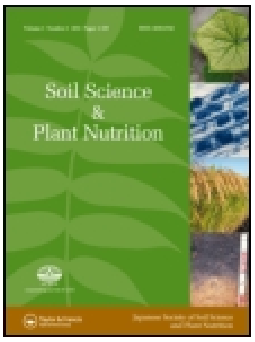

Soil Science & Plant Nutrition

ISSN: 0038-0768 (Print) 1747-0765 (Online) Journal homepage: https://www.tandfonline.com/loi/tssp20

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**To cite this article:** Keizo Hirai , Joãn Ferraz , Sávio F. Ferreira & Masahiro Kobayashi (2005) Change in Physical Properties of Ferralsols with Tree Planting in the Central Amazon, Brazil, Soil Science & Plant Nutrition, 51:5, 761-765, DOI: 10.1111/j.1747-0765.2005.tb00108.x

**To link to this article:** https://doi.org/10.1111/j.1747-0765.2005.tb00108.x

Published online: 17 Dec 2010.

# Change in Physical Properties of Ferralsols with Tree Planting in the Central Amazon, Brazil

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Received March 15, 2004; accepted in revised form March 28, 2005

**We examined the effects of mixed planting of fast growing tree species with indigenous Amazon tree species and soil tillage practices on soil physical properties in a deforested site used for agricultural cultivation. The site was located in the Central Amazon and consisted of Ferralsols. Bulk density and soil hardness were compared in the mixed planting site and an area where only indigenous tree species were planted. Many roots of the fast growing trees penetrated into the profile and caused changes in soil physical properties, i.e., decreasing bulk density and hardness. When tillage practices prior to planting were combined with mixed planting, the changes in soil physical properties were enhanced and the growth of not only the planted fast growing trees but also indigenous species such as mahogany, *Swietenia macrophylla*, which is shade tolerant, was accelerated.**

***Key Words:*** **Central Amazon, Ferralsols, mixed planting of fast growing tree species, soil physical properties, tillage practice.**

In the Amazon basin, deforestation reached 587,000 $km^2$ in 2000, which corresponds to 12% of the total Amazon region (INPE 2003). Deforestation as a result of logging and ground fires often causes severe land degradation in the eastern Amazon (Gerwing 2002). In the Brazilian Amazon, Ferralsols (ISSS 1998), are the predominant soil type, and occupy almost 46% of the total area (Nortcliff 1989). The forests cover the plateaus of this area, and known locally as "floresta da terra-firme" (Higuchi et al. 1998). Ferralsols are poor in nutrition, especially phosphorus, although they have favorable physical conditions for agricultural cultivation, that is, the soil is usually deep, high in permeability and less prone to erosion (ISSS 1998) under natural condition in general. Therefore, most research has been focused on the nutrients and related constraint (Nortcliff 1989). But, physical constraints might also pose severe limitations to productivity (Nortcliff 1989). For example, when land is mechanically cleared of forest by bulldozers, physical degradation such as an increment of bulk density and mechanical impedance or increased penetration resistance and decreased water infiltration capacity and macro porosity occur (Dias and Nortcliff 1985; Alegre et al. 1986). Thus during agricultural land use, if adequate soil management practices such as tillaging are not conducted, recovery of soil condition before forest clearing will be insufficient and crop yields will subsequently decrease (Alegre et al. 1986). Cattle tramping will also increase bulk density, total porosity and water retention (Koutika et al. 1997). Root penetration is inhibited in areas with high bulk density (Van Wambeke 1991). Such physical problems occur when the soil has extremely high clay content (FAO/UNESCO 1971).

It is therefore necessary to diminish deforestation to prevent soil degradation and to reclaim the physical properties of soil for reforestation in degraded areas. Tree planting is an effective way of rehabilitating these areas to the forest. The objective of this research is to clarify the effects of mixed planting of fast growing tree species and soil tillage practices on soil physical properties such as soil hardness and bulk density in the land used for crop cultivation after deforestation in the Central Amazon.

