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ARTIGO ORIGINAL

Mortality of girdled trees and survival of seedlings in canopy gaps after logging in an upland forest in the Brazilian Amazon

Mortalidade de árvores aneladas e sobrevivência de mudas em clareiras após exploração florestal em uma floresta de terra firme na Amazônia brasileira

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ABSTRACT: Post-harvest silvicultural practices in managed forests are seldom applied in the Amazon region. To tackle this problem, an experiment was established in 700 ha of upland dense forest in the Brazilian Amazon, aiming to test the main silvicultural treatments applied elsewhere in the tropics, in order to select the most promising ones and recommend their application as part of forest management practices in the region. The experimental area is located in the Rio Capim Forest Management Unit, municipality of Paragominas (2° 25'-4° 09' S and 46° 25'-48° 54' W), State of Para, Brazil, where some post-harvest silviculture activities such as tree girdling, planting in gaps and assistance of natural regeneration in gaps are performed. Among the girdled trees, the large-sized ones presented higher mortality rates, corroborating some studies carried out in the Amazon and elsewhere. In general, the survival of planted seedlings was considerably high (over 75%). The prospects of success of this approach as post-harvest silviculture are very promising. The survival of seedlings from natural regeneration of commercial species, mainly of the light-demanding ones, was high in the gaps created by logging, suggesting that natural regeneration can establish stands of commercial value.

RESUMO: *A prática de silvicultura pós-colheita em florestas manejadas é rara na Amazônia. Para tratar esse problema, um experimento foi estabelecido em 700 ha de floresta de terra firme na Amazônia brasileira, com o objetivo de testar os principais tratamentos silviculturais aplicados em florestas tropicais, selecionando os mais promissores e então recomendá-los para serem aplicados como parte das práticas de manejo florestal na Amazônia. O experimento, desenvolvido na Área de Manejo Florestal da Fazenda Rio Capim, município de Paragominas (2° 25'-4° 09' S e 46° 25'-48° 54' W), no Pará, envolve atividades de silvicultura pós-colheita, como anelagem de árvores, plantio de mudas e condução de regeneração natural em clareiras. Entre as árvores aneladas, aquelas de maior porte tiveram taxas de mortalidade mais altas, corroborando com estudos desenvolvidos em outras áreas de florestas tropicais. Em geral, a sobrevivência de mudas plantadas foi alta (acima de 75%). As perspectivas de sucesso das práticas testadas como alternativa para tratamentos silviculturais são promissoras. A sobrevivência das mudas de regeneração natural de espécies comerciais, principalmente daquelas intolerantes à sombra, foi alta nas clareiras, sugerindo que a regeneração natural pode ser suficiente para formar florestas de alto valor no futuro.*

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1 Introduction

Post harvest silvicultural practices in managed forests are seldom applied in the Amazon region. Foresters are not aware of their benefits although research exists in the region and elsewhere in the tropics whose results support indication to their adoption as a normal management practice. In Brazil only one case of post harvest silviculture exists in a certified FSC (Forest Stewardship Council) forest management unit, located in the State of Amazonas, western Brazilian Amazon. Demonstration areas and publication of technical guidelines are examples of initiatives towards adopting such practices.

Post-harvesting trials have been carried out in the Brazilian Amazon with main focus on silviculture (SANDEL; CARVALHO, 2000; OLIVEIRA et al., 2006; WADSWORTH; ZWEEDE, 2006; GOMES et al., 2010), ecology (LOPES; JENNINGS; MATNII, 2008; OLIVEIRA et al., 2005) and economy (LOPES; JENNINGS; MATNII, 2008). Climber cutting, crown liberation thinning, assistance of natural regeneration and planting tree species in gaps are the main types of treatments applied (GOMES et al., 2010). Climber cutting and crown liberation thinning allow faster growth of trees, whereas enrichment in gaps helps to increase stand productivity and the value of the forest.

In 2005 an experiment was established in 700 ha of *terra firme* dense forest of the Brazilian Amazon aiming to test the most applied silvicultural treatments elsewhere in the tropics in order to select the most promising ones to recommend their application as part of management practices in the region. It is part of the research project: "Post-harvesting Silviculture in the Brazilian Amazonia" (Silvicultura pós-colheita na Amazônia brasileira – UFRA/Embrapa/Cikel/CNPq.).

