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# Recovering degraded lands in the Peruvian Amazon by cover crops and sustainable agroforestry systems

## Recuperación de tierras degradadas en la Amazonía peruana por cultivos de cobertura y sistemas agroforestales sostenibles

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**Abstract**

This long term research is being carried out in degraded lands of low fertility conditions in the humid tropics of the Peruvian Amazon. The objective is to recover degraded lands for sustainable agriculture that was affected by shifting agriculture and overgrazed pastures. The recovering trials in three farms are fertilized cover crops with the legume Centrosema (*Centrosema macrocarpum*), and the establishment of th prototype agroforestry systems are based on a) woody trees with *Swietenia macrophylla*, *Guazuma crinita* (GC), *Calycophylum spruceanum* (CS) and *Simarouba amara* (SA), b) woody-fruit trees with *Cedrelinga cateniformis*, GC, SA, *Inga edulis* and *Bactris gasipaes*, and a c) silvopastoral system with Centrosema and woody trees with GC, SA and CS. Initial degraded compacted soils were covered with degraded grass (*Brachiaria brizantha*) and weeds, and the soil were very acid (80% of Al saturation) with 4 ppm of P and low soil organic matter and cation exchange capacity. Soil was weeded and fertilized with a combined fertilizer based on rock phosphate (40 kg/ha), and then Centrosema was planted followed by the plantation of trees with localized fertilization application. In three months we had 100% cover and weeds were controlled. Average Centrosema biomass in 8 months was 8.12 T/ha, and while the different trees were growing with 55 to 89 percentage of survival due to water stress, Centrosema recovered the soil compaction up to 20 cm depth. Biomass can be used as forage for small animals and to enrich soil. Mean total nitrogen accumulation in biomass was 232 kg/ha.

**Keywords:** sustainable systems, change land use, agroforestry, cover crop.

**Resumen**

Esta investigación a largo plazo se está llevando a cabo en tierras degradadas de baja fertilidad en el trópico húmedo de la Amazonía peruana. El objetivo es recuperar tierras degradadas para una agricultura sostenible que fue afectada por la agricultura migratoria y los pastos sobre pastoreados. Los ensayos de recuperación en tres campos agrícolas son cultivos de cobertura fertilizados con la leguminosa Centrosema (*Centrosema macrocarpum*), y el establecimiento de 3 sistemas agroforestales prototipo se basan en a) árboles leñosos con *Swietenia macrophylla*, *Guazuma crinita* (GC), *Calycophylum spruceanum* (CS) y *Simarouba amara* (SA), b) árboles maderables-frutales con *Cedrelinga cateniformis*, GC, SA, *Inga edulis* y *Bactris gasipaes*, y c) sistema silvopastoril con Centrosema y árboles leñosos con GC, SA y CS. Los suelos compactados degradados iniciales fueron cubiertos con hierba degradada (*Brachiaria brizantha*) y malezas, y el suelo fue muy ácido (80% de saturación de Al) con 4 ppm de P y baja materia orgánica del suelo y capacidad de intercambio catiónico. Se deshierbó la tierra y se fertilizó con un fertilizante combinado a base de fosfato de roca (40 kg/ha), luego se plantó el Centrosema seguido de la plantación de árboles con aplicación de fertilización localizada. En tres meses tuvimos un 100% de cobertura y las malezas fueron controladas. El promedio de la biomasa Centrosema en 8 meses fue de 8.12 T/ha, y mientras que los diferentes árboles crecieron con 55 a 89 por ciento de supervivencia debido al estrés hídrico, Centrosema recuperó la compactación del suelo hasta 20 cm de profundidad. La biomasa puede utilizarse como forraje para animales pequeños y para enriquecer el suelo. La acumulación media total de nitrógeno en la biomasa fue de 232 kg/ha.

**Palabras clave:** sistemas sostenibles, cambio en el uso de la tierra, agroforestería, cultivo de cobertura.

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## Introduction

The Peruvian amazon had a reserve of 78.9 million hectares of natural forest, comprising 58.8% of the total Peruvian territory. The high rate of deforestation of 150,000 hectares per year in the Peruvian amazon due to slash and burn and other inadequate land uses has reached the loss of forest of 7,172,554 has by year 2000 (Cabrera et al., 2005).

