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Research Article

# Screening potential local seed species for hydroseeding of post-coal mining land multilayering revegetation

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## Abstract

This study aimed to screen some potential local seed grains for hydroseeding and describe their characteristics based on the literature review and a year of hydroseeding application. This study used six species/variants of Poaceae (*Coix lacryma-jobi, Eleusine indica, Setaria italica* (brown, black, and red), *Sorghum timorense, S. bicolor*, *Themeda arundinaceae*), five species of Leguminosae (*Adenanthera pavonina*, *Cajanus cajan, Sesbania grandiflora, S. sesban, Indigofera* sp.), a species of Cyperaceae (*Cyperus javanicus*), Sapindaceae (*Sapindus rarak*), Rhamnaceae (*Ziziphus jujuba*), and Moringaceae (*Moringa oleifera*). A seed germination test was held using soil media placed in 5 pots per species until 15 days after sowing (DAS). Characters were scored, and data were statistically analyzed. A field record of one-year hydroseeding applied on 6 m x 6 m post-coal mining land plot was presented. Some data such as pH $H_2O$, pH KCl, conductivity, and soil organic carbon among hydroseeding areas, unrevegetated areas, and reference sites were observed. Results showed that there were 13 of 17 species could variably germinate. The fastest germination time was recorded for *S. timorense, S. bicolor,* red *S. italica*, *C. cajan,* and *S. grandiflora*, while the highest germination rate (≥50%) was black *S. italica* (80%), brown *S. italica* (58%) and *S. bicolor* (50%). The annual black and brown *S. italica, S. bicolor,* and *S. timorense* were highly recommended to be used in hydroseeding. The perennial *C. cajan, Indigofera* sp., *S. sesban,* and *T. arundinaceae* were also potential to be added into a hydroseeding slurry to improve pioneer vegetation multilayering structure and diversity.

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## Introduction

Coal mining is an industrial activity that affects an ecosystem as a whole and has a serious impact on its quality (Goswami, 2015; Xu et al., 2017). The degradation of ecosystem quality that can be seen from the water, air, and sound pollution, loss of local biodiversity, land subsidence, the presence of landfill areas, and accidents in mining areas are impacts that arise from these mining activities (Bian et al., 2010; Mishra and Das, 2017). Mitigating ecological impacts on ecosystems disturbed by mining is done through post-mining land reclamation and revegetation efforts (MacDonald et al., 2015; Skousen et al., 2019).

Reclamation is an important part of the rehabilitation process for areas affected by mining activities through geomorphic reshaping, reconstruction of soil, and stabilization of hydrological aspects (Zipper et al., 2013; Feng et al., 2019). Revegetation of post-mining areas is carried out after the completion of land reclamation efforts. This revegetation effort aims to reduce erosion and degradation of soil quality (Sheoran et al., 2010). Revegetation will increase the value of environmental services in degraded areas (Gao et al., 2018). In addition, the increase in post-revegetation vegetation diversity also increases microbial diversity in the area (Guo et al., 2018).

One of the techniques used in post-mining land revegetation is hydroseeding. This technique uses a mixture of water, fertilizer, adhesive, seeds, and natural fibers (Clemente et al., 2016; Parsakhoo et al., 2018), which is sprayed over the entire prepared area (Donze and Lanz, 2015). One of the important things that support the success of hydroseeding and revegetation efforts as a whole is the selection of seeds of plant species used in the hydroseeding mixture. Unfortunately, the current hydroseeding application utilizes the seeds of some introduced plants, such as *Brachiaria decumbens* (signal grass), *Chloris gayana* (Rhodes grass), and *Cynodon dactylon* (Bermuda grass) (Emeka et al., 2021), which potentially would become an invasive alien species. Ultimately, the species selected must be able to facilitate natural succession processes and provide and regulate ecosystem services to the environment. Inappropriate species use, such as introducing fast-growing exotic species, will lead to decreased local species diversity, reduced value of environmental services, and decreased carbon sequestration potential (Maiti et al., 2021).

