Annals of Studies in Science and Humanities
Volume 2 Number 1 (2016) : 16–25

http://journal.carsu.edu.ph/
Online ISSN 02408-3631

Survival and Growth of Plant Species in Agroforestry System for Progressive Rehabilitation of Mined Nickel Sites in Surigao del Norte, Philippines

Rowena P. Varela[1,2,*], *Glenn Arthur A. Garcia*[1,2], *Chime M. Garcia*[2] *and Amelyn M. Ambal*[3]

[1]Department of Agricultural Sciences, College of Agricultural Sciences and Natural Resources, Caraga State University, Butuan City, 8600 Philippines
[2]Department of Natural Resources, College of Agricultural Sciences and Natural Resources, Caraga State University, Butuan City, 8600 Philippines
[3]College of Agriculture, Fishery nd Forestry, Romblon State University, Odiongan, Romblon, Philippines

Received: June 8, 2017 Accepted: December 4, 2017

ABSTRACT

This paper describes the survival and growth of different plant species in an agroforestry system during the early stages of development to assist natural re-vegetation for nickel mine rehabilitation. Narrow agroforestry strips were established along the contours in nickel mined areas to restore the vegetation and eventually serve as a natural filter for soil erosion. A combination of trees and other plant species were planted at various elevations of the mined land. In determining the species with potential as pioneers in mine rehabilitation, the survival and growth of the plant species used in rehabilitation were assessed. Results reveal that with proper cultural management, the survival of the various tree species in the constructed agroforestry strips can reach as high as 100%. *Leucaena leucocephala, Pterocarpus indicus, Samanea saman, Muntingia calabura* and *Terminalia microcarpa* showed relatively high survival in the field. The same species exhibited favorable initial growth as measured by plant height and stem diameter despite the harsh conditions of the mined-out areas. These plant species have high potential to be used in the rehabilitation of nickel areas after surface mining.

Keywords: nickel mining, soil erosion, forest strip, progressive rehabilitation, ecorestoration

* Corresponding Author
Email: rpvarela@carsu.edu.ph

1 Introduction

In nickel ore extraction, surface mining is usually adopted by removing the topmost soil layers stripping off the associated vegetation in the process. This often leads to erosion of soil particles and associated minerals that eventually cause siltation to nearby freshwater and marine water bodies. Establishing narrow strips of vegetation or forest strips to mitigate the impacts of nickel mining to interconnected ecosystems can be the alternative to the natural vegetation. In the establishment of forest strips, contour planting, integration of fruit trees and planting of flowering plant species to attract pollinators are integrated. The role of agroforestry systems in maintaining species diversity is significant, thus, these systems can play an important role in biodiversity conservation in human-dominated landscapes (Bhagwat et al., 2008). While there is a growing recognition of the long-term human involvement in forest dynamics and on the importance of conservation outside protected areas, these conservation efforts are mostly aimed to conserve pristine nature in protected areas. The past and present evidence clearly indicates that agroforestry, as part of a functional landscape, can be a viable land-use option as it offers a number of ecosystem services and environmental benefits in addition to alleviating poverty (Jose, 2012). Agroforestry systems offer a wide array of ecosystem services, such as regulation of soil and water quality, carbon sequestration, support for biodiversity among others. However, proper management is essential because agroforestry can also be the source of numerous disservices depending on management practices.

Since agroforestry was introduced, it has been viewed to provide the necessary combinations of plant species that can serve in buffering soil erosion, supply food and offer protection to biodiversity. With the variety of plant species in agroforestry that support a diverse faunal composition, soil fertility and nutrient cycling are also improved. Thus the establishment of forest strips in mined land adopting agroforestry concepts is viewed to re-establish the population of keystone species that can sustain the biodiversity towards ecosystem restoration. However, different plant species may have varied survival requirements. In a mined land where the condition is generally harsh due to the quality of soil and the full exposure of the land to factors such as extreme temperatures, rain and the wind among others, there is a need to identify plant species that can survive and grow given the condition of a mined land. The results of this study can be very useful in planning for mine rehabilitation of nickel areas.

