

Soil erosion control and nutrient cycling capacity of Palawan State University rubber plantation in Rizal, Palawan, Philippines



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Abstract

The study determined the capacity of the ten-year-old rubber plantation (*Hevea brasiliensis*) of Palawan State University (PalawanSU) and the adjacent natural forest to control soil erosion and cycle nutrients. This was done by collecting eroded soils from these sampling sites every two weeks from February to May 2018. Results of the study show that the PalawanSU rubber plantation has better soil erosion control and nutrient cycling capacity than the adjacent natural forest. There was a significant difference ($p < 0.05$) in the amount of eroded soils in the rubber plantation at 24.34 kg ha⁻¹ yr⁻¹ and the natural forest at 47.69 kg ha⁻¹ yr⁻¹. This means that the plantation's capacity to hold soil in place is almost twice as high. Phosphorus was found to be significantly higher in the rubber plantation soils. Together with potassium, it was also higher in its leaf litter. Additionally, its nutrient conservation mechanism can further increase its value as an essential economic crop that can accommodate seasonal drought stresses in Palawan and elsewhere in the country.

Keywords

rubber plantation, soil erosion, nutrient cycling, rehabilitation of denuded lands, re-translocation of nutrients, nutrient conservation mechanism

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1. Introduction

1.1 Farming as the Main Livelihood of the Palaw'ans Residing in Mount Matalingahan Protected Landscape

There used to be a serious concern for Palawan's highest mountain, Mt. Mantalingahan, standing at 2,072.64 m above sea level and said to be the largest source of income for 98% of the indigenous people (IP) in the Province of Palawan (Docto, 2015). This is because the IP communities living within and near the mountain consider the conventional method and indigenous knowledge in farming and gathering forest products as their primary means of livelihood. Among these IP communities are the Palaw'ans. Like many other IPs residing in Mount Matalingahan Protected Landscape (MMPL), this tribe relies heavily on farming, poaching, and gathering forest products. Docto (2015) reported that among the indigenous people in the province, the Palaw'ans, constituted the majority, 84.2%. In his study describing this tribe's agricultural practices, he cited farming as the area's primary source of Palaw'ans' livelihood. "Nine percent



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of the residents are using the traditional or labor-intensive methods of farming, while the majority (84.8%) are practicing the slash-and-burn or *kaingin* method” (Docto, 2015, p.8). The DENR-Biodiversity Management Bureau (2016) supports the above findings by reporting that the IPs within the MMPL employ the conventional method and indigenous knowledge in farming and gathering forest products as their primary means of livelihood. These conventional means of living include shifting cultivation, locally known as *kaingin* (slash and burn), which is described as a farming method that involves cutting down trees, burning them, and plowing the ashes as fertilizer (DENR-Biodiversity Management Bureau, 2016).

1.2 Palawan State University’s Initiative to Conserve MMPL

Among the government institutions that offered to help conserve MMPL was Palawan State University, which established a 50-ha rubber plantation (*Hevea brasiliensis*) (along the boundary of the villages of Candawaga and Culasian in Rizal, Palawan, Philippines). The plantation was established in sloping areas (at 18% slope) at the foot of the mountain that is dominated by shrubs and grasses and, hence, vulnerable to erosion (Josefsson, 2016; Siswanto & Sule, 2019). Other than protecting the soil from further degradation, the project was to help relieve the mountains from degradation pressures from forest-destructive means of livelihood of the communities living near it. By giving the Palaw’an an alternative means of livelihood and diverting their interests to rubber farming, the proponents of the rubber plantation establishment project aimed to help rehabilitate denuded lands through reforestation and reduce illegal forest activities, particularly *kaingin*. The Development Bank of the Philippines (DBP) Forest Development Program also supported the project to primarily enhance the protection of the environment by selecting open forest areas for planting trees to reduce soil erosion.