Local plants are some species that have been growing in a certain region and habitat and existed for many years. The use of local plant species as a source of seeds is highly recommended because of their ability to adapt to local biotic and abiotic conditions (Oliveira et al., 2013). Local plant species have higher survival rates, stem diameters, biomass, and net primary production than exotic plants (Singh and Kumar, 2022). However, according to Oliveira et al. (2012), the success of the use of local plant species in hydroseeding is still low. This is partly due to the low percentage of seed germination (Clemente et al., 2016). In addition, the availability of some local plant seeds in the market is still limited. To improve the success of hydroseeding, looking for plant species with high seed germination rates and availability in the market is necessary. This study aimed to explore some potential local seed grains for hydroseeding and describe their characteristics.

## Materials and Methods

This study used the seeds of several local plant species that was collected from local market, including six species/variants of Poaceae (*Coix lacryma-jobi, Eleusine indica,* brown *Setaria italica*, black *S. italica*, red *S. italica, Sorghum timorense, S. bicolor, Themeda arundinaceae*), five species of Leguminosae (*Adenanthera pavonina, Cajanus cajan, Sesbania grandiflora, S. sesban, Indigofera* sp.,), a species of Cyperaceae (*Cyperus javanicus*), Sapindaceae (*Sapindus rarak*), Rhamnaceae (*Ziziphus jujuba*), and Moringaceae (*Moringa oleifera*).

To determine the seeds to be germinated, the available seeds were soaked in water for ± 24 hours (Liang et al., 2020). The floating seeds were discarded, and the sinking seeds were used for germination tests. A total of 20 seeds from each species (Al-Hammad and Al-Ammari, 2017; Al-Turki and Baskin, 2017), with five replications, were placed in a pot (9 cm x 6 cm x 11.5 cm) containing ± 400 g soil media without any fertilizer. The soil was sandy loam and collected from the nursery. Seed germination on the media was observed up to 15 days after sowing (DAS) (Azalia et al., 2016) under 27.8 ± 1.1 °C of room temperature with 73.5 ± 8.8% of relative humidity and 63.3 ± 4.4 lux of light intensity.

The germination data were tabulated with Ms Excel. Characters data of local plant species based on literature study, which includes: availability (rare and not for sale, limited sale, or high availability in the market), vegetative growth (slow, moderate, or fast), seed production (low, moderate, or high), life cycle (annual, biannual, or perennials), life form (ground cover, sapling, small tree, or tree), and scored. Germination and character data were then analyzed statistically. Some field records of pioneer species applied and grown in the one-year hydroseeding were presented and discussed. This hydroseeding was applied in a post-coal mining land at Kintap, Tanah Laut Regency, South Kalimantan (Figure 1). The application of hydroseeding was conducted by spraying a slurry mixture (made from water, adhesive, compost, rice husk, wood fiber, and urea, and added by local plant seeds as above) on 6 m x 6 m plots. Some soil quality data such as pH $H_2O$, pH KCl, conductivity, and soil organic carbon were observed and analyzed. Then, the hydroseeding area (AH) data were compared with unrevegetated area (AR10) and reference site (HS) reflecting peat swamp forest.

## Results and Discussion

### *Germination rate among local species seeds*

In general, based on the seed germination test, it was found that *M. oleifera, Indigofera* sp., *T. arundinaceae, S. sesban, C. lacryma-jobi*, and *S. grandiflora* had a low germination rate, indicated by a germination percentage ≤20%. Meanwhile, *S. timorense*, red *S. italica, C. cajan,* and *Z. jujuba* had moderate germination rates with germination percentages >20% and <50%. The highest germination rate was shown by black *S. italica,* brown *S. italica*, and *S. bicolor,* with a percentage ≥50%. Seed germination is the initial stage of the growth cycle in plants (Parihar et al., 2015), which is a complex physiological process that begins with the absorption of water by dry seeds and ends with protrusion of the radicle through the seed coat (Tuan et al., 2019). As the most important stage in the plant life cycle, seed germination is strongly influenced by the availability of water, light, air, and temperature. Stress conditions due to these things can cause germination failure (Biswas et al., 2019). In addition, it is known that there are variations in the initial germination time in each species (Table 1). The fastest early germination time was shown by *S. bicolor, S. timorense,* red *S. italica, C. cajan, S. grandiflora,* which germinated in 1 DAS, and black *S. italica,* brown *S. italica, S. sesban,* which germinated in 2 DAS. Moderate early germination time was indicated by *Z. jujuba, Indigofera* sp., which germinated in 3 DAS, and *M. oleifera, T. arundinaceae,* which germinated in 4 DAS. The slowest early germination time, at 6 DAS, was indicated by *C. lacryma-jobi*.