In the last 30 years, studies of soil degradation in the Amazon region have been documented, indicating that soil degradation by erosion is still the main factor of soil depletion in Latin America (Montanarella et al., 2015). Besides the physical factors, several other causes affect the degradation of the Amazon; the main driving forces of deforestation are the selective extraction of wood, new roads and land tenure (Kaimowitz and Angelsen, 1998). Several technical options to recover degraded land have been studied to recover compacted soils by overgrazed pastures or intensive mechanization (Alegre et al., 1986; Lal, 2015). Some high and low input technologies in long term trials have been tested in the humid acid tropical soil of Yurimaguas, Peru and one of the main options was the agroforestry systems (Palm, 1995; Alegre, 2015). The introduction of perennial cropping systems with coffee or cacao managed with cover crops also offers an alternative to recover degraded land in the Amazon (Puertas et al., 2008; Arévalo-Gardini et al., 2016). The potential of trees and cover crops to contribute to the maintenance and rehabilitation of the soil's physical characteristics such as better bulk density, mechanical resistance and soil aggregation has been well established, including an improvement on productivity (Alegre and Rao, 1996; Rao et al., 1998; Alegre et al., 2005). There is evidence that nutrient cycling of litterfall from shallow or deep roots of trees and cover crops can capture nutrients from topsoil or the subsoil. Therefore, crop production can be improved (Nair et al., 1999). Crops can also force associated trees to take up a great part of nutrient from deep or laterally distant soils, and can deplete these nutrients when they are released from decomposing tree litter (Schroth et al., 2001).

The objective of the present work is to recover degraded lands in the Peruvian Amazon for sustainable agriculture that was affected by shifting agriculture and overgrazed pastures.

## Materials and Methods

This study was located in the Santo Tomas community in Yurimaguas, Loreto, Perú. A total of three farmers with extensive degraded Ultisol lands (Tyler et al., 1978) with overgrazing Brachiaria (*Brachiaria brizantha*) pastures were selected. The degraded pasture was sprayed with contact herbicides. Three plots of 70x40 m with degraded pasture for each of the three farmers were set up (Fig. 1) and each plot was divided in 3 subplots and monitored initially with replicated soil physical (bulk density and mechanical resistance) and chemical soil properties (organic matter, available phosphorus and potassium, cation exchange capacity and aluminum saturation) that were measured from 0-15, and >15 to 30 cm depth.

The recovering trials in three farms were fertilized with 40 kg of P/ha and planted by hand, cover crops with legume *Centrosema macrocarpum* (5 kg/ha of Centrosema seed) and after a month, three prototype agroforestry systems (AFS) were established based on a) AFS 1: multistrata system 1 with woody of fast, medium and slow growing trees species with *Swietenia macrophylla*, *Guazuma crinita* (GC) , *Calycophylum spruceanum* (CS) and *Simarouba amara* (SA), b) AFS 2: multistrata system 2 with fast, medium and slow growing woody-fruit trees species with *Cedrelinga cateniformis*, GC, SA, *Inga edulis* and *Bactris gasipaes*, and c) AFS 3: silvopastoral system with Centrosema and fast and medium woody trees with GC, SA and CS (Fig. 2). Each of the three farmer's sites was considered as a block (three replications) and the three treatments were the three AFS described above. For the statistical analysis, we used LSD test in the R statistical software (R Core Team, 2016).


Figure 1. Picture of a) initial degraded pasture with Brachiaria, b) after burning with herbicide, and c) planting cover crop with Centrosema.

