Ecobelt construction adopting agroforestry for rehabilitation of mined-out nickel areas in Surigao, Philippines

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Abstract. Surface mining to extract nickel ore disturbs the soil and vegetation. This activity removes the topsoil and vegetation, which accelerates soil erosion during the rainy season affecting the freshwater and marine water bodies nearby. Conserving a forest strip to act as a buffer for soil erosion and filter contaminants is a natural way to mitigate the impacts of mining on interconnected ecosystems. The introduction of an 'ecobelt' was done in the nickel mines in Surigao. It is an agro-forest strip designed to provide a corridor for biodiversity to stay and repopulate the degraded areas. Soil erosion and the survival of trees were monitored to assess the effect of the ecobelt. Results revealed that the four tree species having high percentage survival and excellent growth performance in nickel areas were: ipil-ipil (*Leucaena leucocephala* Linn.), narra (*Pterocarpus indicus* Linn.), mansanitas (*Muntingia calabura* Linn.) and calumpit *(Terminalia macrocarpa Steud.)*. The nurse trees: *L. leucocephala, M. calabura*, and *S. saman* have high littering capacities that contribute to the organic matter content of the soil. The soil erosion monitoring results indicated a weak correlation between rainfall and the monthly change in soil height both in the Taganito Mining Corporation (TMC) and Hinatuan Mining Corporation (HMC) ecobelt areas. These results indicate that a higher rainfall amount does not necessarily result in more significant soil erosion.

Key Words: mine rehabilitation, ecobelt, agroforestry, surface mining, ecosystem restoration.

Introduction. Nickel mining in the region adopts surface mining, which removes the topsoil and vegetation. With the surface removal of soil and vegetation, soil erosion occurs primarily during the rainy season that cause siltation in the freshwater and marine water bodies nearby. Thus nickel mining is viewed to be the cause of environmental degradation. Re-vegetation is implemented to rehabilitate the mined-out areas and lessen the impacts of mining on interconnected ecosystems.

Vegetation such as trees and shrubs are natural buffer of soil erosion, thereby preventing the soil from reaching the agricultural systems, human settlements, and the freshwater and marine ecosystems. In Kalimantan, Indonesia, Sudarmadji & Hartati (2016) reported that using cover crops, fast-growing plant species, and undergrowth has shown the potential recovery of the degraded forest ecosystem. The surviving primary species indicate this through decreasing surface run-off/overland flows following increasing soil infiltration capacities, decreasing soil erosion rate and erosion hazard, and an improved environment for wildlife habitat. Vegetation serves as the primary producer, thus crucial in providing nutrients, ground covers, clean air, and habitats for various other life forms. In a study on mine rehabilitation in Transylvania, pasture cover crops most significantly enhanced the soil's microbial activity, organic carbon, nitrogen, phosphorus, and potassium content followed by natural grassland (Buta et al 2019). Early successional trees such as pines, sweet birch, sourwood, red maple, and bigtooth aspen that are fast-growing species provide habitat for birds and other seed-moving animals. These also help suppress grasses in mine reclamation, thus allowing native forest plant species to become established (Groninger et al 2017). Some successional tree species produce fruits that further contribute to forest development by inviting seed-carrying birds and other wildlife.

In Surigao, the nickel mining companies have started rehabilitation towards the restoration of the areas affected by their operations. The Taganito Mining Corporation (TMC) and Hinatuan Mining Corporation (HMC) planted *Casuarina equisetifolia* Linn. and fast-growing species such as *Acacia mangium* Willd. and *Paraserianthes falcataria* Nielsen. Varela & Garcia (2017) reported that arthropods have started colonizing the rehabilitated mined out areas. However, in spite of these initiatives, certain adverse environmental effects (e.g., soil erosion, siltation) are still visible. Hence, the ecobelt technology where there is an integration of trees and other vegetation in a forest strip was evaluated. This study aimed to promote ecosystem restoration by adopting the ecobelt concept where there is a mix of species of nurse trees, trees for timber, fruit trees, and shrubs. Thus the survival and growth of plants and also soil erosion were determined.

Material and Method. The project was done for 3 years covering 2014-2017 in two nickel mines in Surigao del Norte, namely: Hinatuan Mining Corporation (HMC) and Taganito Mining Corporation (TMC). The mining areas are located at the northeastern tip of Mindanao, Philippines, which is part of the Eastern Mindanao Biodiversity Corridor (Figure 1).