Figure 1. Location of one-year hydroseeding application. Note: Black box represents the hydroseeding area, the red box represents the unrevegetated area, and the yellow box represents the reference site.

According to Azalia et al. (2016), the germination time of the Poaceae family was faster than other families. Seeds of *S. rarak, C. javanicus, E. indica,* and *A. pavonina* did not show germination up to 15 DAS. *S. rarak* and other species in the Sapindaceae family are known for low, slow, and uneven germination rates (Sulisetijono et al., 2016). The results of a study conducted by Azalia et al. (2016) showed that *E. indica* and species from Cyperaceae only germinated after 15 DAS. Meanwhile, another study conducted on *A. pavonina* seeds showed that the newly collected seeds did not germinate at all (Jaganathan et al., 2018). Black *S. italica* showed the highest germination rate (80%), followed by brown *S. italica* (58%). The seeds of *S. italica* can germinate with a high germination rate and good growth at an optimum temperature (Setyowati et al., 2020). *S. italica* and sorghum are two species of the Poaceae family that have high resistance to drought stress (Tang et al., 2017; Abdel-Ghany et al., 2020). In general, species from the Poaceae family have a higher germination rate than other families.

***The characters of some local plants***

Based on their availability, black *S. italica*, brown *S. italica, S. bicolor,* red *S. italica, C. cajan, Z. jujuba, M. oleifera, Indigofera* sp., and *S. grandiflora* can be found in large quantities in the market. This supports the success of hydroseeding which requires large amounts of seeds in its application. Based on their vegetative growth, almost all of the species used are able to grow quickly. Except *Indigofera* sp. growing at a moderate rate. The optimum temperature required for *Indigofera* germination is ≥30 °C. *Indigofera senegalensis* germinated at 35°C (Baskin and Baskin, 2014). The seed production of each species varies. *S. timorense* and *T. arundinaceae* are capable of producing large amounts of seeds. While other species can produce seeds at low and moderate levels. In Indonesia, the average productivity of sorghum ranges from 1.67-2.73 t $ha^{-1}$ (Lestari et al., 2019). It means that sorghum could be great potential for regeneration and adaptability for upland reclamation.

The result of cluster analysis of germination rate and 1st day germination data showed that there were four groups of the species (Figure 2a). The first group was black *S. italica.* The second group were *S. timorense, S. bicolor,* and brown *S. italica.* The third group was *C. lacryma-jobi, S. grandiflora, S. sesban,* and *T. arundinaceae.* The fourth group was *Indigofera* sp., *M. oleifera, Z. jujuba, C. cajan,* and red *S. italica.* Based on availability, vegetative growth, and seed production data, cluster analysis result indicated four groups (Figure 2b). The first was *T. arundinaceae* and *S. timorense.* The second group was *S. sesban* and *C. lacryma-jobi.* The third group was *M. oleifera, Z. jujuba,* and *Indigofera* sp. The last group consisted of *S. grandiflora, C. cajan,* black *S. italica,* brown *S. italica, S. bicolor,* and red *S. italica.* Based on life form and life cycle characters, cluster analysis showed that there were four groups (Figure 2c). The first group was *C. lacryma-jobi,* black *S. italica,* brown *S. italica,* and red *S. italica.* The second group consisted of *S. bicolor, T. arundinaceae, Indigofera* sp., and *S. timorense.* The third group was *S. grandiflora, S. sesban,* and *C. cajan.* Moreover, the fourth group consisted *Z. jujuba* and *M. oleifera.*

Table 1. The seed germination rates and the characteristics of some local plant species.

