S. *Konservasi Tanah dan Air*; IPB Press: Bogor, ID, 2010, ISBN 978-493-003-2.
25. Ministry of Forestry. Keputusan Direktorat Jenderal Reboisasi dan Rehabilitasi Lahan No. 41/Kpts/V/1998 tentang Petunjuk Pelaksanaan Penyusunan Rencana Teknik Lapangan Rehabilitasi Lahan dan Konservasi Tanah; Ministry of Forestry of Republic Indonesia: Jakarta, ID, 1986.
26. Ricks, M.D. Evaluation of Hydromulches as an Erosion Control Measure Using Laboratory-Scale Experiments. *Water* **2020**, *12*(2), 515, doi: 10.3390/w12020515.
27. Kumar, M.; Moghal, A.; Rasheed, R.; Rehman, A. Enhancing Durability and Erosion Resistance of Soils with Varying Plasticity Using Crosslinked Biopolymers. *Scientific Reports* **2025**, *15*, doi: 10.1038/s41598-025-96977-6.
28. Liu, X.; Zhang, H.; Chen, Y. Improving Water Stability of Soil Aggregates with Polyvinyl Alcohol as a Polymeric Binder. *Polymers* **2024**, *16*(13), 1758, doi: 10.3390/polym16131758.

29. Thomas, S.C.; Liu, Y.; Tang, E. Polyvinyl Acetate Binders Undermine the Effectiveness of Biochar-Based Seed Coatings. *Land* **2024**, *13*(7), 941, doi: 10.3390/land13070941.
30. Zairina, A.; Soemarno, S.; Rachmansyah, A.; Yanuwiadi, B.; Leksono, A.S. Effect of Hydroseeding Media Materials on Soil Stability from Landslide Sites. *J. Degrad. Min. Lands Manag.* **2025**, *12*(5), 8635-8646, doi: 10.15243/jdmlm.2025.125.8635
31. Anshari, M.F.; Fernandes, A.A.R.; Arisoesilaningsih, E. Comparing Seeds Germination of Some Local Plant Species on Two Hydroseeding Mulches for Post Mining Revegetation. *J. Degrad. Min. Lands Manag.* **2017**, *5*(2), 1103–1110, doi: 10.15243/jdmlm.2018.052.1103.
32. Azalia, D.; Retnaningdyah, C.; Arisoesilaningsih. Germination of Seeds of Some Local Pioneer Plant Species in Different Hydroseeding Mulches for Revegetation of Post-Coal Mining Soil. *J. Degrad. Min. Lands Manag.* **2016**, *3*(4), 609–615, doi: 10.15243/jdmlm.2016.034.609.
33. Vourlitis, G.L.; Griganavicus, J.; Gordon, N.; Bloomer, K.; Grant, T.; Hentz, C. Hydroseeding Increases Ecosystem Nitrogen Retention but Inhibits Natural Vegetation Regeneration After Two Years of Chaparral Post-Fire Recovery. *Ecol. Eng.* **2017**, *102*, 46–54, doi: 10.1016/j.ecoleng.2017.01.041.
34. Zink, T.A.; Allen, M.F. The Effects of Organic Amendments on the Restoration of a Disturbed Coastal Sage Scrub Habitat. *Restor. Ecol.* **1998**, *6*, 52–58. doi: 10.1046/j.1526-100X.1998.00617.x
35. Anshari, M.F. Revegetation of Postmining Soil Using Hydroseeding of Local Plant Seeds in Tanah Laut Regency, South Kalimantan Province. Thesis, Brawijaya University, Malang, 2015.
36. Utomo, B. Seeds Ecology. Available online: http://repository.usu.ac.id (accessed on 29 June 2025).
37. Lamichhane, J.; Debaeke, P.; Steinberg, C.; You, M.; Barbetti, M.; Aubertot, J. Abiotic and Biotic Factors Affecting Crop Seed Germination and Seedling Emergence: a Conceptual Framework. *Plant and Soil* **2018**, *432*, 1–28, doi:10.1007/s11104-018-3780-9.
38. Farooq, M.A.; Ma, W.; Shen, S.; Gu, A. Underlying Biochemical and Molecular Mechanisms for Seed Germination. *International Journal of Molecular* Sciences **2022**, *23*(15), 8502, doi:10.3390/ijms23158502.
39. Cherrate, M.; Radouane, N.; Ezrari, S.; Echchgadda, G.; Maissour, A.; Makroum, K.; Plăvan, G.; Abd-Elkader, O.; Bourioug, M. Effects of Temperature, pH, and Salinity on Seed Germination of *Acinos alpinus* subsp. *meridionalis* and FTIR Analysis of Molecular Composition Changes. *Sustainability* **2023**, *15*(6), doi:10.3390/su15064793.
40. Abella, S.C.; Gunn, J.L.; Daniels, M.L.; Springer, J.D.; Nyoka, S.E. Using a Diverse Seed Mix to Establish Native Plants on a Sonoran Desert Burn. *Native Plants J.* **2009**, *10*(1), 21–31. doi: 10.2979/NPJ.2009.10.1.21
41. Naikawadi, V.B. Seed Germination of Important Medicinal Plant *Tephrosia purpurea* (Linn.), Pers. *Int. Res. J. Nat. Appl. Sci.* **2016**, *3*(8), 186–207.
42. Miransari, M.; Smith, D.L. Plant Hormones and Seed Germination. *Environ. Exp. Bot.* **2014**, *99*, 110–121. doi:10.1016/j.envexpbot.2013.11.005.
43. Merlin, G.; Digioia, I.; Goddon, C. Comparative Study of the Capacity of Germination and of Adhesion of Various Hydrocolloids Used for Revegetalization by Hydroseeding. *Land Degrad. Dev.* **1999**, *10*, 21–34, doi:10.1002/(SICI)1099-145X(199901/02)10:13.0.CO;2-M.
44. Anshari, M.F.; Boedianto, E.; Fernandes, A.A.R.; Arisoesilaningsih, E. Hydroseeding Application Using Pioneer Local Plant Seeds for Coal Postmining Soil in Tanah Laut Regency, South Kalimantan. *J. Degrad. Min. Lands Manag.* **2018**, *5*(4), 1335–1345, doi:10.15243/jdmlm.2018.054.1335.
45. Islam, M.S.; Khan, A.J.; Siddique, A.; Saleh, A.M.; Nasrin, S. Control of erosion of hill slope top soil using geo jute and vegetation. In Proceedings of the National Seminar on Jute Geotextiles, Dhaka, Bangladesh, 2014, 27-34.
46. Cereno, M.M.; Tan, F.J.; Uy, F.A.A. Combined Hydroseeding and Coconet Reinforcement for Soil Erosion Control. In *Hydraulic Structures*; IntechOpen: London, UK, 2011.
47. Riyanto, H.D.; Pahlana, U.W.H. Efficiency and Effectiveness of the Formulation of Hydroseeding Materials on the Germination of Forest Plant Seeds. In National Seminar on Integrated Watershed Management, Malang, ID, 10 – 16 March 2014.