1.3 Rubber Plantations’ Significant Contributions to Nutrient Cycling and Soil Erosion Control

However, the problem with establishing a rubber plantation in the past 10 to 15 years was that while the purpose is to rehabilitate and reforest denuded lands, plantations have been viewed negatively by the majority. This is because in some areas of the country and other parts of the world, increasing demands for this high-value crop rubber has led to the massive land conversion of forest lands to rubber plantations, causing biodiversity loss, soil erosion, and other environmental damages (Josefsson, 2016; Lan et al., 2017; Li et al. 2016; Roy et al., 2014). Studies have also shown that the leading cause of the ecological adversities of rubber plantations is their monoculture nature, as cited by Chakraborty et al. (2018), He and Martin (2015), and Ziegler et al. (2009). Monoculture plantations, as explained by these authors, are less capable of nurturing understory vegetation, a significant control of soil erosion.

Contrary to the opposing views about rubber plantation establishment being detrimental to the environment and amid rising issues about soil loss along with soil nutrient depletion due to land conversions from natural forests to rubber plantations, research conducted by Josefsson (2016), Lan et al. (2017), Li et al. (2016), and Roy et al. (2014) suggested that rubber plantations have significant ecological contributions. Among these ecological functions are nutrient cycling and soil erosion control. Rubber trees have the nutrient conservation process of re-translocation of nutrients, which distributes nutrients to the different parts of their system. This process reduces the trees’ reliance on soil nutrients and enhances soil nutrients through the trees’ leaf litter, where nutrients have been re-translocated (Li et al., 2016).

1.4 Need to Determine PalawanSU Rubber Plantation’s Ecological Contribution

This rubber plantation project of Palawan State University has been instrumental in raising family income among indigenous people beneficiaries. It was generally perceived by the project recipients to be moderately successful based on a survey conducted by Tuquero and Pulanco in 2017. However, 10 years after the establishment of the plantation, no scientific study has yet been conducted to determine the project’s ecological contribution, which is one of the main objectives of its establishment. This study determined the PalawanSU rubber plantation’s capacity to control soil erosion and restore soil nutrients by describing the capacities of the rubber plantation and an adjacent undisturbed natural forest in nutrient cycling and soil erosion control.

Generally, the study sought to determine whether the PalawanSU rubber plantation has a significant environmental contribution to soil erosion control and nutrient cycling capacity. Specifically, it determined the following:

- 1) amount of soil eroded (in grams) from PalawanSU rubber plantation and an adjacent natural forest land;
- 2) amount of nutrients present in the soil and leaf litter of PalawanSU rubber plantation and in the natural forest, specifically nitrogen, potassium, and phosphorus; and
- 3) significant difference in capacities of both forests in controlling soil erosion and nutrient cycling.

2. Methodology

The study area is at the Socialized Industrial Forest Management Agreement (SIFMA) project site located in the boundary of Barangays Culasian ($8^{\circ}48'45.3''$ N $117^{\circ}32'26.4''$ E) and Candawaga ($8^{\circ}51'02.5''$ N $117^{\circ}33'16.3''$ E) at the foot of Mount Mantalingahan in the Municipality of Rizal, Palawan, Philippines (Figure 1). The said project site is part of the 321.92 ha ancestral land granted to the Department of Environment and Natural Resources (DENR) to Palawan State University in 2006 and through the issuance of SIFMA by the Department. Under Executive Order No. 263 dated 19th of July 1995, PD No. 705, and as amended to Executive Order No. 278 dated 25th of July 1987. The PalawanSU “SIFMA project” was developed to ensure the equitable access and sharing of rights to natural resources development utilization by providing opportunities to the people to participate actively in forest plantation development. On the part of PalawanSU, the project was conceived to primarily serve as a demo farm to motivate and capacitate the IP farmers to engage in rubber production in their farms through technology transfer.