| Species | Family | Germination rate (%)* | 1st day germination* | Availability | Vegetative growth | Seed Production | Life cycle | Life form ** |
|---|---|---|---|---|---|---|---|---|
| Black *S. italica* | Poaceae | 80 | 2 | high | fast | Moderate | annual | gc |
| Brown *S. italica* | Poaceae | 58 | 2 | high | fast | Moderate | annual | gc |
| *S. bicolor* | Poaceae | 50 | 1 | high | fast | Moderate | biannual | gc |
| *S. timorense* | Poaceae | 42 | 1 | rare | fast | High | perennials | gc |
| Red *S. italica* | Poaceae | 26 | 1 | high | fast | Moderate | annual | gc |
| *C. cajan* | Leguminosae | 26 | 1 | high | fast | Moderate | perennials | sapling |
| *Z. jujuba* | Rhamnaceae | 24 | 3 | high | fast | Low | perennials | st |
| *M. oleifera* | Moringaceae | 20 | 4 | high | fast | Low | perennials | tree |
| *Indigofera* sp. | Leguminosae | 17 | 3 | high | moderate | Low | perennials | gc |
| *T. arundinaceae* | Poaceae | 8 | 4 | rare | fast | High | perennials | gc |
| *S. sesban* | Leguminosae | 8 | 2 | limited | fast | Moderate | perennials | sapling |
| *C. lacryma-jobi* | Poaceae | 8 | 6 | limited | fast | Low | annual | gc |
| *S. grandiflora* | Leguminosae | 6 | 1 | high | fast | Moderate | perennials | sapling |
| *S. rarak* | Sapindaceae | 0 | 0 | limited | fast | Moderate | perennials | tree |
| *C. javanicus* | Cyperaceae | 0 | 0 | rare | fast | High | annual | gc |
| *E. indica* | Poaceae | 0 | 0 | rare | fast | Low | annual | gc |
| *A. pavonina* | Leguminosae | 0 | 0 | limited | fast | High | perennials | tree |

* Until 15 DAS, ** gc ground cover, st small tree.