2 Methodology

2.1 Study Site

The study was conducted in Hinatuan Mining Corporation (HMC) in Hinatuan Island, Taganaan, Surigao del Norte and Taganito Mining Corporation (TMC) in Claver, Surigao del Norte. The nickel mines were established mines in the declared Surigao Mineral Reserve located in northeastern Mindanao, Philippines (Fig. 1).

2.2 Establishment of the Agroforestry Strips

Different tree species were propagated in the nursery and planted in the identified mined-out study sites of HMC and TMC. The various species were planted by cluster across the mountain slope to provide the initial sources of propagules for assisted re-vegetation of the sites. In addition, fruit trees and flowering plant species were also included to attract pollinators, which are important agents of dispersal. Planting was done on July 2014 for HMC, while it was done on October 2014 for TMC. However, despite the project duration to last only until June 2015, the monitoring and assessment of the ecobelt continued in partnership with the mining company's Environmental Management Division.

Soil amelioration technologies for soil quality improvement (*e.g.* application of commercial fertilizer and compost) were introduced to boost plant growth and development. Watering was also done when the plants were still young, especially, during dry spell.

2.3 Data Collection and Analysis

Data such as survival rate of the various plant species, plant growth as measured by plant height and stem diameter were gathered to assess the performance of different plant species for rehabilitation in nickel mined-out areas. The data on survival rate were taken three months after planting, while the data on growth performance were gathered a year and 1.5 years after planting for HMC, while these were taken a year and 1.1 years after planting for TMC. Data were analyzed using descriptive statistics, using the sums, mean and frequency.

3 Results and Discussion

The percentage survival of tree species planted in the agroforestry strips established in the mined-out areas of HMC and TMC is presented in Tables 1 and 2. The survival rate of the various plant species is necessary for consideration in mine rehabilitation to determine the suitable species tolerant to the unfavorable conditions of the mined sites. The different species planted in HMC had over 50% survival on the average. Narra (*Pterocarpus indicus*), which is a native species, reached to as high as 100%. Lower survival was noted for Mabolo (*Diospyrus philippinensis*), Sampalok (*Tamarindus indicus*) and Rambutan (*Nephelium lappaceum*). The low survival rate of rambutan in the site can be attributed to the poor soil condition. The nickel mined-out area is generally deficient in organic matter which cannot favorably supply the survival requirements of rambutan. The results of the soil analysis indicated very low levels of macronutrients (NPK), particularly, the organic matter. Organic matter is vital in the survival of plants. However, only 0.66 to 1.52% OM (Table 3) was recorded in the backfilling material of HMC, while only 0.41 to 0.72% OM (Table 4) in TMC. The tree grows well in deep soil, clay loam or sandy loam rich in organic matter, and thrives on hilly terrain as they require good drainage (Tindall, 1994; Salakpetch, 2003). The survival of plants and their initial development are basic in re-vegetation inasmuch as these determine the success of mine rehabilitation. Thus, nursery trials for various species planted on soil with high nickel and iron content are essential. This will ensure future success and cost-effectiveness in nickel mine rehabilitation. In addition, the survival of plants with high leaf litter production that can potentially contribute to the enrichment of the soil is crucial.

In the past few years in China, establishment and colonization of several pioneer plant species growing on Pb/Zn mine spoils have been successful (Wong, 2003). Among the pioneer species are grasses and legumes. Plant species that easily colonize mined-out areas include *Vetiveria zizanioides* grass, *Sesbania rostrata*, herb legume and *Leucaena leucocephala*, woody legume (Shu et al., 2002; Yang et al., 1997; Zhang et al., 2001). The selection of appropriate plant species that can survive and colonize metal-contaminated soils is indeed important for successful reclamation of mined sites. *L. leucocephala* had the highest survival rate and grew well in mined-out nickel areas in Surigao. However, there are factors that need to be noted as these influence the survival and growth of the species. In a study conducted by Ssenko et al. (2014), they cited that although the plant grew fastest in untreated pyrite and copper tailings, reaching reproductive maturity in 7 months after planting, the relative growth rates of the species and the other tree species were not significantly different at all sites.