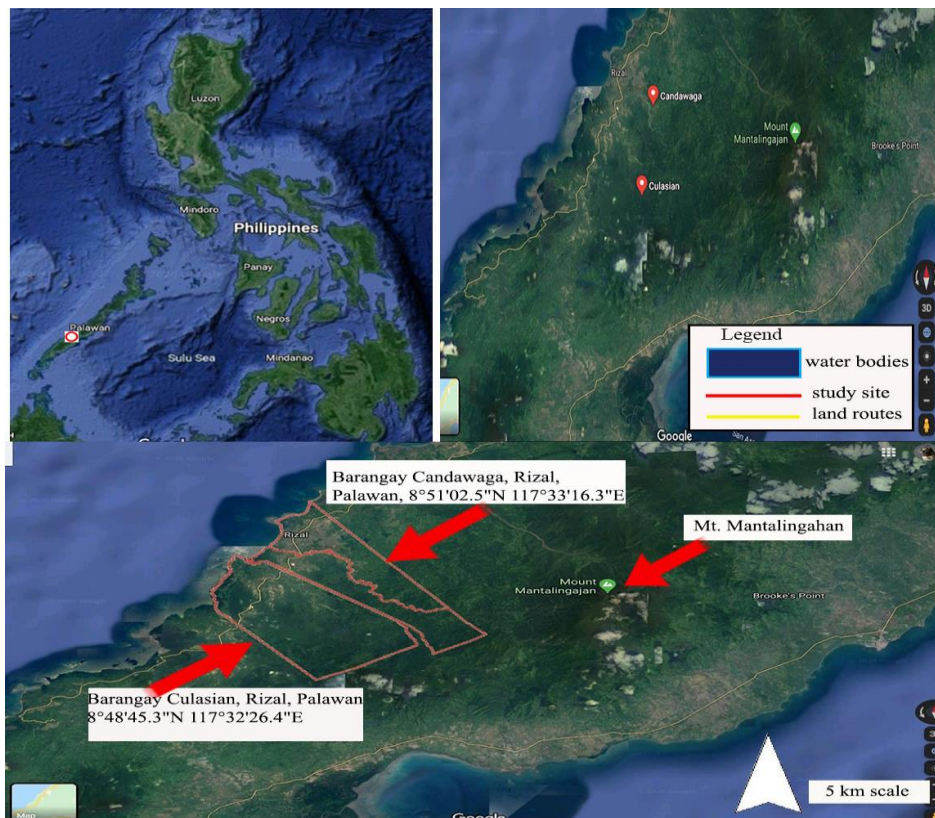


Figure 1. The SIFMA project site lying in the boundary of Barangay Culasian and Candawaga at the foot of Mount Mantalingahan in the Municipality of Rizal, Palawan, Philippines (Source: <https://www.google.com/maps/search/Barangay>)



Two experimental areas were set up in the study, namely, in the 50-ha rubber plantation established in 2008 encompassing the two villages of Culasian and Candawaga, Rizal, Palawan, Philippines, and in the adjacent undisturbed natural forest located around 150-meter away from the plantation. An experimental site was installed in these ecosystems to measure their capacity for soil erosion control and nutrient cycling. An independent T-test was used to analyze the data statistically.

2.1 Materials and Methods for Soil Erosion Control Capacity

The sampling area for rubber plantations and natural forests measured 20 m². Within this sampling area, a 2-m-long fine net was installed at the bottom of a 10-m-long sloping area of the rubber plantation and the natural forest. The net was to catch the eroded soils. Two trials were done for each of the ecosystems. A small sample plot of 20 m² was used to simplify the process and minimize spatial scale uncertainties (Moosavi & Sadeghi, 2021). Small plots to assess soil erosion were also used by studies of Anache et al. (2017), Bagarello et al. (2018), Du et al. (2020), Gholami et al. (2018), Sadeghi et al. (2013), and Zhang et al. (2019).