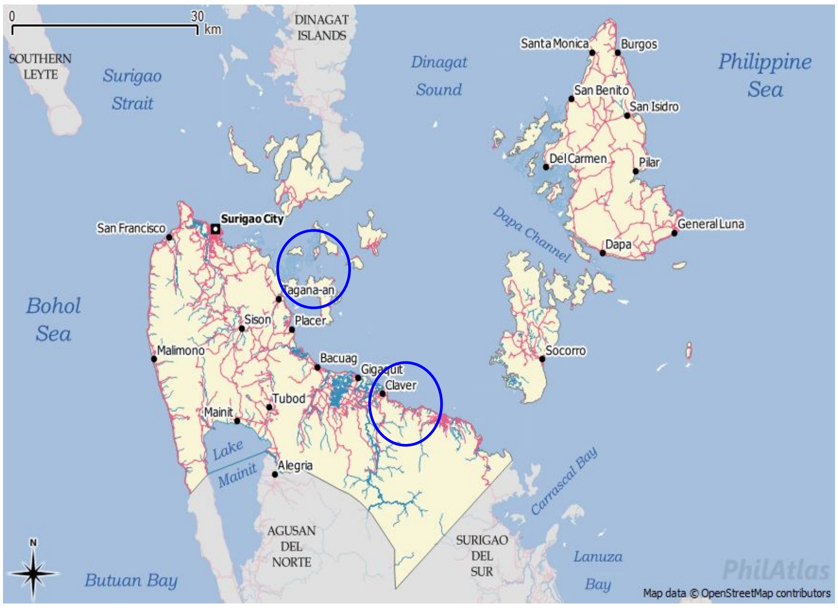

Figure 1. Map of Surigao Province, Philippines showing the research sites (encircled in blue). Photo credit to PhilAtlas.

Ecobelt establishment in mined-out areas. Slope re-shaping was done in the mined-out area. This was followed by the spreading of the overburden to return the topsoil to the site. Different native plant species and fast-growing species to serve as nurse trees were then planted in the site. The list of plant species used is shown in Tables 1 and 2 for HMC and TMC, respectively. The plants were transplanted in strips for re-vegetation of the area and provide biodiversity corridors. In establishing the ecobelt, the concepts of agroforestry are employed, such as contour planting, integration of fruit trees, and planting of flowering plant species to attract pollinators, which are the agents of dispersal. Data on plant survival and growth were gathered.

The ecobelt concept (Figure 2) is adopted to give an alternative approach to the rehabilitation of mined areas. Contour planting was done to prevent soil erosion. The distances of the forest strips are based on the slope of the mountain to be rehabilitated. This approach is designed to give the mining companies an option in mine rehabilitation since the mining companies have started planting *P. falcataria* Nielsen and *C. equisetifolia* in monoculture.

Table 1
Tree species planted in the forest strips at Hinatuan Mining Corporation, Taganaan, Surigao del Norte

Tree species	*Common name*	*Family*
Terminalia microcarpa Steud.	Calumpit	Combretaceae
Artocarpus blancoi (Elmer) Merr.	Antipolo	Moraceae
Diospyros philippinensis A. DC.	Mabolo	Ebenaceae
Petersianthus quadrialatus Merr.	Toog	Lecythidaceae
Leucaena leucocephala (Lam.) de Witt.	Ipil-Ipil	Fabaceae
Pterocapus indicus Willd.	Narra	Fabaceae
Syzygium brevistylum (C.B. Rob.) Merr.	Sagimsim	Myrtaceae
Samanea saman (Jacq.) Merr.	Acacia	Fabaceae
Artocarpus odoratisimus Blanco	Marang	Moraceae
Muntingia calabura Linn.	Mansanitas	Muntingiaceae
Tamarindus indicus Linn.	Sampalok	Fabaceae

Table 2
Tree species planted in the forest strips at Taganito Mining Corporation, Claver, Surigao del Norte

Tree species	*Common name*	*Family*
Terminalia microcarpa Steud.	Calumpit	Combretaceae
Diospyros philippinensis A. DC.	Mabolo	Ebenaceae
Petersianthus quadrialatus Merr.	Toog	Lecythidaceae
Leucaena leucocephala (Lam.) de Witt.	Ipil-Ipil	Fabaceae
Pterocapus indicus Willd.	Narra	Fabaceae
Syzygium brevistylum (C.B. Rob.) Merr.	Sagimsim	Myrtaceae
Samanea saman (Jacq.) Merr.	Acacia	Fabaceae
Muntingia calabura Linn.	Mansanitas	*Muntingiaceae*
Vitex parviflora A. Juss.	Molave	Verbenaceae
Swietenia macrophylla King	Mahogany	Meliaceae
Psidium guajava Linn.	Guava	*Myrtaceae*

