TREE GIRDLING TREATMENTS FOR TIMBER STAND IMPROVEMENT IN BOLIVIAN TROPICAL FORESTS

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Received April 2002

PARIONA, W., FREDERICKSEN, T. S. & LICONA, J. C. 2003. Tree girdling treatments for timber stand improvement in Bolivian tropical forests. The efficacy and costs of three tree girdling treatments to remove non-commercial trees were evaluated in both dry and humid Bolivian tropical forests that were recently harvested. The treatments included chainsaw girdling only and chainsaw girdling immediately followed by application of two different herbicide solutions (glyphosate and 2,4-D) to the girdled surfaces. Two years following the application, girdling + 2,4-D killed more than 75% of the crown on 75% of treated trees, while girdling + glyphosate and girdling only treatments killed 61 and 14% respectively. No significant differences in treatment efficacy were observed between forest types, although there were differences between tree species in response to treatments. Glyphosate killed trees more slowly than 2,4-D. Treatment costs were $0.16 / tree for girdling + 2,4-D, $0.32 / tree for girdling + glyphosate and $0.09 / tree for girdling only.

Key words: Herbicide - silviculture - tropical forest management - crop tree liberation

PARIONA, W., FREDERICKSEN, T. S. & LICONA, J. C. 2003. Rawatan penggelangan pokok bagi pembaikan dirian pokok di hutan tropika Bolivia. Keberkesanan dan kos bagi tiga rawatan penggelangan pokok untuk menyingkir pokok yang tiada nilai komersial dinilai di hutan tropika Bolivia yang kering dan yang lembap yang baru dibalak. Rawatannya ialah penggelangan menggunakan gergaji rantai dan penggelangan menggunakan gergaji rantai diikuti serta-merta oleh rawatan dengan dua larutan herbisid berlainan (glifosat dan 2,4-D) pada

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Specific study areas at both sites were installed in areas where timber was harvested in late 1998 to early 1999 using chainsaw felling and extraction of logs with rubber-tyred skidders. The La Chonta study site was located within the harvesting compartment 1998-3. Selection harvesting there was limited to nine species using minimum diameter limits of 50 to 70 cm dbh, removing a total volume of 12 $m^3 ha^{-1}$. In Amazonic, the study site was 1998-A within which selection harvesting was limited to nine species using a minimum diameter limit of 40 cm dbh, removing a volume of 7 $m^3 ha^{-1}$.

Experimental design and data collection

Eight 4-ha plots were established in each forest. In each plot, an average of 15 defective non-commercial trees was selected for treatment. Half of the plots were randomly selected for a chainsaw girdling treatment without herbicide application. The trees in the other four plots received a girdling treatment with herbicide application. Two of the herbicide plots received 2,4-D and the other two received glyphosate.

A chain-saw was used to girdle non-commercial trees. Girdles formed a contiguous ring approximately 2.5 cm deep and approximately 0.5 to 1.5 m above ground level. Occasionally, extreme convolutions on the stem of some tree species (e.g. *Simira rubescens*) prevented the completion of contiguous rings. Herbicide treatments were carried out with a 50% aqueous solution of amine formulation of 2,4-D applied to cut surfaces immediately following girdling using a 500 ml plastic squirt bottle. Herbicide was applied until the point of run-off and covered both the upper and lower surfaces of the girdle. Herbicides were selected based on their relatively low cost and availability in Bolivia. Each herbicide was applied to trees in one-half of each treated plot. Treatments were carried out in September and October, coinciding with the end of the dry season.

For the purpose of this study, the experimental unit considered was the individual treated tree, therefore creating three treatments: girdling only, girdling + 2,4-D and girdling + glyphosate. The numbers of trees in these treatments at the humid forest site were 63, 33 and 30 respectively. The numbers treated at the dry forest site were 58, 31 and 29 respectively. The numbers of treated species were 26 in the humid forest and 11 in the dry forest.

During treatments, the volume of formulation applied, gasoline and chain-saw oil consumed, and the time taken to complete treatments were recorded for each tree to determine the relative costs of treatments. Equipment costs (i.e. chain-saw) and time travelling between logging gaps were not considered in cost calculations. Treatments were done by local labourers trained in application methods with the exception of herbicides, which were applied by the authors because labourers were not certified in herbicide application procedures. Local labour cost at the time of study was $6.70/day.

After one and two years following treatment applications, the treated trees were revisited and the responses to treatments were observed using classes of per cent crown mortality as indicators of efficacy. Classes included 0–25, 26–50, 51–75 and

76–100% crown mortality. The evaluation of treated trees coincided with the recovery of full leaf at the beginning of the rainy season. In addition to crown mortality, the presence of resprouts below the girdle and any evidence of cambial regrowth over girdles were noted on treated trees.

Data analysis

A χ^2 analysis was used to test for differences in the response of trees to treatments. Differences were considered statistically significant at $p \leq 0.05$.