Some woody plants have been regarded to be important in mined area rehabilitation due to their capability to absorb heavy metals. In TMC, *L. leucocephala* and *Terminalia microcarpa* which are both woody species had the highest survival rate. Woody plants may have an advantage in metal-phytoremediation over herbaceous plants (Zhang et al., 2001). In this study, the woody legume *L. leucocephala* grown on the tailings with a topsoil cover of 8 cm was the most dominant species. The combination of fast-growing exotic species, legumes and native flowering plant species is viewed to be essential in initiating ecological succession. Davis et al. (2012) cited that tree and shrub species of lesser commercial value are important to wildlife. Thus, in addition to crop trees, other tree and shrub species should be prescribed for improving wildlife habitat.

3.1 Plant growth

The growth and survival of plants in the agroforestry strips have been promising in the first 2 years. Ipil-ipil (*L. leucocephala*) and rain tree (*S. saman*), which are used generally as nurse trees, have been growing propitiously as indicated by their height and stem diameter (Tables 5 & 6). The selection of these two species apart from their high survival rate in the mined-out area is also based on their high litter production capacity. Both species have higher litter fall that contributes to the organic matter build-up. Species that are tolerant to soils which are deficient in nitrogen and have high littering capacity are good pioneers in mined areas where soil conditions are generally tough. In New Caledonia, fast-growing native species such as *Acacia spirorbis* and *Casuarina collina* are used being nitrogen-fixing species and improve environmental conditions (Sarrailh & Ayrault, 2001). The behavior of these species has been well known and these can be easily managed from planting to harvesting, so these are the most widely used.

Some species survived in the constructed forest strips, however, the growth is slow. The thin layer of topsoil after backfilling is not sufficient to support the needs of the plants to grow normally and develop. Layering and thickness of the surface soil materials, as well as meso- and micro-topographic variation, are key to the re-establishment and sustainability of forest ecosystems and plant communities (Macdonald et al., 2015). Ipil-ipil (*L. leucocephala*) and mansanitas (*M. calabura*) showed superior performance in terms of plant height and stem diameter over other species planted particularly at the HMC research site (Table 5). At three months after planting, both plants have started to flower and bear fruits which are important characteristics of vegetation for eco-restoration. However, caution has been recommended in using *L. leucocephala* as it is listed as an aggressive colonizer of wastelands and on secondary or disturbed vegetation in Mexico, in the Yucatán Peninsula and in many parts of Asia (Weber et al., 2008). It is even classified as highly invasive (Richardson et al.,2004; Binggeli et al., 1999). Its categorization as invasive is anchored on its characteristic to flower and fruit year-round with abundant seed production, self-fertility, the presence of a hard seed coat, an ability to build up a seed bank, and ability to re-sprout after fire or cutting. Similarly, *M. calabura* can thrive in poor soils and can tolerate drought. Its seeds are dispersed by birds and fruit bats making it a good pioneer plant because rapid spread of the population in mined-out areas is essential to provide ground cover, thereby, conditioning the soil and making it habitable to other plants and animals. 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. Planting different species of plants has been reported to be promising to hasten natural recolonization of the mined-out areas.

Macdonald et al. (2015) cited that combining optimization of stock type and planting techniques with early planting of a diversity of tree species have been recommended to encourage natural regeneration.

4 Conclusion

The role of agroforestry systems has been considered essential in mined land rehabilitation, particularly, in maintaining species diversity. Planting of diverse plant species on the contours of mined lands can initiate the ecosystem restoration process. The relatively high survival of *L. leucocephala, P. indicus, S. saman, M. calabura* and *T. microcarpa* indicated their tolerance to the conditions in the mined-out areas wherein the soil has low fertility and with considerable amounts of Fe and Ni. The species, particularly, ipil-ipil (*L. leucocephala*) and mansanitas (*M. calabura*), have also shown superior growth which qualifies them as good pioneer species. Moreover, ipil-ipil and mansanitas have characteristics to flower year-round that attract pollinators and other herbivores which are important in the ecological dynamics of the developing ecosystem. Incorporation of these plant species in the agroforestry system for mined land rehabilitation is recommended, however, proper monitoring is necessary as part of the mine rehabilitation management.