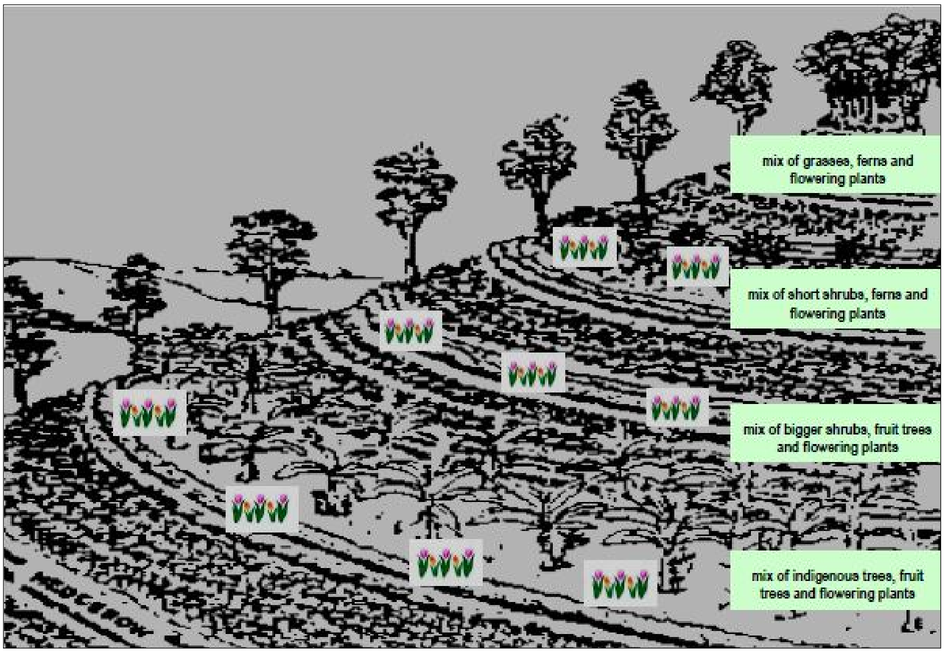

Figure 2. Planting design of the mine rehabilitation strategy adopting the ecobelt concept.

Soil erosion measurement. To monitor the initial rate of soil erosion in the ecobelt, soil erosion bars were installed randomly in the area. Data gathering was made by measuring the height of the bar from the soil surface to the top of the bar level using a meter stick. The corresponding changes in the height of the ground surface were determined from the erosion bars regularly. The monitoring and measurement were done in the newly established ecobelts and the old plantings of *C. equisetifolia* and *P. falcataria*.

Results and Discussion

Growth and survival of selected tree species for rehabilitation. The growth response of the different plant species to the conditions in the mined-out areas in HMC and TMC varied (Tables 3 and 4). The fast-growing trees among the various species planted in the ecobelts in both mining sites were: a) ipil-ipil (*L. leucocephala*), b) mansanitas (*M. calabura*), and c) acacia (*S. saman*). *L. leucocepaha, M. calabura*, and *S. saman* were selected to serve as nurse trees for the other slow-growing indigenous tree species in the ecobelt that require a certain degree of shade. *L. leucocepaha* and *S. saman* have high littering capacity that can contribute to the organic matter content of the soil. These plants also have a higher percentage of survival, even in the very harsh condition of the area (Varela et al 2016). *L. leucocepaha* and *M. calabura* were observed to be the very first species of trees to produce flowers and fruits in the area. However, between these two plant species, *L. leucocepaha* was the only species to have grown some seedlings from the fallen seeds of its matured pods. These seedlings were observed growing within its base or a short distance away from the source plant (Figure 2). The different planted tree species showed a high survival rate in all sampling sites. *Pterocarpus indicus, Terminalia microcarpa,* and *L. leucocephala* were also among the species with high survival rates in both sites (Tables 3 and 4).

Figure 2. Seedlings of *L. leucocephala* from the originally introduced plants in the ecobelt at HMC.