Results

Differences between treatments were similar between forest types after one and two years. In both forests, after two years, girdling plus herbicide was significantly more effective in causing crown mortality of treated trees than girdling alone ($\chi^2 = 30.7$, df = 2, $p < 0.001$ for humid forest and $\chi^2 = 21.9$, df = 2, $p < 0.001$ for dry forest). For girdling treatments with herbicide, a strong trend was observed for greater efficacy of 2,4-D compared with glyphosate in both forest types ($\chi^2 = 3.1$, df = 1, p = 0.07 for humid forest and $\chi^2 = 2.7$, df= 1, p = 0.09 for dry forest). Considering both forest types, 68–82% of trees treated by girdling + 2,4-D had crown mortality > 75%, while girdling + glyphosate, and girdling alone treatments caused similar reactions in 55–67% and 14% of the trees respectively (Table 1).

Herbicide decreased the percentage of trees that developed callus formation over girdles, with the exception of glyphosate in the humid forest (Table 2). Herbicides also decreased the incidence of resprouting below girdle cuts, with the exception of glyphosate in the dry forest (Table 2).

No differences were observed in efficacy of herbicide treatments for individual tree species, so the results of the two girdling + herbicide treatments were combined and compared with the girdling alone treatment to determine the efficacy of the treatments on individual species. In the humid forest, a few species (*Chorisia speciosa*, *Heliocarpus americana* and *Simira rufescens*) appeared to be easily controlled with girdling + herbicide, with all individuals of these species having > 75% crown mortality one year after treatment (Table 3). Species more difficult to control included *Gallesia integrifolia*, *Margaritaria nobilis*, *Myriciaria* sp., *Piptadenia* sp. and *Pseudolmedia laevis*; all of which had only 28–33% of individuals in the > 75% crown mortality class. However, after two years, girdling with herbicide caused > 75% mortality in all *Myrciaria* sp. individuals and increased the efficacy on *P. laevis* to > 75% crown mortality of 71% (Table 3). In the dry forest, most common species had more than two-thirds of trees with > 75% crown mortality with girdling + herbicide, with the exception of *Acosmium cardenasii*, a very common species which only had 21% of treated trees in the highest crown mortality class for girdling + herbicide treatment and no individuals in this class for the girdling alone treatment (Table 3).

Table 1 Efficacy of girdling treatments by percentage of trees in per cent crown mortality classes one and two years after application in humid and dry tropical forests in Bolivia

Humid forest		Number of trees and percentage of trees in each crown mortality class			
Treatment (sample size)		0–25%	26–50%	51–75%	76–100%
Girdling only (n = 63)	1 year	36 (57%)	17 (27%)	5 (8%)	5 (8%)
	2 years	44 (70%)	7 (11%)	3 (5%)	9 (14%)
Girdling + 2,4-D (n = 33)	1 year	1 (3%)	1 (3%)	7 (21%)	24 (73%)
	2 years	1 (3%)	1 (3%)	4 (12%)	27 (82%)
Girdling + glyphosate (n = 30)	1 year	4 (13%)	4 (13%)	9 (30%)	13 (43%)
	2 years	5 (17%)	2 (7%)	3 (10%)	20 (67%)

Dry forest		Number of trees and percentage of trees in each crown mortality class			
Treatment (sample size)		0–25%	26–50%	51–75%	76–100%
Girdling only (n = 58)	1 year	40 (69%)	5 (9%)	6 (10%)	7 (12%)
	2 years	39 (67%)	9 (16%)	2 (3%)	8 (14%)
Girdling + 2,4-D (n = 31)	1 year	4 (13%)	4 (13%)	2 (6%)	21 (68%)
	2 years	4 (13%)	4 (13%)	2 (6%)	21 (68%)
Girdling + glyphosate (n = 29)	1 year	10 (34%)	4 (14%)	3 (10%)	12 (41%)
	2 years	11 (38%)	1 (3%)	1 (3%)	16 (55%)

Table 2 Per cent of trees showing callus formation over girdles and resprouting below girdles one and two years following girdling treatments in humid and dry tropical forests in Bolivia

Humid forest Treatment (sample size)		% of trees with callus formation	% of trees with resprouts
Girdling only (n = 63)	1 year	87	30
	2 years	87	8
Girdling + 2,4-D (n = 33)	1 year	24	3
	2 years	24	3
Girdling + glyphosate (n = 30)	1 year	53	13
	2 years	43	0

Dry forest Treatment (sample size)		% of trees with callus formation	% of trees with resprouts
Girdling only (n = 58)	1 year	86	22
	2 years	82	7
Girdling + 2,4-D (n = 31)	1 year	32	6
	2 years	32	3
Girdling + glyphosate (n = 29)	1 year	45	38
	2 years	44	7

Table 3 Percentage of common tree species with > 75% crown mortality one and two years following treatment by girdling + herbicide or girdling only in humid and dry tropical forests in Bolivia