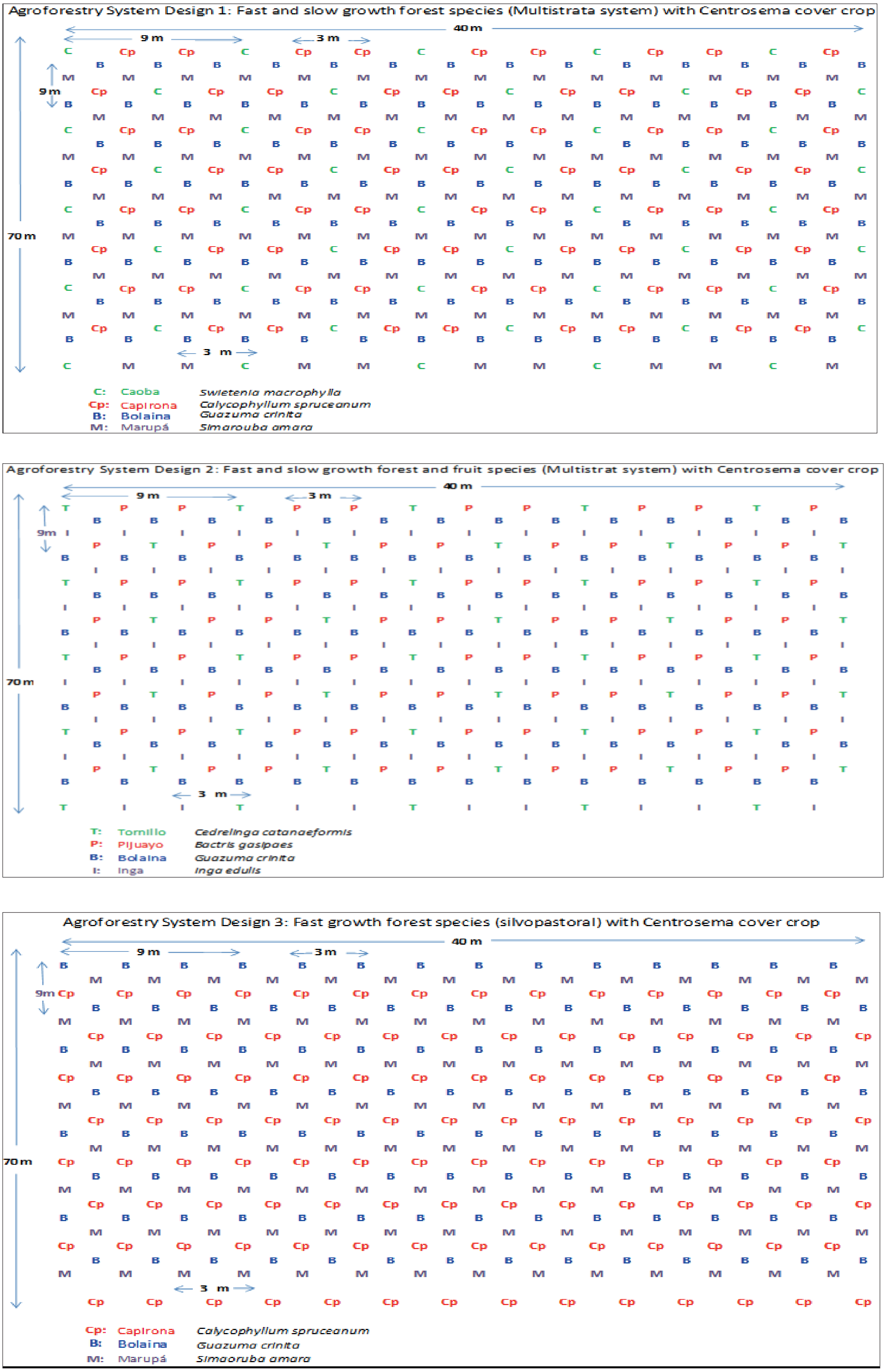


Figure 2. Prototype of three agroforestry systems of different tree species in Santo Tomas, Yurimaguas.

All nursery trees during plantation were fertilized with a tropical Fertiphos fertilizer (rock phosphate fertilizer enriched with calcium and magnesium, and some organic matter components) at the rate of 200 g/plant in a 20x30 cm hole.

## Results and Discussion

Initial degraded compacted soils were covered with degraded grass (*Brachiaria brizantha*) and weeds, and the topsoil was very acid with a pH ranging from 3.8 to 4.8 with low organic matter and very low phosphorus level (less than 3 ppm) and medium level of potassium, and low CEC with aluminum saturation fluctuating from low (8.77%) to high (72.44%) levels as shown in Table 1.