2 Material and Methods

The study is being carried out by Embrapa/UFRA and supported by CNPq, in the Rio Capim Forest Management Unit (RCFMU), that belongs to Cikel Brasil Verde Madeiras, located in the Municipality of Paragominas (2° 25'-4° 09' S and 46° 25'-48° 54' W), Brazilian Amazonia. The climate is Awi according to the Köppen system. The mean annual air temperature is *c*. 26 °C, mean relative humidity of 81% and mean annual rainfall of 1800 mm. Topography is mostly flat. Yellow Latosol is the main soil type occurring in the study area. The forest type in the area is Ombrophylus Dense Forest (*terra firme* equatorial rain forest).

The statistical design was entirely random. Seven treatments were established. The experimental area comprises 700 ha, distributed in 14 Working Units (WU) in the RCFMU. Each WU was divided into four 25 ha square plots, totaling 56 plots, of which 28 were randomized to constitute the treatments replications. Each treatment was replicated four times, totaling 100 ha per treatment. From the total sample area, 600 ha were logged (Reduced Impact Logging – RIL) in 2004 and 100 ha remain unlogged as a control. Silvicultural treatments (climber cutting, girdling of trees, planting in gaps) were applied in 2005. Details of each treatment are as follows:

T1 – RIL + Classical liberation (WADSWORTH, 1997) thinning by girdling and climber cutting on Potential Crop Trees - PCT. In this treatment all trees from commercial and potentially commercial species were selected as PCT; on average, 5.8 tress ha^{-1} with DBH > 35 cm were selected; no minimum distance was considered between PCT; all climbers of any size present on the boles or on the crown of the PCT were cut; all competitors were eliminated by complete girdling (SANDEL; CARVALHO, 2000) to favoring the PCT using a small axe or a machete.

Other procedures adopted to eliminate the competitors in T1: all competitors with DBH > 10 cm located 2 m distant from the PCT were girdled; all trees of non-commercial species whose crowns were overtopping a PCT were girdled; and all trees of non-commercial species whose crowns were competing (same height, interlaced) with the crowns of a PCT were girdled, observing a minimum distance between the competitor and the PCT, according to Wadsworth (1997).

T2 – RIL + Modified liberation thinning by girdling and climber cutting on PCT: an adaptation of the classical T1. Difference between T2 and T1 was that in T2 those rules involving distance (all competitors with DBH > 10 cm located 2 m distant from the PCT were girdled; and the minimum distance observed between the competitor and the PCT) were not adopted.

T3 – RIL + Climber cutting on trees of any commercial or non-commercial species, *i.e.* considering all species as PCTs. Difference between T3 and T2 was that in T3 all trees from any species (commercial, potentially commercial or non-commercial) were selected as PCT, and no girdling were applied in T3.

T4 – RIL + Planting commercial species in gaps, keeping and tending natural regeneration seedlings of commercial species and climber cutting on PCT. In this treatment all rules of T3 were applied plus planting of commercial species in gaps and assisting of natural regeneration seedling of commercial species in gaps. The species planted in gaps (17 species) were fast growing occurring in the RCFMU, except for *Schizolobium parahyba var. amazonicum* (paricá), which is rare in natural forests of Paragominas region. They were selected according to their diameter growth and height growth rates, from the list of species logged by Cikel. The seedlings planted in gaps were collected from natural regeneration in the skid trials and transplanted to gaps, except from seedlings of *S. parahyba var. amazonicum* which were produced in the Rio Capim Cikel nursery.

On average, 2 gaps ha^{-1} (200 gaps in total in T4) were selected, considering that 5 trees ha^{-1} were harvested in the study area and the criteria to determine that number (2 gaps ha^{-1}) was that the number of gaps to be monitored should be up to 50% of the number of trees harvested per hectare. The gap size varied from $200m^2$ to $1300m^2$. Spacing of planted seedlings was *c*. 5m. On average 9 to 10 seedlings were planted in each gap and 7 seedlings from natural regeneration of commercial species were selected for assisting in each gap.

T5: –(T2 + T4) - Treatment 5 is a combination of T2 activities plus T4 activities.

T6: – Logged Forest – Treatment 6 is composed by plots where RIL was carried out but no silvicultural treatments were applied. All trees of any species with DBH > 35 cm healthy and good form were recorded as PCT. As in the other treatments, no minimum distance was considered between PCT.