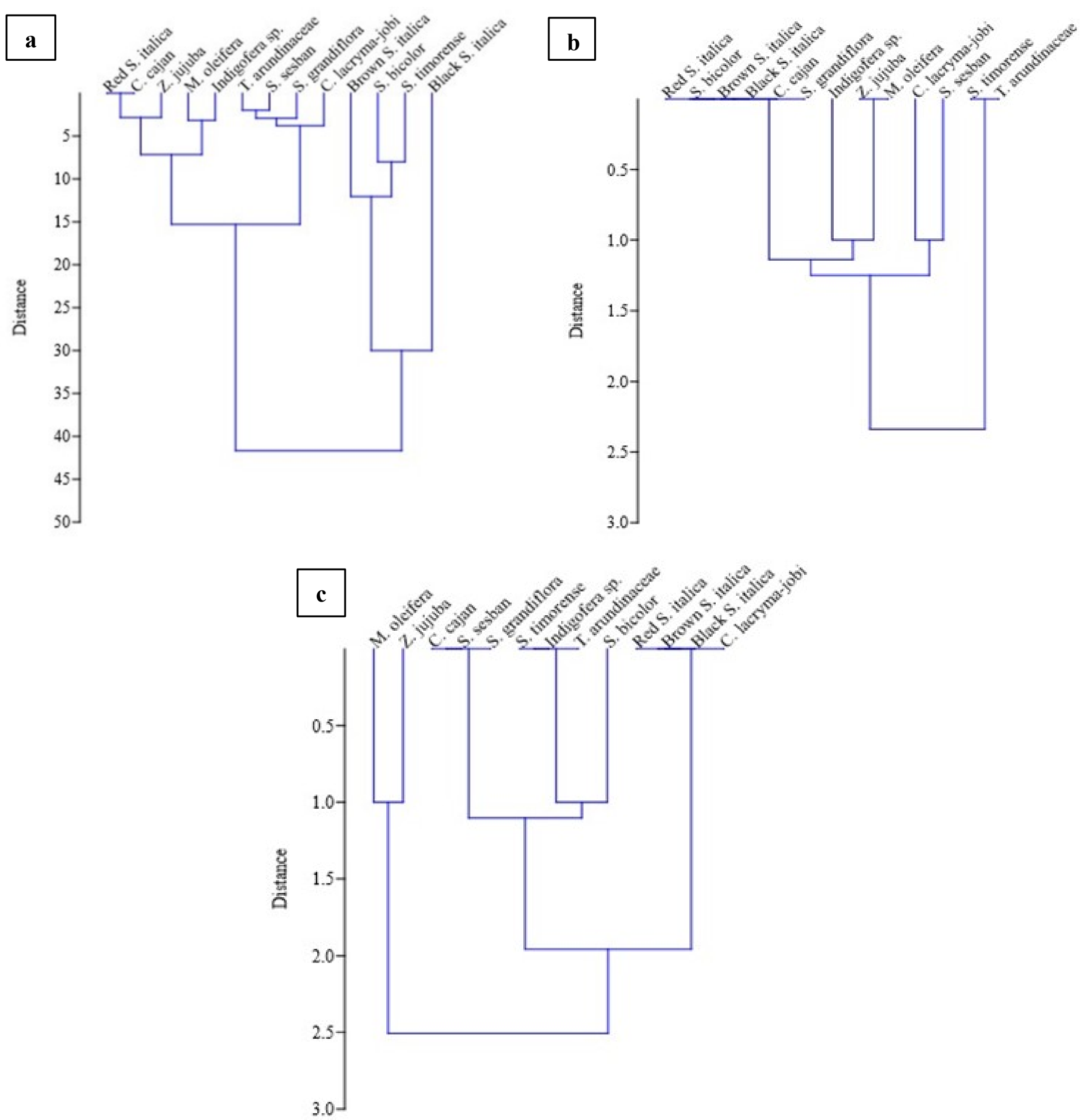


Figure 2. Cluster analysis result of (a) germination rate and 1st day germination, (b) availability, vegetative growth, and seed production, (c) life form and life cycle.

The result of the biplot analysis of all data showed that there were five groups, and every group had specific characteristics among group members. The first group consisted of black *S. italica,* brown *S. italica,* red *S. italica,* and *S. bicolor,* characterized by a high germination rate. These species were promising as fast-growing grasses for the open area to develop a dense ground cover. *Setaria* is one of the plants grown well in some regions, such as Papua (Biak Numfor) and Maluku (Buru Island) (Suharno et al., 2015), Java, Central Kalimantan, and Western Sulawesi. This plant was reported to be used in handling sand tailing associated with arbuscular mycorrhizal fungi (Suharno et al., 2021). The second group consisted of *S. timorense* and *T. arundinaceae, and* was characterized by a high level of vegetative growth and seed production. The third group was *S. sesban, S. grandiflora*, and *C. cajan*, and they had a long-life cycle character. These local species were fast-growing small leguminous shrubs in the degraded soil, and *S. sesban* was grown in a wide variety of soils from loose sandy soils to heavy clays (Heuze et al., 2016), silt siltstone, limestone, silty shale, sandy soils, and clays. Another promising perennial leguminous local tree species *Cassia siamea* that was reported to grow well on quartz tailings of a former tin mining area in Bangka Island (Narendra and Pratiwi, 2016). The fourth group, *C. lacryma-jobi,* was characterized by a long first germination time. The last group was characterized by its life form. The members of this group were *Z. jujuba, Indigofera* sp., and *M. oleifera* (Figure 3).