## MATERIALS AND METHODS

**Site description.** The experimental site is located in Presidente Figueiredo about 120 km north of Manaus, capital of the Amazonas State, Brazil. The mean annual temperature is 26.9°C and rainfall was 2,300 mm from 1973 to 2002 at Manaus. Monthly rainfall is not less than 60 mm in the semi-dry period from June to October. Tropical rainforest known locally as "floresta da terra-firme" (Higuchi et al. 1998) is the major vegetation on the plateaus, and the predominant soils at the experi-

**Table 1.** Overview of the experimental sites established at Presidente Figueiredo in Amazonas state, Brazil.

| Site (latitude and longitude) | Plot | Soil type[a] | Topography | Tree species or forest type | Age[d] (years) | Soil preparation |
|---|---|---|---|---|---|---|
| | TP | | | indigenous species[b] with fast growing species[c] | 5 | tillage |
| Presidente Figueiredo | NP | Ferralsols | plateau with flat, no inclination | indigenous species with fast growing species | 5 | without tillage |
| (1°56′S, 60°01′W) | NN | | | indigenous species | 5 | without tillage |
| | PF | | | primary forest | uncertain | — |

[a]Classified by ISSS Working Group RB (1998). [b]*Swietenia macrophylla, Dypterix odorata, Hymenaea courbaril, Carininiana micrantha* and *Parkia pendula*. [c]*Ochroma lagopus*. [d]Stand age in 2002.

mental site are Ferralsols. The site was a primary forest until 1983 at which point selective cutting and logging started. In 1985, the forest was completely cleared manually throughout the entire area of experimental site, and the site was burned just after clearing and abandoned for 7 years. After recovering with second growth, the site was cleared and burned again in September 1992, and the site was used for the cultivation of cassava and banana until the beginning of our experiment. There were no records regarding the management practices during this cultivation period. In early 1998, cultivation was stopped and site preparation for our experiment was commenced.

**Outline of the experimental plots.** In May 1998, three experimental plots (48×78 m) were established in the area to examine the effects of tree planting and tillage practices on soil physical properties. A plot was also set in an area of primary forest (PF) adjacent to the plantation site to show the original soil conditions use (Table 1). Balsa, *Ochroma lagopus*, which is a fast growing tree species, was planted in two plots (TP and NP) and not planted in one plot (NN). One of the two plots planted with balsa (TP) was plowed prior to planting to a depth of 30 cm using a disk harrow. The other plot (NP) was not plowed. In the fifteen sub plots (9×9 m) in each plot, five species of indigenous Amazon trees were planted. In the plot, each indigenous species were planted in the three sub plots. Trees were planted at intervals of 3×3 m both in the plots and sub plots, that is, 1.5×1.5 m interval of trees at the two plots planted with fast growing and indigenous tree species.

**Field survey and analytical methods.** All of the field survey and soil sampling was done in the subplot which planted mahogany (*Swietenia macrophylla*). The soil profile was described according to the guideline for soil description by FAO and soil samples were collected to determine the physical property. The pipette method was applied to determine particle size distribution.

To determine soil bulk density, soil core samples ($n=3$) were collected from the center depths of every soil horizon in the profiles of center of each plot until a depth of 145 cm using 100 cm$^3$ soil-sampling cylinders. The soil samples were dried at 105°C for 24 h before weighing. Soil hardness was measured using a penetrometer (DIK-5553, Daiki, Japan) at a depth of 2.5, 7.5, 15, 25, 35, 50, 65, 80, and 100 cm in the profiles of each plot (five replication). All measurements were conducted at intermediate points between the planted or standing trees in the plantation or primary forest plots, respectively, from May to June 2002, which was in the rainy season. Especially, as soil hardness is reflected by soil water content, measurements in the field were conducted in early June to ensure the same environmental conditions in all experimental sites.

## RESULTS AND DISCUSSION

### Effects of mixed planting on soil physical properties

Clay content in the surface horizon ranged from 820 to 870 g kg$^{-1}$ in the each plot and did not differ among plots. Texture was therefore classified as clay in the all plots.

The soil hardness of the NN, the NP and the PF is shown in Fig. 1. Soil hardness was higher in the NP than in the PF at a depth of 2.5 to 25 cm, and 80 cm, but it was significantly lower in the NP compared to the NN at depths of 7.5 to 25 cm, and 100 cm. In the NP, the soil hardness values for depths of 7.5 to 25 cm were lower