T7 – Unlogged Forest (control). The same T6 activities except RIL were applied.

All PCT in the 7 treatments were recorded, measured and evaluated, according to the guidelines for measuring trees in continuous forest inventory.

All trees girdled in T1, T2, T3 and T5 were recorded, measured and evaluated according to Sandel and Carvalho (2000), that suggested to observe some symptoms of devitalization in the crowns (e.g. leaves color, leaves fall, branches dying, branches fall) and in the boles (e.g. bark dying, wood dying, presence of insects, natural resin or gum reducing, tree dying). Mortality rate of girdled trees was calculated from 2005 to 2009.

A total of 6,243 trees were selected as PCT (9 trees.ha^{-1}) to be assisted by silvicultural treatments.

Four hundred gaps with area from 200 m^2 to 1300 m^2 were selected, being 200 in T4 and 200 in T5. Species for planting were chosen according to growth rate found in the literature and based on a list of Cikel's commercial species.

In the 400 gaps created by logging 3,834 seedlings (9.5 seedlings per gap) of 17 species were planted, and 2,865 seedlings (7 seedlings per gap) of natural regeneration from 51 species were identified and kept for assistance (tending).

Seedlings survival was evaluated in the 400 gaps created by logging. The first evaluation of seedlings (planted or natural regeneration) was carried out in March-April 2005 and the second evaluation occurred 12 months later. On both occasions, the gaps were cleaned, mainly by cutting of natural regeneration of lianas, to prevent the establishment of undesirable species that should prejudice the establishment and growth rate of the selected seedlings.

3 Results and Discussion

Twelve months after girdling 32% of the girdled trees died. Up to 36 months after girdling mortality rate was 65% but increased to 74% up to 48 months after girdling. In the first 12 months mortality was higher for trees with DBH higher than 60 cm (50%), compared to 42% for trees with 40-59 cm DBH and 27% for trees with 10-39 cm DBH. For the whole study period (48 months), mortality was higher (90%) for trees with DBH > 60 cm, compared to 83% for trees with 40-59 cm DBH, 75% for trees with 10-19 cm DBH and 57% for trees with 20-39 cm DBH.

Independent of DBH size, the species more susceptible to girdling were: *Licania paraensis* Prance (12 months after girdling = mortality of 100%), *Inga paraensis* Ducke (12 months after girdling = 71%; 48 months after girdling = 86%), *Pouteria oppositifolia* (Ducke) Baehni (67%; 75%), *Rinorea guianensis* Aubl. (22%; 73%) and *Duguetia* sp. (14%; 100%). *Poecilanthe effusa* (Huber) Ducke also had a high mortality rate (89%) 48 months after girdling. *Neea floribunda* Poepp. & Endl. (no dead tree) and *Pouteria decorticans* T.D. Penn. (mortality only 16%) were the species more resistant to girdling during the 48-month period.

Some trees, mainly those that produce latex (e.g. from genus *Pouteria*) resisted to girdling and had their bark regenerated from top to bottom of the ring.

Higher mortality rates were observed in individuals in the higher diameter classes corroborating results of some studies carried out in Amazonia and elsewhere. This treatment when properly applied is efficient for any tree size regardless of the species. However, more studies on post-harvesting silviculture are necessary to identify families or group of species more susceptible or more resistant to girdling.

Most of the planted species had high survival rate in the study period, mainly those light-demanding species that are well adapted to the environment conditions found in gaps. *Chrysophyllum lucentifolium subsp. pachycarpum* Pires & T.D. Penn., *Manilkara huberi* (Ducke) A. Chev. and *Astronium gracile* Engl., the only species considered as shade-tolerant (SWAINE; WHITMORE, 1988) had survival rate of 82%, 87% and 90%, respectively, because they were favoured by the high intensity of solar radiation present in gaps (GOMES et al., 2010).

The survival rate of planted seedlings of *Schizolobium parahyba var. amazonicum* (Huber ex Ducke) Barneby was 92%. In plantation projects evaluated by Galeão et al. (2006) its survival rate varied from 50% to 98%, according to the stand age but mainly because of the previous land uses.

Cedrela odorata L. had high survival rate (93%). And although it is a species very susceptive to attacks of *Hypsipyla grandella* Zeller; attacks that could prejudice its performance were not observed, a fact that encourages planting the species in gaps.