The steep parts of the plantation were selected as sampling areas to collect eroded soils with an estimated slope of 18%. Eroded soils were collected every two weeks, with eight collections from February to May 2018. Stones and visible debris were removed from the collected fresh soil sample, after which the sample was sieved and oven-dried at 103°C to remove the moisture. The weight of samples from the catchments was then averaged and used to estimate the eroded soil in kg ha⁻¹ yr⁻¹ in the rubber plantation and the natural forest (Jain & Singh, 2003; Olivares et al., 2016). Independent T-test was used in the statistical analysis.

2.2 Materials and Methods for Nutrient Cycling

The nutrients in the soil and leaf litter collected from the rubber plantation and the natural forest were accounted for to determine the nutrient concentration in both ecosystems. The soil was sampled using a W pattern, measuring 12 x 16 m. Within this W pattern, 15 spots were identified, and 1 kilogram of soil was collected from each spot (Peters et al., 2022). The collected soil from 15 spots was mixed thoroughly. From this mixture, four soil samples weighing 1 kg each were obtained for analysis of pH level and the presence of elements deemed crucial for the growth and development of plants, namely, nitrogen (N), phosphorus (P), and potassium (K). Laboratory analysis results were obtained by sending the samples to the National Institute of Biotechnology and Molecular Biology Analytical Laboratory of the University of the Philippines Los Baños.

To measure the amount of nutrients in the leaf litter, a fine net measuring 7 x 2 m with a mesh size of 0.8mm was used to trap the leaves falling from the trees. Two plots were established both in the rubber plantation and in the adjacent natural forest. Fallen leaf collection was done every two weeks from February to May 2018 for eight collections. The leaf litter samples from each of the rubber plantations and natural forests were then ground and analyzed for significant nutrient contents, namely, nitrogen (N), phosphorus (P), and potassium (K). Results were expressed in kg ha⁻¹ yr⁻¹ and analyzed using descriptive and inferential statistics.

3. Findings on Soil Erosion and Nutrient Cycling Capacities

3.1 Soil Erosion Between the PalawanSU Rubber Plantation and its Adjacent Natural Forest

Eroded soils from the rubber plantation were only more than half of that of the natural forest. The estimated value of eroded soils for one year from the rubber plantation and natural forest was 24.34 kg ha⁻¹ yr⁻¹, while that of the natural forest is 47.69 kg ha⁻¹ yr⁻¹ (Table 1). This shows that the rubber plantation established by Palawan State University in 2008, encompassing barangays Candawaga and Culasian in Rizal, Palawan, has a significant holding capacity to keep soil from erosion.

This is adequately supported by the studies of Jacob (2000), Philip et al. (1996), and Sethuraj (1996), which said that rubber as a plant can play a role in soil erosion because the root concentration in rubber plantations occurs in top 0.18 m of the soil, and horizontally spread to two meters from the plant base. Rahman (1994) also emphasized that once the trees have established a complete canopy, the rate of runoff generally differs little from that in similar areas with natural forests. When water runoff decreases, soil moisture status is improved, and soil erosion is prevented. This is consistent with the explanation of Sethuraj (1996), who mentioned in his study that being a surface feeder, rubber trees afford good soil binding and hence reduce the erodibility of soil considerably. Another study corroborating the above finding was conducted in Xishuangbana, China, in 2011 by Zheng-Hong et al., which states that the annual run-off of rubber plantation was only 65 % of that in the rainforest, improving soil moisture status and preventing soil erosion. However, the study on soil health impacts of rubber farming conducted by Nguyen et al. in Quang Tri Province, Vietnam, in 2020 somehow contradicts this finding as results of the authors' study revealed that soil health was higher in natural forests than in rubber plantations with higher values in higher biomass forests (Nguyen et al., 2020).

Table 1.