5 Acknowledgment

This study is made possible with the cooperation of the Hinatuan Mining Corporation (HMC) and Taganito Mining Corporation (TMC). Recognition is also extended to the Mines and Geosciences Bureau of Caraga Region (MGB-13) for facilitating the link with the mining companies and to DOST-PCIEERD for the financial assistance.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

References

Bhagwat, S. A., Willis, K. J., Birks, H. J. B., & Whittaker, R. J. (2008). Agroforestry: a refuge for tropical biodiversity? *Trends in ecology & evolution, 23*(5), 261-267. `doi.org/10.1016/j.tree.2008.01.005`

Binggeli, P., Hall, J. B., & Healey, J. R. (1999). Invasive woody plants.

Davis, V., Burger, J. A., Rathfon, R., & Zipper, C. E. (2017). Selecting tree species for reforestation of Appalachian mined lands. *In: Adams, Mary Beth, ed. The Forestry Reclamation Approach: guide to successful reforestation of mined lands. Gen. Tech. Rep. NRS-169. Newtown Square, PA: US Department of Agriculture, Forest Service, Northern Research Station: 7-17-10.*, 1-10.

Jose, S. (2012). Agroforestry for conserving and enhancing biodiversity. *Agroforestry Systems, 85*(1), 1-8. `doi:10.1007/s10457-012-9517-5`

Macdonald, S.E., Landhäusser, S.M., Skousen, J., Franklin, J., Frouz, J., Hall, S., Jacobs, D.F. & Quideau, S.(2015). Forest restoration following surface mining disturbance: challenges and solutions. *New Forests, 46*(5-6), pp.703-732. `doi: 10.1007/s11056-015-9506-4`

Richardson, D. M., Binggeli, P., & Schroth, G. (2004). Invasive agroforestry trees: problems and solutions. *Agroforestry and biodiversity conservation in tropical landscapes.* Island Press, Washington, DC, 371-396.

Salakpetch, S. (2003). Rambutan production in Thailand. In *II International Symposium on Lychee, Longan, Rambutan and other Sapindaceae Plants 665* (pp. 67-72). doi:10.17660/ActaHortic.2005.665.7

Sarrailh, J. M., & Ayrault, N. (2001). Rehabilitation of nickel mining sites in New Caledonia. *Unasylva (FAO).*

Shu, W. S., Xia, H. P., Zhang, Z. Q., Lan, C. Y., & Wong, M. H. (2002). Use of vetiver and three other grasses for re-vegetation of Pb/Zn mine tailings: field experiment. *International Journal of Phytoremediation, 4*(1), 47-57.

Ssenku, J. E., Ntale, M., Backéus, I., & Oryem-Origa, H. (2014). Assessment of seedling establishment and growth performance of *Leucaena leucocephala* (Lam.) De Wit., *Senna siamea* (Lam.) and *Eucalyptus grandis* W. Hill ex Maid. in amended and untreated pyrite and copper tailings. *Journal of Biosciences and Medicines, 2*(01), 33.

Tindall, H. D. (1994). *Rambutan cultivation (No. 121).* Food & Agriculture Organization, Rome, Italy.

Weber, E., Sun, S. G., & Li, B. (2008). Invasive alien plants in China: diversity and ecological insights. *Biological Invasions, 10*(8), 1411-1429.

Wong, M. H. (2003). Ecological restoration of mine degraded soils, with emphasis on metal contaminated soils. *Chemosphere, 50*(6), 775-780.

Yang, Z. Y., Yuan, J. G., Xin, G. R., Chang, H. T., & Wong, M. H. (1997). Germination, growth, and nodulation of *Sesbania rostrata* grown in Pb/Zn mine tailings. *Environmental Management, 21*(4), 617-622.