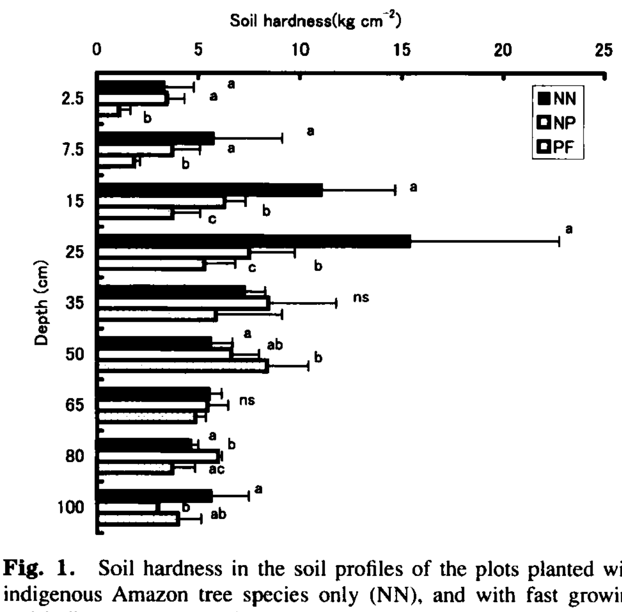


**Fig. 1.** Soil hardness in the soil profiles of the plots planted with indigenous Amazon tree species only (NN), and with fast growing and indigenous tree species (NP), and the area left as primary forest (PF) at Presidente Figueiredo. See Table 1 for legend. The error bars show the standard deviation. Different letters among plots at the same depths indicate statistical significance ($n=5$, $p<0.1$).

**Table 2.** Description of horizon, soil color and root distribution in the soil profile of the plots at Presidente Figueiredo.

| Plot[a] | Horizon | Depth (cm) | Soil color | Root distribution | Remarkable observation |
|---|---|---|---|---|---|
| PF | Ah | 0–5 | 7.5YR 4/3 | Common; medium and coarse | Root was distributed through the profile and mainly until 30 cm. Coarse root between (4 to 5 cm ϕ) was distributed 0 to 5 cm depth. Root between 50 to 140 cm depth distributed common. Infiltration of organic matter was observed until 50 cm depth. |
| | AB | 5–22 | 10YR 6/6 | Common; medium | |
| | BA | 22–40 | 10YR 6/6 | Few; fine | |
| | B1 | 40–60 | 10YR 6/6 | Few; fine | |
| | B2 | 60–100 | 7.5YR 6/8 | Very few; fine | |
| | B3 | 100–140 | 7.5YR 6/8 | Very few; fine | |
| | B4 | 140–150+ | 7.5YR 7/8 | Very few; fine | |
| TP | Ap | 0–35 | 10YR 5/6 | Many; very fine. Fine; medium and coarse | Fine root (<1 mm ϕ) is distributed until 150 cm depth. Discontinuous infiltration of organic matter is observed until 85 cm depth. Feces of earthworm was distributed until 50 cm depth. A slight soil compaction was observed until 35 to 50 cm depth. |
| | BA | 35–50 | 10YR 6/4 | Few; fine | |
| | B1 | 50–80 | 10YR 7/6 | Few; fine and medium | |
| | B2 | 80–140 | 7.5YR 7/8 | Few; fine | |
| | B3 | 140–150+ | 7.5YR 7/8 | Few; fine | |
| NP | Ah | 0–10 | 7.5YR 5/4 | Many; very fine. Common; fine. Few; medium | Root zone was observed 0–10 cm, 70 cm and 90–110 cm depth. Grass root was concentrated within 0–5 cm depth. Soils between 70 to 95 cm was very friable and many roots was distributed. Few feces of earthworm was distributed between 20 to 40 cm depth. |
| | AhB | 10–20 | 10YR 7/6 | Many; very fine. Common; fine. Few; medium | |
| | BA | 20–40 | 10YR 7/6 | Many; very fine. Common; fine. Few; medium | |
| | B1 | 40–75 | 10YR 7/6 | Many; very fine. Few; fine. Very few; medium | |
| | B2 | 75–90 | 10YR 7/6 | Common; very fine. Few; fine. Very few; medium | |
| | B3 | 90–135 | 7.5YR 7/8 | Common; very fine. Few; fine. Very few; medium | |
| | B4 | 135–150+ | 7.5YR 6/8 | Very few; fine | |
| NN | Ah | 0–10 | 10YR 5/3 | Many; fine, medium and coarse | Root was distributed at 0 to 8 cm depth mainly and deepest point of root penetration was 140 cm depth. Organic matter was infiltrated until 7 cm depth. Soil compaction was observed 0 to 35 cm depth. Feces of earthworm was distributed until 60 cm depth. |
| | AB | 10–40 | 10YR 6/8 | Common; fine and medium | |
| | BA | 40–60 | 7.5YR 7/6 | Few; fine and medium | |
| | B1 | 60–90 | 7.5YR 7/8 | Few; very fine and fine | |
| | B2 | 90–140 | 7.5YR 6/6 | Few; very fine and fine | |
| | B3 | 140–150+ | 7.5YR 7/8 | Few; fine | |

[a]See Table 1 for plots.

than those in the NN by one third to one half, but these values were not so different at the deeper depth than 35 cm.