Amounts of eroded soils collected from February-May 2018 from the 50-ha Palawan State University rubber plantation and adjacent natural forest of Candawaga and Culasian in the Municipality of Rizal, Palawan, Philippines

Area	Weight of eroded soil (kg)		Estimated erosion (kg ha ⁻¹ yr ⁻¹)
	Trial 1	Trial 2	
RP 1	0.000	0.039	
RP 2	0.001	0.024	24.338
Average	0.001	0.032	
NF 1	0.008	0.051	47.685
NF 2	0.008	0.060	
Average	0.008	0.056	

Note: RP = Rubber Plantation; NF = Natural Forest

It was also worth noting that abundant understory vegetation was observed in the PalawanSU rubber plantation. (Figure 2). The understory vegetation of the rubber plantation was observably thicker than that of the natural forest because rubber trees are purposely planted distant from each other, thus allowing the penetration of rainfall and sunlight. The rubber plantation provides a favorable environment for vegetation growth. According to Josefsson (2016), this helps control erosion because the protective understory vegetation outweighs the erosive power of rainfall compared to an area where vegetation growth is inhibited. Liu et al. (2016) similarly accentuate the importance of an intact layer in rubber plantations to protect the soil against splash erosion.

Other studies, like those conducted by Josefsson (2016) and Zhao-Lu et al. (2001), described rubber plantations as having caused a high rate of soil erosion, leading to adverse environmental effects. However, the high erosion rate in these studies is mainly attributed to land-use change and the



monoculture approach of plantations. The PalawanSU rubber plantation is more agroforestry-based than monoculture being used to be intercropped with abaca, which could explain the minimal soil erosion in the area. High-value fruit trees like mangosteen, *lanzones*, *rambutan*, pineapple, and indigenous tree species like *apitong* and *balayong* are also planted in specific patches within the rubber plantation. As Brown et al. (2018) mentioned, agroforestry can improve the agricultural systems' resiliency and mitigate the impacts of climate change.



Figure 2. The sampled understory vegetation of the PalawanSU rubber plantation (pictures at the left) shows that there was visibly more abundant understory vegetation compared with the sampled adjacent natural forest (pictures at the right) in Candawaga and Culasian, in the Municipality of Rizal, Palawan, Philippines

3.2 Nutrient Cycling Between the PalawanSU Rubber Plantation and its Adjacent Natural Forest

Table 2 below presents the nutrient content of the soil of the rubber plantation and that of the adjacent natural forest, particularly nitrogen (N), phosphorus (P), and potassium (K), the primary nutrients needed by plants to grow. Results showed that the rubber plantation had an estimated N, P, and K contents of 117.19 parts-per-million (ppm) ha⁻¹, 2630 ppm ha⁻¹, and 3072.9 ppm ha⁻¹, respectively. Meanwhile, the natural forest had an N, P, and K contents of 130.21 ppm ha⁻¹, 2083.33 ppm ha⁻¹, and 6718.75 ppm ha⁻¹, respectively. Results showed that soils in both ecosystems are within the neutral and acceptable pH levels of 5.6 and 5.5, respectively.

Table 2.

Nutrient content of soil samples collected from February-May 2018 from the 50-ha PalawanSU rubber plantation and adjacent natural forest of Candawaga and Culasian in the Municipality of Rizal, Palawan, Philippines

Soil Sample	Nitrogen (% Organic Matter)	Phosphorus (P) (ppm)	Potassium (K) (ppm)
RP 1	3.0	86.0	60.0
RP 2	2.0	68.0	56.0
RP 3	2.0	38.0	56.0
RP 4	2.0	10.0	64.0
Average	2.25	50.5	59.0
NF 1	2.5	42.0	132.0
NF 2	2.5	46.0	128.0
NF 3	2.5	36.0	128.0
NF 4	2.5	36.0	128.0
Average	2.5	40.0	129.0

Nitrogen (N) and potassium (K) were higher in the soil of the natural forest, while phosphorus (P) was higher in the soil of the rubber plantation. While there is not much difference in terms of nitrogen content in the soils of both ecosystems, phosphorus was found to be higher in the rubber plantation. At the same time, potassium was higher in the natural forest soils.