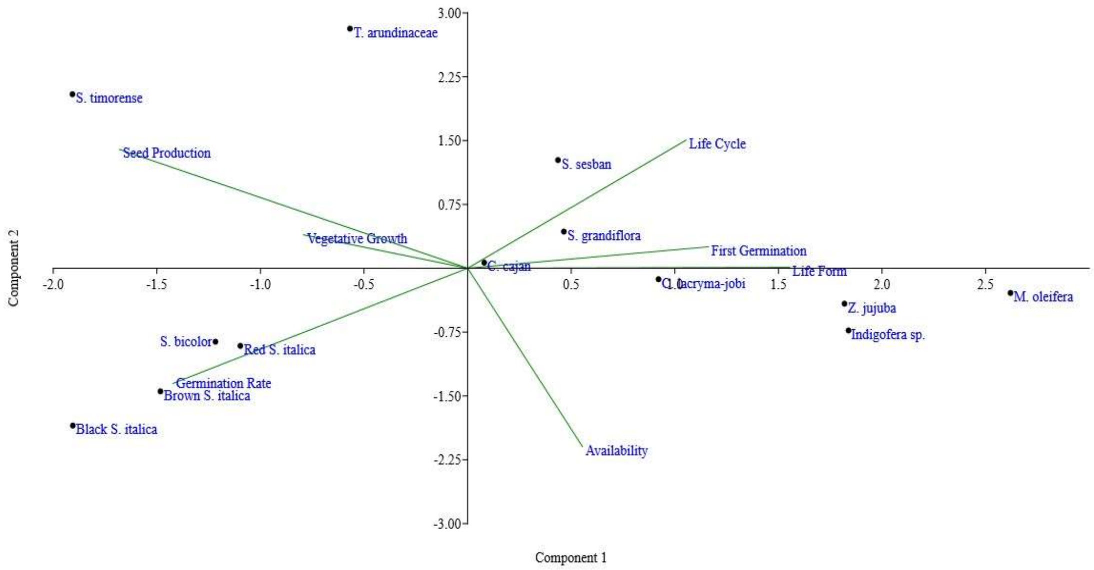


Figure 3. Biplot analysis result of germination rate, 1st day germination, availability, vegetative growth, seed production, life form, and life cycle.

### *Some pioneer plant species applied, grown, and survived in the one-year hydroseeding*

The observation of the hydroseeding plot showed the differences between that plot over time. Figure 4a revealed that the plot was almost bare of any vegetation before the hydroseeding application. One month after application, hydroseeding accelerated land covering and improved multilayer vegetation (Figure 4b). *Sorghum* sp. grew most rapidly after the hydroseeding application (Figure 4d). Generally, *Sorghum* sp. tolerates drought stress (Abreha et al., 2022). One year after application (Figure 4c), some vegetation survived and regenerated, like *C. cajan, Indigofera* sp., *S. sesban,* and *T. arundinaceae* (Figure 4e-h). These vegetations, such as sorghum, are also known for their resistance to heavy metals (Patra et al., 2020; Allamin et al., 2021) and salinity (Nadir et al., 2018).

### *Soil quality after hydroseeding application*

Generally, the hydroseeding area showed changes in soil quality compared to the unrevegetated area and reference site (Table 2). The score of pH $H_2O$, pH KCl, and conductivity in the hydroseeding area was lower than the unrevegetated area, while the percentage of soil organic carbon was higher than it. This all indicated a more similar value to the reference site. pH $H_2O$ and pH KCl are two main obligatory indices to represent soil acidity (Wang et al., 2019). In a peat swamp forest, the soil pH score ranged between 3.7-5.2. This low pH is caused by bad organic acid hydrolysis (Rinaldi et al., 2019). A low electric conductivity value in areas resulted from the interaction between sulphidic and peat materials. A study conducted by Fahmi et al. (2019) showed that the range of conductivity value in peaty soil is 0.030-0.142 mS $cm^{-1}$.

Table 2. Soil quality.

| No | Location | pH $H_2O$ | pH KCl | Electric Conductivity (mS $cm^{-1}$) | Soil organic carbon (%) |
|---|---|---|---|---|---|
| 1 | HS | 4.80 | 3.98 | 0.10 | 1.88 |
| 2 | AR10 | 6.08 | 5.31 | 0.18 | 0.68 |
| 3 | AH | 5.57 | 4.94 | 0.13 | 0.71 |

Note: HS (reference site), AR10 (unrevegetated area), AH (hydroseeding area).

## Conclusion

The fastest germination time was shown by *S. timorense, S. bicolor,* red *S. italica*, *C. cajan,* and *S. grandiflora*, which germinated in 1 DAS, while species with the highest germination rate (≥50%) were black *S. italica* (80%), brown *S. italica* (58%) and *S. bicolor* (50%). Based on the germination rate of the seeds and their time as well as their characteristics (vegetative growth, seed production, availability, life cycle, and life form), the annual black and brown *S. italica, S. bicolor,* and *S. timorense* are highly recommended to be used in hydroseeding. Besides, based on a year of hydroseeding application, the technique can enhance soil conditions closer to the condition of the reference site. The perennial *C. cajan, Indigofera* sp., *S.sesban,* and *T. arundinaceae* can also potentially be added into a hydroseeding slurry to improve the vertical structure and diversity of pioneer vegetation.


Figure 4. Hydroseeding plot and vegetation (a) before hydroseeding application, (b) a month after application, (c) a year after application, (d) *Sorghum* sp., (e) *C. cajan,* (f) *Indigofera* sp., (g) *S. sesban,* (h) *T. arundinaceae.*

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