Table 1. Initial level of soil nutrients at 0 - 15 cm depth in the three farmers sites under overgrazing pastures in Santo Tomas, Yurimaguas.

| Farmers sites | pH | OM (%) | Available P (ppm) | Available K (ppm) | CEC meq.100/g | Al saturation (%) |
|---|---|---|---|---|---|---|
| Washington | 4.16 | 0.96 | 3.0 | 62 | 5.94 | 18.80 |
| Roberto | 4.80 | 1.81 | 2.6 | 44 | 9.35 | 8.77 |
| Clais | 3.82 | 1.18 | 2.3 | 50 | 11.38 | 72.44 |

Rainfall distribution during 2016 was very variable. For some months, rainfall was less than the average for the area (Figs. 3 and 4).

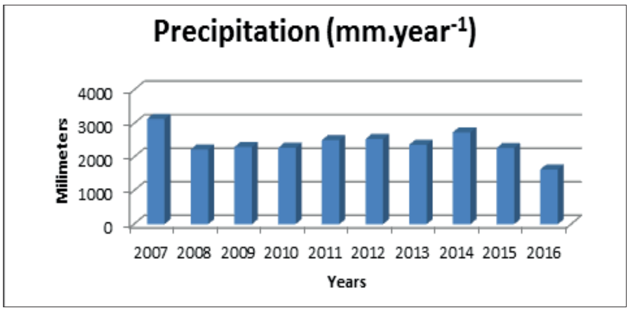


Figure 3. Annual rainfall distribution from 2007 to 2016 in Santo Tomas, Yurimaguas.

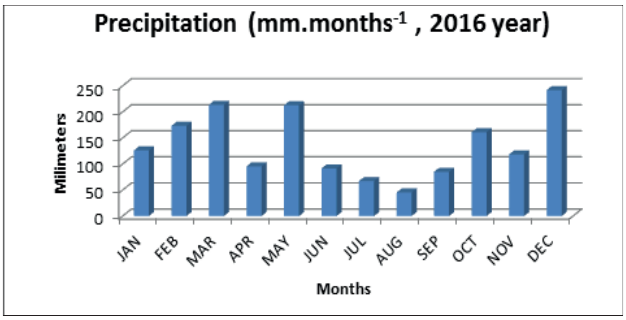


Figure 4. Monthly rainfall distribution during 2016 in Santo Tomas, Yurimaguas.

Three months after planting the cover crops, we had 100% of soil surface covered with Centrosema at two farmer's site, and weeds were controlled. Total average of Centrosema dry biomass of each farmer site ranged from 7 to 8.25 T/ha (Fig. 5). The farmers site "W" had the highest Centrosema biomass production because the farmer planted Centrosema before and it got adapted, responding more efficiently to the P application.

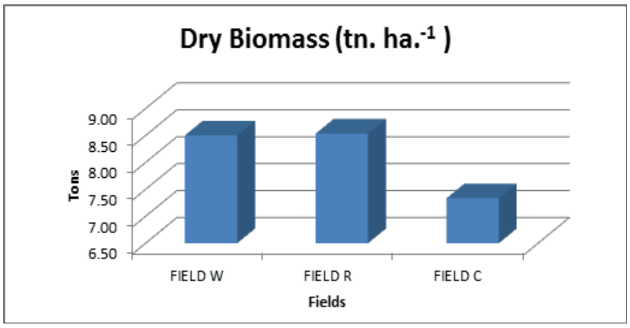


Figure 5. Eight month year old dry biomass in the three farms in Santo Tomas, Yurimaguas (W, R and C are Washington, Roberto and Clais farmers, respectively).

There were significant differences between AFS for the Centrosema biomass production between farmer's sites as shown in Figure 6. Agroforestry system 1 produced 9.77 T/ha of dry biomass which was significantly higher than the other two AFS with 7.99 and 7.2 for AFS 2 and AFS 3, respectively. Also AFS 1 had more tree species and some of the fast growing species were self-pruned, consequently, the litterfall was increased. (Figs. 7a,b).