Table 3.

Macronutrient content of litterfall samples collected from February-May 2018 from the 50-ha PalawanSU rubber plantation and adjacent natural forest of Candawaga and Culasian in the Municipality of Rizal, Palawan in the rubber plantation and the adjacent natural forest.

Ecosystem	% Nitrogen (N) (weight by weight)	Phosphorus (P) (ppm)	Potassium (K) (ppm)
Rubber Plantation	0.99	1244	6290
Natural Forest	1.02	363	5895



While a slightly lower level of nitrogen (0.99 weight by weight) was obtained in the leaf litter of the rubber plantation, the phosphorus and potassium contents in the latter's leaf litter were higher than those of the natural forest.

The higher phosphorus content in the soils of the rubber plantation in this study is similarly attributed to the rubber tree's re-translocation mechanism, which, based on Li et al.'s (2016) study, moves 42.77 % of its leaf phosphorus to its leaf litter and returns 57.23 % of the same element to its tree body. As rubber trees are deciduous trees that shed leaves annually, phosphorus could be one of the elements that accumulate in the plantation's soil due to the greater volume of litterfall that returns nutrients to the soil through decomposition and nutrient mineralization.

The same mechanism explains why, despite the natural forest's probably higher organic buildup, there was only a very slight difference at 0.25 % organic matter (OM) in terms of nitrogen content in the soils of both ecosystems. Li et al. (2016) explained that while rubber returns 40.77 % of its leaf nitrogen to the tree body before leaf shedding, it retains 59.23 % of its leaf nitrogen on the leaves that are transferred to the soil through litterfall.

Potassium in the soil of the rubber plantation turns out to be the highest among the macro-elements considered in the study. Like leaf phosphorus of rubber, which is usually returned to the tree body, 52.78 % of potassium is also returned to the body before litterfall, and only 47.22 % of the leaf potassium will go to the soil through its leaf litter (Li et al., 2016). However, due to the greater volume of litterfall shed annually, much of this element could have been accumulated in the soil through the years. Moreover, since the rooting system of rubber holds the soil better, much of this nutrient is prevented from being leached away. This result will be verified through further studies, which will consider other variables like varieties or clones and the health of the rubber trees.

The soil collected from both experimental areas was also examined for physical properties, particularly texture and color. The soil collected from the rubber plantation was clay loam, brown, and porous. The soil in the natural forest was clayish, aggregated, and had a reddish color.

Results of the study show that rubber can be used to rehabilitate areas stripped of vegetation. It is not only to prevent near-to-absolute pressure of natural forests from people who depend on it for a living or to divert a community from a more forest-destructive means of livelihood. Rubber can also purposely prevent the soil from eroding and restore soil quality. This is especially considering that rubber, due to its nutrient re-translocation efficiency, can withstand survival in nutrient-poor surroundings and areas prone to cold or drought, as mentioned earlier.

4. Conclusions and Recommendations

Considering the results of the study that the PalawanSU rubber plantation does have soil erosion control and nutrient cycling capacity comparable with that of the adjacent natural forest, this study gives some basic information that could be useful for taking any onward attempt to establish a rubber plantation to rehabilitate denuded lands. The nutrient conservation strategy rubber trees possess further increases their importance as industrial crops that can survive in a nutrient-poor environment and withstand drought stresses in Palawan and elsewhere in the country.

The authors recommend replicating the study in rubber plantations established in sloping areas in Palawan or any part of the country to verify the findings. A study that considers factors like species and edaphoclimatic conditions, rubber clones, management and plant health, and timing in data collection may be conducted. Similarly, a study comparing the status of the soil in terms of nutrients present and the amount of erosion before and after the establishment of a rubber plantation will also strengthen the finding that rubber plantations can offer a better option for rehabilitating denuded lands.

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Declaration of Conflict of Interest

The researchers declare that there is no conflict of interest in this study.

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