Table 3

Survival and growth of different plant species in the ecobelt at Hinatuan Mining Corporation site

Plant species	*Survival rate (%)*	*Plant height (cm)*		*Stem diameter (cm)*	
		At planting	*After 1 year*	*At planting*	*After 1 year*
Samanea saman	73.03	139.5	159.60	1.84	2.11
Lecucaena leucocephala	85.71	140.8	198.75	1.35	1.95
Muntingia calabura	86.54	105.4	120.86	1.21	1.56
Diospyros philippinensis	35.71	44.00	53.45	1.00	1.20
Syzygium brevistylum	75.00	35.25	45.76	0.74	1.19
Petersianthus quadrialatus	62.50	50.00	65.56	0.86	1.25
Terminalia microcarpa	66.67	46.75	53.35	0.77	1.13
Tamarindus indicus	29.41	44.20	60.43	0.55	1.01
Pterocarpus indicus	100.00	53.50	61.00	0.65	0.70
Artocarpus odoratisimus	61.22	63.40	75.90	0.67	0.82
Terminalia microcarpa	92.50	55.50	70.87	0.98	1.19

Table 4

Survival and growth of different plant species in the ecobelt at Taganito Mining Corporation site

Plant species	*Survival rate (%)*	*Plant height (cm)*		*Stem diameter (cm)*	
		At planting	*After 1 year*	*At planting*	*After 1 year*
Samanea saman	90.79	88.55	104.15	0.72	1.39
Leucaena leucocephala	100.00	118.4	151.6	1.23	1.63
Muntingia calabura	83.02	73.08	86.77	1.39	1.58
Psidium guajava	41.33	71.69	78.75	0.75	0.84
Diospyrus philippinensis	78.38	32.50	36.21	0.63	0.68
Swietenia macrophylla	89.50	55.13	56.94	0.69	0.83
Vitex parviflora	76.75	59.29	64.55	0.71	0.94
Pterocarpus indicus	91.30	50.07	57.65	0.54	0.58
Syzygium brevistylum	34.88	41.80	47.50	0.46	0.58
Petersianthus quadrialatus	48.00	33.33	37.40	0.46	0.54
Terminalia microcarpa	98.02	65.35	67.90	0.68	0.73

At three months after planting, both *L. leucocepala* and *M. calabura* have started to flower and bear fruits. CABI (2013) listed *L.leucocepala* as an aggressive colonizer of wastelands and on secondary or disturbed vegetation both in Mexico, in the Yucatán Peninsula, and many parts of Asia. The species is even classified as highly invasive due to its characteristic to flower and fruit year-round with abundant seed production, self-fertility, and presence of a hard seed coat, an ability to build up a seed bank, and ability to re-sprout after a fire or cutting (Binggeli 2001). *M. calabura*, on the other hand, thrives in poor (acidic and alkaline) soils and can tolerate drought. Besides, birds and fruit bats readily distribute the seeds of *M. calabura*, making it a right pioneer plant because the rapid spread of the population in mined-out areas is essential to provide ground cover for conditioning the soil. The importance of birds and fruit bats as seed dispersal agents have been extensively studied in the Philippines (Ingle 2003; Gonzales et al 2009). Nonetheless, monitoring of the spread of its population is recommended since it has the potential to be an invasive species which may out-compete indigenous plants. *S. saman* is also a fast-growing species with dense branching and broad spreading crown (Staples et al 2006). It has a symbiotic relationship with many strains of Rhizobium. The deciduous nature of the species where the shedding of leaves happen is the primary mechanism of improving soil fertility in areas planted to *S. saman*.

Soil erosion in undisturbed and rehabilitated mind-out areas. The result of the soil erosion monitoring indicated a weak correlation between rainfall and the monthly change in soil height both in the TMC and HMC ecobelt areas (Figures 3 and 4). This result points out that a higher rainfall amount does not necessarily induce more significant changes in soil height as measured by the erosion bars. The movement of soil particles during heavy rains sometimes leaves some portions eroded and some parts covered with silt, particularly where there are elements that trapped the material (e.g., log, rocks). The lowest readings in the change in soil height at TMC were observed in May in both 2014 and 2015 at 0.41 cm and 0.24 cm, respectively (Figure 3). The month of May also corresponds to low rainfall, suggesting that minimal movement of soil particles occurred due to the limited water that forces erosion. The most significant change in soil height, on the other hand, was observed in July and June in 2014 and 2015 at 0.95 cm and 0.90 cm, respectively. Assuming that the soil in the area has a bulk density of 1 g cm^{-3}, these readings would respectively correspond to 41 tons and 24 tons per hectare of eroded soil material for the lowest readings. The highest readings would then correspond to 95 tons and 90 tons per hectare of eroded soil material for 2014 and 2015, respectively, using the same assumption of having a bulk density of 1 g cm^{-3}. The correlation between rainfall and soil erosion tends to decrease as the amount of rainfall increases, mainly where the rainfall was higher than 200 mm/month (Figure 4).