Zhang, Z. Q., Shu, W. S., Lan, C. Y., & Wong, M. H. (2001). Soil seed bank as an input of seed source in re-vegetation of lead/zinc mine tailings. *Restoration Ecology, 9*(4), 378-385.

Table 1: Percentage survival of tree species planted in the forest strips at Hinatuan Mining Corporation, Taganaan, Surigao del Norte after one (1) year from planting.

Tree Species	**Family**	**No. of Trees planted**	**% Survival**[1]
Calumpit (*Terminalia microcarpa*)	Combretaceae	32	86.67
Antipolo (*Artocarpus blancoi*)	Moraceae	49	61.22
Mabolo (*Diospyrus philippinensis*)	Ebenaceae	28	35.71
Toog (*Petersianthus quadrialatus*)	Lecythidaceae	16	62.50
Ipil-Ipil (*Leucaena leucocephala*)	Fabaceae	170	85.71
Rambutan (*Nephelium lappaceum*)	Sapindaceae	40	0.25
Narra (*Pterocapus indicus*)	Fabaceae	18	100.00
Sagimsim (*Syzygium brevistylum*)	Myrtaceae	46	75.00
Acacia (*Samanea saman*)	Fabaceae	189	73.03
Marang (*Artocarpus odoratisimus*)	Moraceae	10	80.00
Mansanitas (*Muntingia calabura*)	Muntingiaceae	52	86.54
Sampalok (*Tamarindus indicus*)	Fabaceae	51	29.41

[1]planted on July 2014

Table 2: Percentage survival of tree species planted in the forest strips at Taganito Mining Corporation, Claver, Surigao del Norte

Tree Species	**Family**	**No. of Trees Planted**	**% Survival**[1]
Calumpit (*Terminalia microcarpa*)	Combretaceae	202	98.0267
Mabolo (*Diospyrus philippinensis*)	Ebenaceae	222	78.38
Toog (*Petersianthus quadrialatus*)	Lecythidaceae	25	48.00
Ipil-Ipil (*Leucaena leucocephala*)	Fabaceae	55	100.00
Rambutan (*Nephelium lappaceum*)	Sapindaceae	70	5.71
Narra (*Pterocapus indicus*)	Fabaceae	23	91.30
Sagimsim (*Syzygium brevistylum*)	Myrtaceae	43	34.88
Binunga (*Macaranga tanarius*)	Euphorbiaceae	5	80.00
Acacia (*Samanea saman*)	Fabaceae	390	90.79
Mansanitas (*Muntingia calabura*)	Muntingiaceae	53	83.02
Molave (*Vitex parviflora*)	Verbenaceae	141	94.33
Mahogany (*Swietenia macrophylla*)	Meliaceae	69	66.67
Guava (*Psidium guajava*)	Myrtaceae	75	41.33
Vetiver (*Chrysopogon zizanioides*)	Poaceae	121	68.00

[1]planted on October 2014

Table 3: Growth of different plant species in the forest strips at HMC site, Taganaan, Surigao del Norte.

Plant Species	Mean Plant Height and Stem Diameter (1 yr after planting)		(1.5 yrs after planting)	
	Height (cm)	Girth (cm)	Height (cm)	Girth (cm)
Acacia (*Samanea saman*)	139.5	1.84	159.60	2.11
Antipolo (*Artocarpus blancoi*)	63.4	0.67	75.90	0.82
Calumpit (*Terminalia microcarpa*)	46.75	0.77	53.35	1.13
Ipil-ipil (*Leucaena leucocephala*)	140.8	1.35	198.75	1.95
Mabolo (*Diospyros philippinensis*)	44.00	1.00	53.45	1.20
Mansanitas (*Ziziphus jujuba*)	105.40	1.21	120.86	1.56
Sagimsim (*Syzygium bravistylum*)	5.25	0.74	25.76	1.19
Sampaloc (*Tamarindus indicus*)	44.20	0.55	60.43	1.01
Talisay (*Terminalia catappa*)	55.50	0.98	70.87	1.19
Toog (*Petersianthus quadrialatus*)	50.00	0.86	65.56	1.25

Table 4: Growth of different plant species in the forest strips at TMC site, Claver, Surigao del Norte.