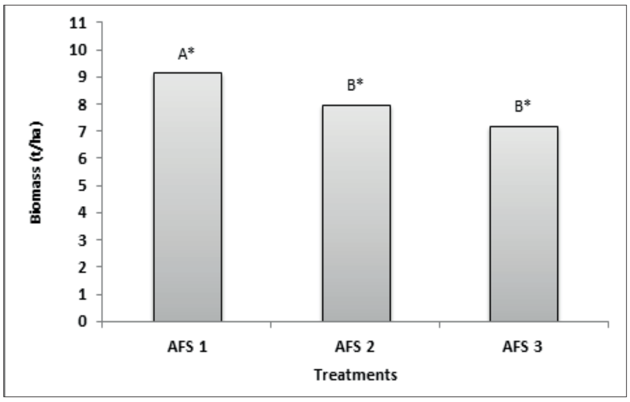


Figure 6. Biomass production of Centrosema covers for each of the agroforestry systems established in Santo Tomas Yurimaguas.

* Means fallowed with the same letter are not significant different at 0.05 probability

AFS 1 is a multistrata system with fast and slow growing woody tree species

AFS 2 is a multistrata system with slow and fast growing woody and fruit species

AFS 3 is a silvopastoral system with fast growing woody species.


Figure 7. Recovered degraded pasture with Centrosema (A), and trees (B) in agroforestry forestry systems.

Trees suffered water stress during planting time on January 2016 because of an unusual reduction of rainfall with less than 120 mm during few rainfall events. Normally by this time of the year it rains between 250-300 mm. (Figs. 3 and 4). The fast growing tree species presented more susceptibility to water stress, and *Simarouba amara* presented the highest percentage of mortality with 43% followed by *Calycophylum spruceanum* with 24% of mortality. For the rest of trees the percentage of mortality was less than 11% (Fig. 8).

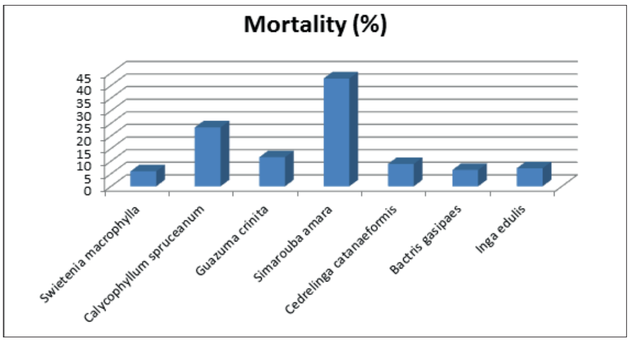


Figure 8. Average percentage of mortality of trees planted for each species in the three farmer's sites in Santo Tomas, Yurimaguas.

The cutting of Centrosema around trees during the growing phase of the perennial trees was used in some cases as forage for small animals, and in other cases it was left as mulch to enrich soil with nitrogen (N). Results showed an average biomass accumulation of 215-250 kg/ha of N (Fig. 9), which is more than the average of 150 kg/ha that was found in non-fertilized plots in Yurimaguas (Palm, 1995; Alegre et al., 2005). There was also a significant increase in potassium and calcium levels in the Centrosema biomass due to recycling biomass and lower recycling levels in phosphorus.

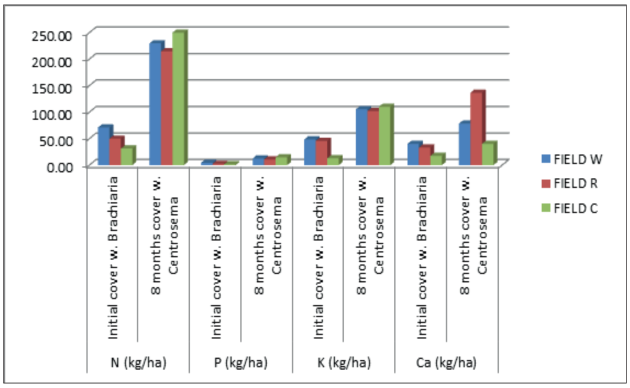


Figure 9. Mean content of N, P, K and Ca in the Centrosema biomass in three farmer's sites in Santo Tomas, Yurimaguas.

Soil strength (SS) is shown in Figure 10 and there was compaction of up to 20 cm in depth with SS higher than 100 kpa, ranging from 117 to 204 kpa. After a year of recovering with Centrosema cover and trees, these values of MR were reduced to less than 100 kpa with ranges from 25 to 85 kpa. Bulk density followed the same trends.