Jacaranda copaia (Aubl.) D. Don. reached survival of 91% probably because it belongs to the light-demanding species ecological group that is favoured by the high solar radiation found in gaps. Serrão, Jardim and Nemer (2003) recorded survival of 85% in seedlings planted in gaps created by logging in a dense forest in Moju, PA. Also in that forest, Nemer, Jardim and Serrão (2002) recorded survival of 80% for this species three years after planting in gaps. These results confirm the adaptation of seedlings of *J. copaia* in gaps.

Tabebuia impetiginosa (Mart. ex DC.) Standl. had a survival rate of 93% which is close to that found by Serrão, Jardim and Nemer (2003) for *Tabebuia serratifolia* (Vahl) G. Nicholson (91%) in gaps created by logging in the Moju forest. In projects evaluated by Galeão et al. (2006) in the Santarem region, the species *T. serratifolia* in enrichment planting in old secondary forests had a survival rate of 88%. In the municipality of Breves, Para, the survival rate of seven-year-old trees of the species was 94% when planted in cleared areas. According to these results the species can perform well in places with high solar radiation and for that it can be suggested for planting in gaps. According to Schulze et al. (2008), the sustainable management of the genus *Tabebuia* needs a combination of enrichment planting and tending of established seedlings of natural regeneration of that genus found in logged forests. The present study is already contributing to improve the knowledge on enrichment and tending of plants in gaps created by logging.

Pseudopiptadenia suaveolens (Miq.) J.W. Grimes had a mean survival of 80% three months after planting in forest gaps in Moju (NEMER; JARDIM; SERRÃO, 2002). The species can grow better in high intensity of light, with high survival in the center of gaps when compared to those planted in understory (SERRÃO; JARDIM; NEMER, 2003). This information is confirmed by the results of the present study where survival of *P. suaveolens* was 100%.

In enrichment planting in primary forest in Amazonas Tanaka and Vieira (2006) found that *Cordia goeldiana* Huber is exigent on solar radiation. In secondary forests evaluated by Galeão et al. (2006) in the Santarém region, survival of *C. goeldiana* was 88% six years after planting. In the present study its survival was 89%, which confirms the preference of the species for sites with high solar radiation.

Parkia gigantocarpa Ducke, *Simaruba amara* Aubl., *Sterculia pilosa* Ducke and *Laetia procera* (Poepp.) Eichler, which also belong to the light-demanding ecological species group, kept high survival rates in gaps, varying from 80% to 94%. *Dinizia excelsa* Ducke and *Schefflera morototoni* (Aubl.) Maguire, Steyerm. & Frodin, although being light-demanding species, had a survival rate of 78% and 75% respectively, which is considered low if compared to the other species evaluated. According to forest workers there is a possibility of these two species also suffer herbivorous attacks.

According to the survival rates one year after planting, *S. pahayba var. amazonicum*, *C. odorata*, *J. copaia*, *M. huberi, A. gracile, C. lucentifolium subsp. pachycarpum*, *T. impetiginosa*, *P. suaveolens*, *C. goeldiana*, *P. gigantocarpa*, *S. amara, S. pilosa*, *L. procera*, *D. excels* and *S. morototoni* can be promising for enrichment in gaps created by reduced impact logging.

We do not suggest *Caryocar villosum* (Aubl.) Pers. (survival 47%) and *Bagassa guianensis* Aubl. (89%) for planting in gaps in the Rio Capim Forest Unit, because they suffered herbivorous attacks, although *B. guianensis* had a high survival rate.

Due to the low number of individuals in the natural regeneration of some species, only 20 species with higher number of individuals (more than 22) were chosen to be analysed in this paper.

Parkia multijuga Benth., *D. excelsa*, *P. gigantocarpa*, *Parkia pendula* (Willd.) Benth. ex Walp., *S. pilosa*, *L. procera*, *P. suaveolens, S. amara, J. copaia, Trattinnickia rhoifolia* Willd. and *B. guianensis*, with survival rate higher than 80%, considered light-demanding species, are adapted to the microclimate in gaps.

Survival of *C. villosum*, even being a pioneer species was only 47%, probably because of herbivorous attacks suffered by the species in the study area.