There were no clear differences in bulk density between the NP and the PF, while the values of bulk density in the NN were greater than those of both the NP and the PF throughout the profile except for the BA horizon (Table 3). Clear differences were observed between the NP and the NN throughout the profile. In these two plots, the values of bulk density at a depth below 25 cm in the NN and 30 cm in the NP were over 1.1 g $cm^{-3}$.

Ferralsols in eastern Amazon experience an increased soil bulk density with alternation from primary forest to pasture, and the values at pasture were higher than 1.1 g $cm^{-3}$ (Koutika et al. 1997). In the NN, bulk density below surface horizon was higher than 1.1 g $cm^{-3}$, and at a depth of around 25 cm, the highest values of bulk density and soil hardness of all the experimental sites were obtained (Table 3, Fig. 1). A compacted soil horizon was, therefore, existed in the NN. It was also suggested that alternation of original vegetation by deforestation to another land use such as agricultural cultivation resulted in soil compaction. The bulk density values of the NN at below 25 cm were higher than 1.15 g $cm^{-3}$ (Mg $m^{-3}$), which is the mean value of the B horizon of Oxisols in the Amazon region (Bernoux et al. 1998). In Ferralsols, root penetration is inhibited at values over 1.10 g $cm^{-3}$ and over 1.35 g $cm^{-3}$ (Van Wambeke 1991). Because the bulk densities in the NN were over 1.10 g $cm^{-3}$ and inhibition of root penetration could be occurred in this site. Soil profile observations revealed that in the NN the abundance of roots were restricted to the surface horizon within a depth of 10 cm, but in the NP roots reached to the B3 horizon at a depth of 95 cm (Table 2).

From these results, it is clear that mixed planting of fast growing balsa trees with indigenous Amazon tree species decreases bulk density and soil hardness compared to planting mahogany, indigenous tree species only. It is suggested therefore that mixed planting is an effective way of relieving soil compaction by balsa root development. Indigenous species alone do not change soil physical properties, as evidenced by the compacted soil horizon in the plantation site (NN). There is the reason that root development with tree growth of indigenous tree was slower than that of balsa, fast growing tree species (Table 2).

## Effects of tillage practices on soil physical properties

The effect of tillage practices on the soil physical properties was examined by comparing the TP and the NP. Soil hardness was lower in the TP from the surface to a depth of 25, 50 cm, and 80 to 100 cm (Fig. 2). Bulk density was lower in the TP than in the NP from the surface to the B1 horizon at a depth of around 50 cm (Table. 3). The differences between the TP and the NP

**Table 3.** Bulk density of each soil horizon in the profile of the plots at Presidente Figueiredo.

| Plot*[1] | TP | | | NP | | | NN | | | PF | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Horizon order | Depth (cm) | Horizon | Mean (sd) ($g\ cm^{-3}$) | Depth (cm) | Horizon | Mean (sd) ($g\ cm^{-3}$) | Depth (cm) | Horizon | Mean (sd) ($g\ cm^{-3}$) | Depth (cm) | Horizon | Mean (sd) ($g\ cm^{-3}$) |
| Surface | 17 | Ap | 0.63(0.06)$^{a}$ | 5 | Ah | 0.60(0.07)$^{a}$ | 5 | Ah | 0.93(0.07)$^{b}$ | 2 | Ah | 0.63(0.06)$^{a}$ |
| Sub surface | 17*[2] | Ap | 0.63(0.06)$^{a}$ | 13 | AhB | 1.03(0.02)$^{b}$ | 25 | AB | 1.27(0.02)$^{c}$ | 13 | AB | 0.95(0.01)$^{d}$ |
| 3rd*[3] | 43 | BA | 0.88(0.06)$^{a}$ | 30 | BA | 1.14(0.03)$^{b}$ | 50 | BA | 1.19(0.02)$^{c}$ | 30 | BA | 1.13(0.08)$^{bc}$ |
| 4th | 65 | B1 | 1.03(0.02)$^{a}$ | 53 | B1 | 1.14(0.03)$^{b}$ | 68 | B1 | 1.19(0.04)$^{c}$ | 50 | B1 | 1.09(0.05)$^{ab}$ |
| Below 5th | | | | 80 | B2 | 1.14(0.01) | | | | 80 | B2 | 1.01(0.05) |
| | 110 | B2 | 1.06(0.06) | 110 | B3 | 1.08(0.04) | 105 | B2 | 1.21(0.04) | 120 | B3 | 0.98(0.04) |
| | 145 | B3 | 1.11(0.04) | 145 | B4 | 1.14(0.01) | 145 | B3 | 1.21(0.02) | 145 | B4 | 1.00(0.06) |
| Below 5th mean | | | 1.08(0.04)$^{a}$ | | | 1.12(0.01)$^{a}$ | | | 1.21(0.02)$^{b}$ | | | 0.99(0.06)$^{c}$ |

*[1] See Table 1 for plots. *[2] Sub surface horizon in TP was corresponds to Ap horizon. *[3] The depth below tillage zone (>30 cm). Different letters among plots at the same depths indicate statistical siginificance ($p<0.1$, $n=3$ in the each horizon).