Plant Species	Mean Plant Height and Stem Diameter (1 yr after planting)		(1.1 yrs after planting)	
	Height (cm)	Girth (cm)	Height (cm)	Girth (cm)
Acacia (*Samanea saman*)	88.55	0.72	104.15	1.39
Calumpit (*Terminalia microcarpa*)	65.35	0.68	67.90	0.73
Guava (*Psidium gaujava*)	71.69	0.75	78.75	0.84
Ipil-ipil (*Leucaena leucocephala*)	118.40	1.23	151.6	1.63
Mansanitas (*Ziziphus jujuba*)	73.08	0.39	86.77	0.58
Mabolo (*Diospyros philippinensis*)	32.50	0.63	34.21	0.65
Mahogany (*Swietenia macrophylla*)	55.13	0.69	56.94	0.83
Molave (*Vitex parviflora*)	59.29	0.71	64.55	0.94
Narra (*Pterocarpus indicus*)	50.07	0.54	57.65	0.58
Sagimsim (*Syzygium brevistylum*)	41.80	0.46	47.50	0.5
Toog (*Petersianthus quadrialatus*)	33.33	0.46	37.40	0.5

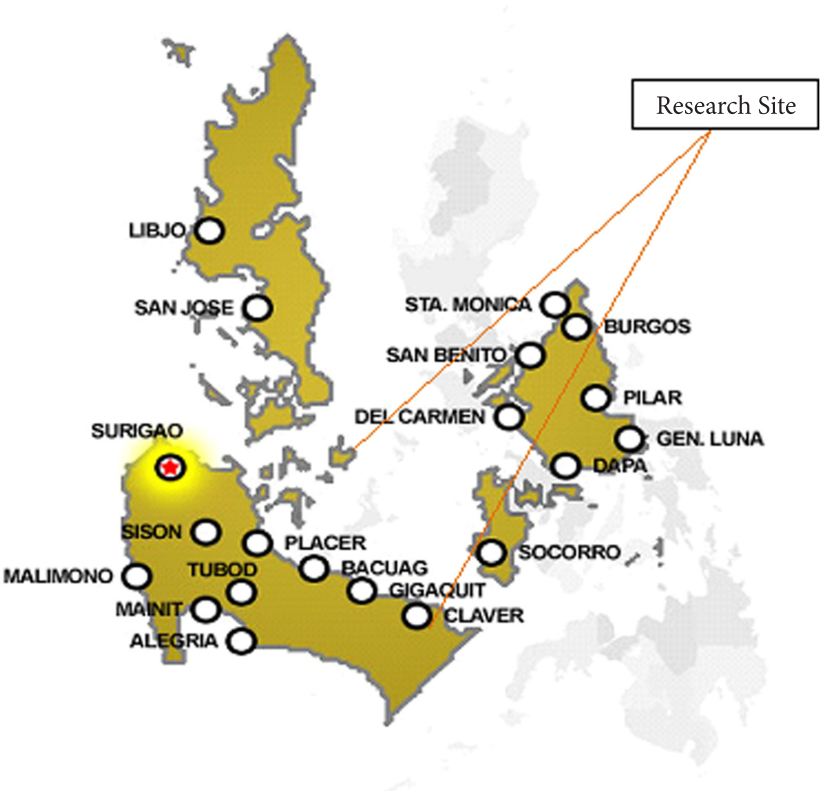

Fig. 1: Map of Surigao del Norte, Philippines showing the Research Site (Source: Province of Surigao del Norte)