In a study carried out by Francez, Carvalho and Jardim (2007) in another area also in the RCFMU, trees (DBH > 10 cm) of *L. procera*, *P. gigantocarpa* and *S. amara* disappeared after logging, but in the present study these species were found with a high number of seedlings in gaps, suggesting that they continue in the juvenile community and hopefully they will become part of the adult community.

The ingrowth of five species, including *J. copaia*, *S. amara* and *D. excelsa* was recorded by Oliveira et al. (2005) in a logged area at the Tapajos National Forest. In the same study area, Carvalho (2002) observed that some species disappeared a year after logging, including *D. excelsa*, *B. guianensis* and *P. pendula* but that *B. guianensis* and *D. excelsa* reappeared seven years after logging. *J. copaia* was one of the four species that appeared one year after logging.

From the 20 species evaluated in the present study, Pinheiro et al. (2007) recorded 17 species considering trees DBH > 20 cm in a permanent preservation area in the RCFMU but *Ceiba pentandra* (L.) Gaertn., *D. excelsa* and *Ocotea caudata* (Nees) Mez were not found. In the present study the canopy opening caused by logging improved the natural regeneration of those species.

M. huberi, Manilkara paraensis (Huber) Standl., *Hymenaea courbaril* L., *A. gracile, O. caudata* and *Enterolobium schomburgkii* (Benth.) Benth. belong to the shade-tolerant ecological species group but had good performance in gaps with survival rate higher than 80%, suggesting that they can endure high intensity of light in the initial phase of growth.

In another study also in the RCFMU, Hirai, Carvalho and Pinheiro (2008) reported that *M. huberi* was one of the most abundant species and it was well represented in all size classes, suggesting an ecological sustainability in the area. According to Rosa and Pokorny (2004), *M. huberi* was among the ten species with higher Importance Value Index (IVI) in two forests, both in Moju, one was logged just once in 1970 and the other was logged many times from 1970 to 2004.

In the study of Silva et al. (1995) at the Tapajos National Forest, *M. huberi* was one of the most abundant species considering trees DBH > 5 cm during 11 years (1981-1992). But there was no ingrowth of trees (DBH > 5 cm) of this species during the period, suggesting a low growth rate for plants DBH < 5 cm. Also at the Tapajós National Forest, Costa, Carvalho and Berg (2007) studied the growth of *M. huberi* after logging and found that trees DBH > 10 cm that were totally or partially exposed to light had better growth rate than those whose crowns were not receiving light directly and concluded that *M. huberi* needs high intensity of light to boost its growth.

This information confirm the high potential of *M. huberi* for guaranteeing its natural regeneration considering that there are adult trees in the forest and thus the low growth of the species can be boosted by applying silvicultural treatment in the area.

Some studies carried out in Amazonia (CARVALHO, 2002; CARVALHO; SILVA; LOPES, 2004; OLIVEIRA et al., 2005, 2006; FRANCEZ; CARVALHO; JARDIM, 2007; PINHEIRO et al., 2007; COSTA; SILVA; CARVALHO, 2008; FRANCEZ et al., 2009) also gave importance to those species evaluated in the present study due to the abundance of their individuals in both juvenile and adult populations in logged forests. The presence of adult individuals of tree species in the forest plus the high survival rate of seedlings in gaps created by logging can guarantee the stock for succeeding harvestings.

Survival of seedlings from natural regeneration of commercial species, mainly light-demanding, was high in the gaps created by logging, suggesting that natural regeneration of the species in the forest can establish stands of commercial value.

L. procera, *P. pendula*, *C. pentandra* and *O. caudata* need silvicultural treatments (e.g. elimination of competitors by cleaning gaps) to boost natural regeneration. Planting in gaps for increasing abundance of these species also can be an alternative for enriching the forest, if adult trees of these species do not occur near that forest or occur in very low abundance.

4 Conclusions

The tree girdling as silvicultural treatment was more efficient for killing bigger diameters individuals, thus allowing the entrance of more solar radiation into the forest, that can favor the establishment and growth of natural regeneration of commercial tree species;

Most of the species planted in gaps became well adapted to the site and can be considered as promising for post-harvesting silviculture in the Rio Capim Forest Management Unit; and

The natural regeneration of some species that have timber of commercial value had high survival in the canopy gaps caused by logging and can be considered as potential species to post-harvesting silviculture programs.

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