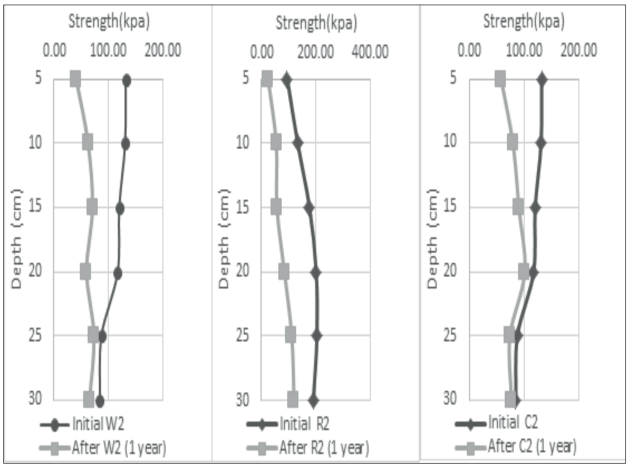


Figure 10. Soil strength at different depths before and one year after establishing the cover crops and trees in three farmers sites in Santo Tomas, Yurimaguas.

Soil nutrients improvement in 8 months were only for organic matter (OM) and available potassium (K) as shown in Figures 11 and 12 due to higher Centrosema litterfall production and fast decomposition rates that incorporate good quality organic matter to the soil in the short time. For the other nutrients, there were no differences, and it is expected that trees will build organic matter in the medium to long term with the continuous addition of litterfall.

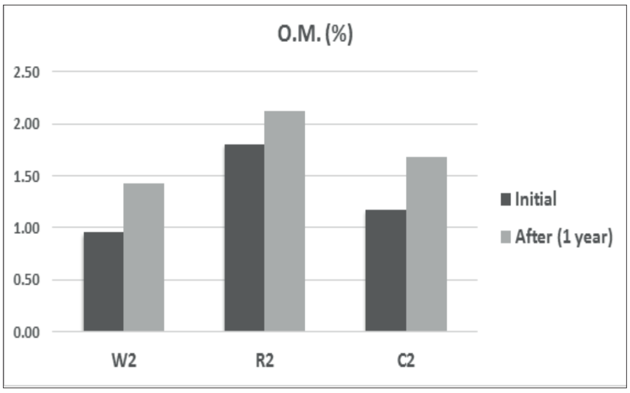


Figure 11. Soil organic matter content after eight months of cover crops establishment and trees planted in three farmers sites in Santo Tomas, Yurimaguas.

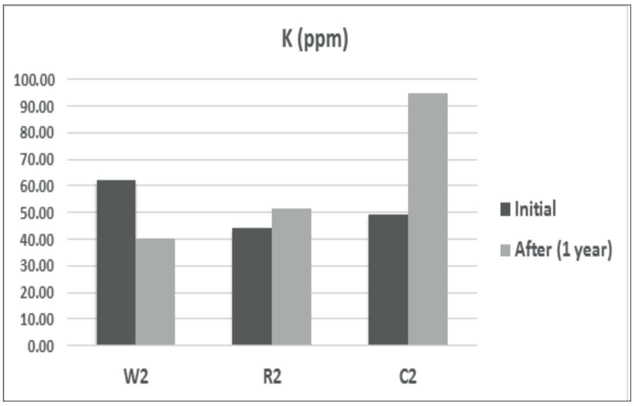


Figure 12. Soil available potassium content eight months after one year of cover crops establishment and trees planted in three farmers sites in Santo Tomas, Yurimaguas.

## Conclusions

In three months we had 100% cover with Centrosema and weeds were controlled. Total average Centrosema biomass in 8 months was 8.12 T/ha. The Multistrata agroforestry system 1 with more planted species produced 9.77 T/ha of dry biomass which was significantly higher than the other two AFS. While the trees were growing, there was a 55 to 80% of survival due to water stress; Centrosema can be used as forage for small animals and to enrich soil. Nitrogen accumulation in biomass was 232 T/ha. Soil compaction was reduced at 20 cm depth and organic matter and potassium level were increased in the short time after cover crops and trees establishment.

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