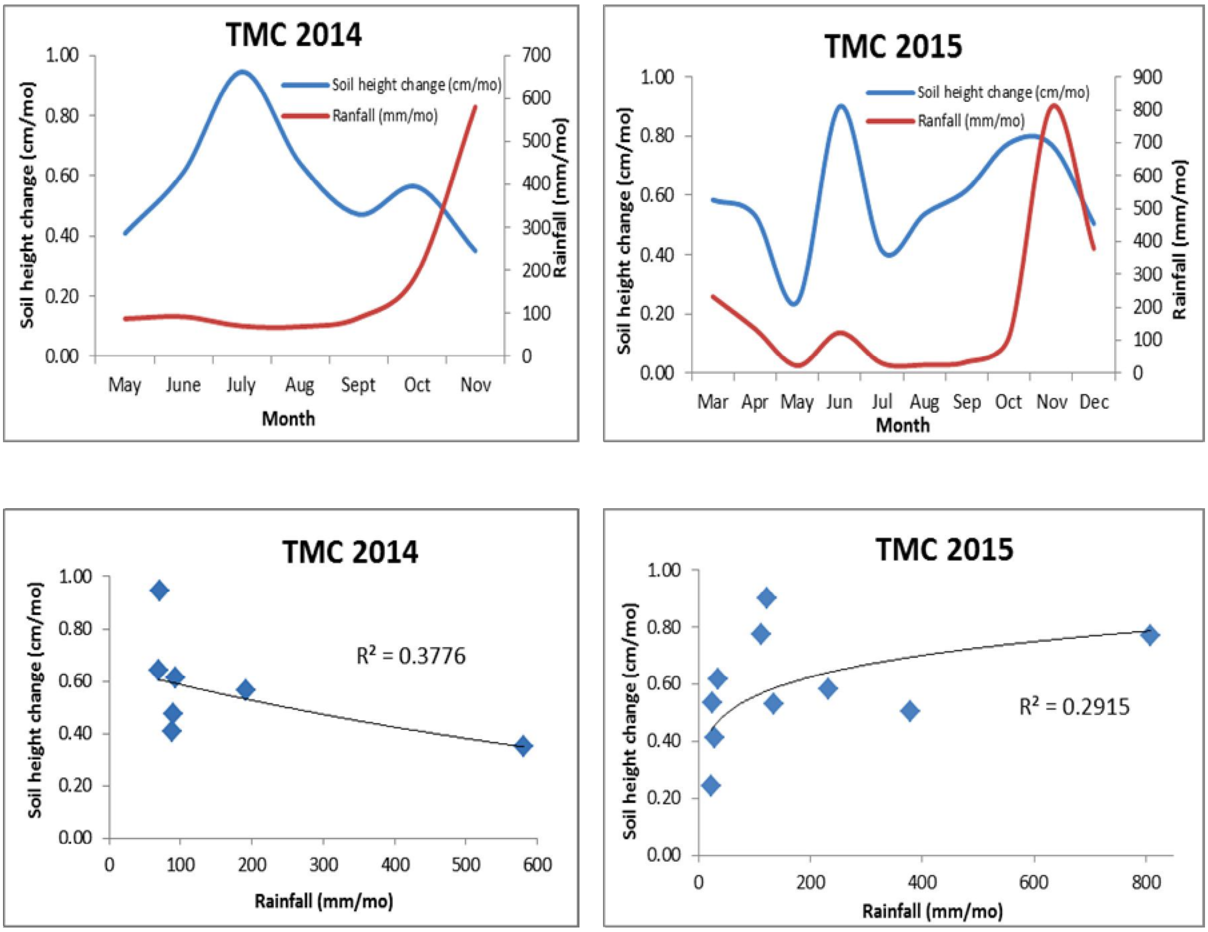

Figure 3. Correlation analysis between rainfall and change in soil height at TMC in 2014 and 2015.