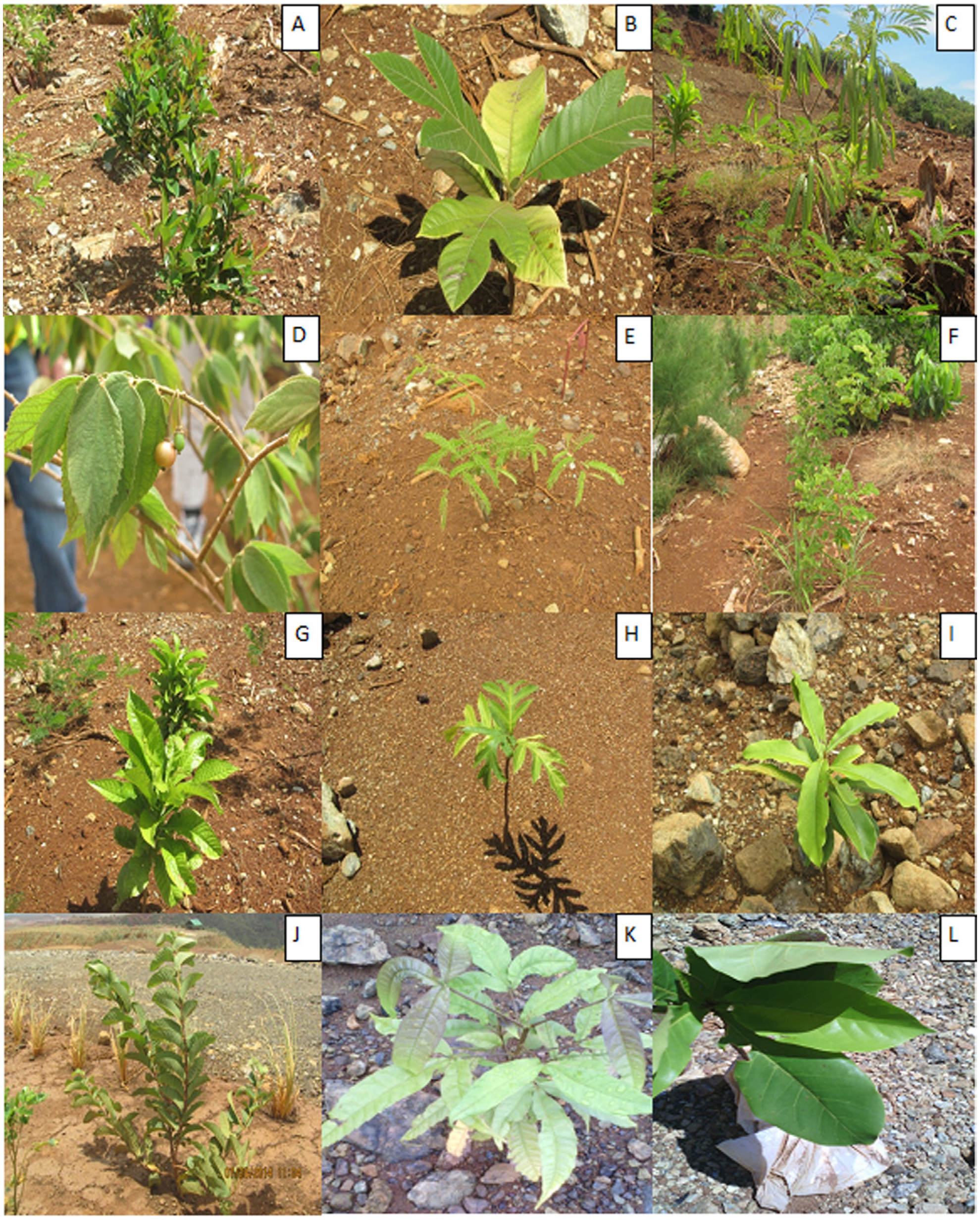

Fig. 2: Tree species planted on the agroforestry strips in HMC and TMC: (A) Sagimsim (*Syzygium brevistylum*); (B) Marang (*Artocarpus odoratisimus*); (C) Ipil-ipil (*Leucaena leucocephala*); (D) Mansanitas (*Muntingia calabura*); (E) Sampalok (*Tamarindus indicus*); (F) Acacia (*Samanea saman*); (G) Toog (*Petersianthus quadrialatus*); (H) Antipolo (*Artocarpus blancoi*); (I) Mabolo (*Diospyrus philippinensis*); (J) Guava (*Psidium guajava*); (K) Molave (*Vitex parviflora*); (L) Talisay (*Terminalia cattapa*).