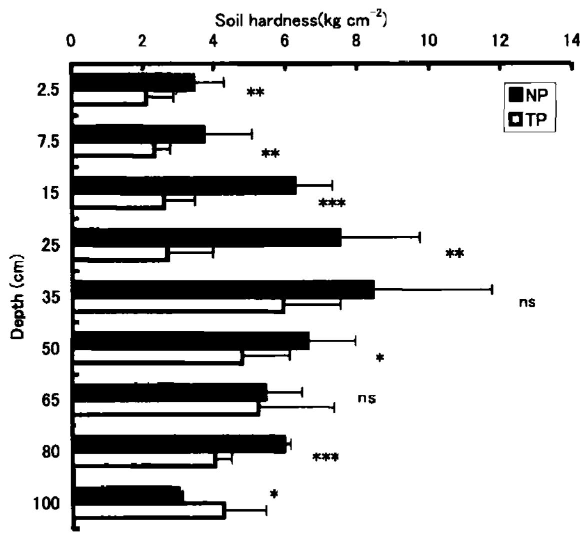


**Fig. 2.** Soil hardness in the soil profiles of the tillaged (TP) and non-tillaged (NP) plots: mixed planting of fast growing and indigenous tree species was introduced in both sites. See Table 1 for legend. The error bars show the standard deviation ($n=3$). ***$p<0.01$, **$p<0.05$, *$p<0.1$, ns: no significance.

for both soil hardness and bulk density were large from the surface to the BA horizon at around 30 cm compared to the layers below 30 cm (Fig. 2 and Table 3). This corresponds to the tillage depth, which was 30 cm. The soil profile observations also suggested that in the TP a plow horizon (Ap) was formed in which many very fine to coarse sized roots were distributed (Table 2). Compacted layer was observed at a depth of between 35 to 50 cm which was a BA horizon, but discontinued infiltration of organic matter which was darker color part compared to the soil matrix in the horizon was observed until around a depth of 85 cm and fine root penetration occurred until a depth of 150 cm (Table 2). On the other hand, the A horizon in the NP was thin (10 cm thick) (Table 2).

In the TP, tillage practices itself destruct the compacted horizon formed by deforestation and agricultural activity as observed in the NN, therefore low values of soil hardness and bulk density in the tillage zone was observed in the TP. In the TP, even in the depth below the tillage zone, except at a depth of 110 cm, bulk density was lower than in the NP. Until 110 cm, which corresponded to the B2 horizon, the bulk density values in the TP were lower than 1.10 $g\ cm^{-3}$, the value at which root penetration is inhibited (Van Wambeke 1991). These results suggest that the effects of tillaging reached not only the tillaged zone, but lower zones as well. It is suggested therefore that tillaging prior to planting destroys the compacted horizon, thus providing good soil physical properties for root development, particularly for fast growing trees. The resultant good root growth in the TP accelerated growth of the fast growing trees compared to in the NP.

The mean height of balsa in 2001, 3 years after planting, was 11.42 m in the TP and 9.64 m in the NP (Barbosa et al. 2003). But growth of the five indigenous tree species was not affected because of insufficient light conditions due to the canopy of balsa. These indigenous tree species therefore grew slowly compared to balsa (Barbosa et al. 2003). Of the five indigenous Amazon species planted, mahogany which is shade tolerant (Pancel 1993), grew significantly better in the TP than in the NP (Barbosa et al. 2003). Lehmann (2003) reported that the root systems of shaded tree crops such as coffee and cacao tend to have shallower roots than tree crops, which are usually grown in monoculture. This is the possible reason for the good growth of mahogany in the TP under the balsa canopy. The improved soil physical conditions (hardness and bulk density) in the surface soil of the tillaged site compared to the non-tillaged site were also effective in promoting the growth of mahogany. As a result, these changes accelerate the growth of planted fast growing trees as well as shade tolerant trees.

*Acknowledgments.* This research was conducted under the Brazilian Amazon Forest Research Project with the JICA and INPA. We would like to thank Dr. Isao Hotta, for his valuable advice regarding the research plan, and the INPA staff for their support with the field and laboratory work. We also thank Dr. Masamichi Takahashi, FFPRI, Japan for his comments and critical review of the early manuscript.

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