48. Ballesteros, M.; Canadas, E.M.; Marrs, R.H.; Foronda, A.; Martin-Peinado, F.J.; Lorite, J. Restoration of Gypsicolous Vegetation on Quarry Slopes: Guidance for Hydroseeding Under Contrasting Inclination and Aspect. *Land Degrad. Dev.* **2017**, *28*(7), doi:10.1002/ldr.2740.

49. Zairina, A.; Mondiana, Y.Q. The effect of Slope Level and Hydroseeding Formula on the Growth of *Cyperus brevifolius* and *Pueraria javanica* Seedlings. *Biodiversitas* **2020**, *21*(11), 5008–5012, doi:10.13057/biodiv/d211104.

50. Latifah, D.N.; Kendarto, D.R.; Bafdal, N.; Dwiratna, S.N.P.; Herwanto, T. Effect of Geo-Jute and Hydroseeding on the Growth Ability of Bermuda Grass (*Cynodon dactylon*) Seeds on Sloping Land. In National Seminar on Biodiversity Biology, Bandung, ID, 12 April 2018.

51. Ministry of Forestry. Peraturan Menteri Kehutanan Nomor 4 Tahun 2011 tentang Pedoman Reklamasi Hutan; Ministry of Forestry of Republic Indonesia: Jakarta, ID, 2011**.**