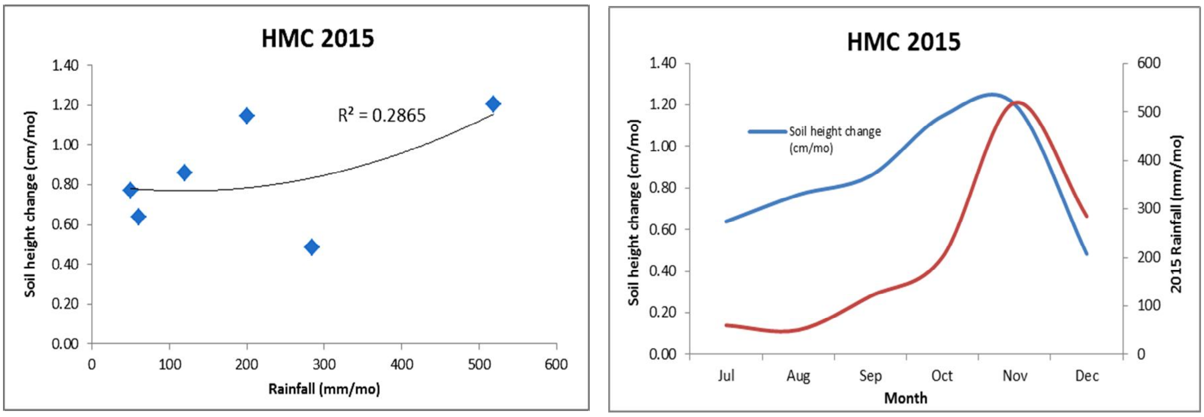

Figure 4. Correlation analysis between rainfall and soil height at HMC.

At HMC, the lowest change in soil height was in December 2015 (0.48 cm), while the most significant change was in November 2015 (1.20 cm). On the assumption that the soil in the area has a bulk density of 1 g cm^{-3}, these readings would respectively correspond to 48 tons and 120 tons per hectare of eroded soil material for the lowest and highest readings. The rainfall and soil change height are not directly correlated (Figure 4). The conditions are relatively similar to that of TMC wherein certain factors refrain the soil particles from moving at certain portions; thus, readings in certain erosion bars are high (Wang et al 2013). Some parts of the ecobelt area have high readings of soil height change due mainly to the wearing away of soil particles resulting from the effect of wind. This is primarily for areas where the wind is.

A higher correlation between rainfall and monthly soil height change was observed under the *C. equisetifolia* L. and *P. falcataria* Nielsen areas. The fast-growing *C. equisetifolia* and *P. falcataria* prevented massive soil erosion because tall vegetation can affect sediment transport (Kothyari et al 2009). On the other hand, no correlation was noted between the soil height change and rainfall in the undisturbed area. On average, the lowest readings in the shift in soil height were noted in the mature *C. equisetifolia* L. area (0.37 cm/month), which is equivalent to 37 tons/ha/month of eroded soil material. This was followed by the undisturbed area (0.38 cm/month). This indicates that using *C. equisetifolia* L. plants for rehabilitation is effective in controlling erosion in the mined-out areas. However, the planting arrangement can probably be reviewed to prevent soil erosion further. Also, re-shaping of the mined-out area into a series of benches (terracing) can be considered as a bio-engineering approach to reducing the erosion of soil material in the rehabilitated sites. Terracing, combined with additional soil conservation practices, prevents soil erosion. An essential soil conservation practice is the maintenance of a permanent soil cover (Dorren & Rey 2010). The slope and span of the benches are likewise essential to be studied mainly in tropical countries like the Philippines because of the wind, temperature, and rain that may contribute to the vulnerability of the soil surface to erosion. Hedgerows and vegetation ridges, such as in the ecobelt, may be good alternatives for terraces, but eventually, they work in the same way. Terraces reduce both the amount and velocity of water moving across the soil surface, reducing soil erosion (Wheaton & Monke 2001) significantly. However, changes in soil height generally increase from the upper slope to the lower slope, indicating that more soil is eroded in the upper slopes that accumulated in the lower slopes.

Conclusions. Among the various species planted in the ecobelts in both mining sites, the fast-growing trees were: a) ipil-ipil (*L. leucocephala*), b) mansanitas (*M. calabura*), and c) acacia (*S. saman*). Of the tree species planted, *P. indicus, T. microcarpa,* and *L. leucocephala* were among the species with a high survival rate in both mining sites. *L. leucocepaha, M. calabura*, and *S. saman* served as good nurse trees for the slow-growing indigenous tree species in the ecobelt because they provided not only shade but also soil nutrients. Due to their high littering capacities, they contribute to the organic matter content of the soil.

There was a weak correlation between rainfall and the monthly change in soil height in mined-out areas indicating that erosion is influenced by factors other than rain. Construction of benches and the establishment of ecobelts have the potential to reduce soil erosion. Nonetheless, more studies have to be conducted in the Philippines because there are other factors (e.g. wind, temperature, rain frequency) that need to be considered.

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