Humid forest Species		Girdling + herbicide No.	Girdling + herbicide %	Girdling only No.	Girdling only %
Ampelocera ruizii	1 year	8	50	14	7
	2 years		62		7
Chorisia speciosa	1 year	5	100	3	0
	2 years		100		0
Gallesia integrifolia	1 year	3	33	6	0
	2 years		33		0
Guazuma ulmifolia	1 year	2	50	3	0
	2 years		50		0
Heliocarpus americana	1 year	4	100	3	33
	2 years		100		66
Margaritaria nobilis	1 year	3	33	1	0
	2 years		33		0
Myriciaria sp.	1 year	6	33	6	16
	2 years		100		16
Piptadenia sp.	1 year	3	33	2	0
	2 years		33		0
Pseudolmedia laevis	1 year	7	28	6	0
	2 years		71		16
Simira rufescens	1 year	2	100	3	0
	2 years		100		33
Others	1 year	20	70	16	12
	2 years		80		18

Dry forest Species		Girdling + herbicide No.	Girdling + herbicide %	Girdling only No.	Girdling only %
Acosmium cardenasii	1 year	19	21	18	0
	2 years		32		5
Anadenanthera colubrina	1 year	16	69	17	18
	2 years		69		18
Caesalpinia pluviosa	1 year	13	69	12	0
	2 years		85		8
Piptadenia sp.	1 year	6	67	4	50
	2 years		67		50
Others	1 year	6	83	7	28
	2 years		100		28

Treatment costs were higher in the humid forest than in the dry forest, which coincided with larger tree diameters in the humid forest (Table 4). Average costs of girdling alone ranged from $0.05 per tree in the dry forest to $0.13 per tree in the humid forest, while average costs ranged from $0.10 per tree (dry forest) to $0.23 (humid forest) and $0.22 (dry forest) to $0.43 (humid forest) for additional application of 2,4-D and glyphosate respectively.

Table 4 Mean (± standard error) size of trees, time of treatment, volume of herbicide used and cost per tree of girdling treatments in dry and humid forests in Bolivia

	Dry forest	Humid forest
Mean DBH (cm)	34.0 ± 1.21	38.3 ± 1.17
Mean time to treat one tree – girdling only (s)	50.0 ± 2.88	170.0 ± 10.72
Mean time to treat one tree – girdling + herbicide (s)	70.0 ± 2.97	200.0 ± 14.10
Mean volume of herbicide used per tree (ml)	18.6 ± 1.32	32.3 ± 1.91
Treatment cost per tree (US$) – girdling only	0.05 ± 0.00	0.13 ± 0.03
Treatment cost per tree (US$) – girdling + 2,4-D	0.10 ± 0.01	0.23 ± 0.23
Treatment cost per tree (US$) – girdling + glyphosate	0.22 ± 0.02	0.43 ± 0.41

Discussion

The most effective and least costly of the girdling treatments was girdling + 2,4-D, causing extensive crown loss or whole tree mortality in 75% of treated trees after two years, followed by glyphosate which severely affected more than 60% of treated trees. 2,4-D acted more rapidly than glyphosate, killing between 25 and 30% more trees after one year. In contrast, girdling without herbicide was very ineffective in both forest types, severely affecting approximately only 14% of treated trees after two years. Slow mortality responses of trees girdled without herbicide were also observed in other tropical forests (Lamprecht 1990, Negreros-Castillo & Mize 1993).

Tissue regrowth in many trees girdled without herbicide often allowed for rapid reconnection of tissues across the girdle cut, negating the effect of the girdling. Some of these trees may eventually die, particularly during years of extreme drought, but the effect of liberation or refinement will be long delayed compared with that for trees dying soon after treatment. In addition, many girdled trees not receiving herbicide resprouted from the stem below the girdle. While these resprouts have no effect on liberated trees since resprouting occurs low on the stem below the girdle, resprouting trees become sources of poorly-formed non-commercial stems, which will occupy growing space and reduce stand quality.

Differences in efficacy between herbicides may be partially accounted for by the mode of action of the two herbicides. The mode of action of 2,4-D is hormonal, causing severe growth abnormalities resulting in the death of the tree. This chemical is very effective in preventing callus formation over girdles and resprouting in both forest types. In contrast, glyphosate kills plants by inhibiting the manufacture of the amino acid phenilalanine, causing the slow starvation of the plant. It is possible that trees treated with glyphosate will take longer to die than those treated with 2,4-D because death will only occur in these trees after the extensive carbohydrate reserves in tree trunks and roots have been exhausted. In a study in Peru, Maruyama and Carrera (1989) found that 26 months after girdling and treatment with glyphosate, 20 of 33 families of trees had mortality rates greater than 80% of trees with herbicide solutions much lower (15–33%) than those used in our study (50%). Regardless of ultimate mortality rates, however, it is often important that girdled trees die rapidly, in order to rapidly accrue the benefits of release for overtopped commercial regeneration. Contact herbicides that work rapidly may therefore be more desirable than slow-working chemicals.

Season of application may have some effect on the efficacy of herbicide treatments. Applications near the end of the rainy season may be more effective since translocation patterns are directed downward towards the roots (Smith 1986). Herbicides are therefore more effectively spread through root systems, increasing the potential for tree mortality.

In this study, however, treatments were applied at the end of the dry season, coinciding with or just preceding new leaf expansion for many tree species. The efficacy of girdling treatments in different seasons remains to be tested.

Chain-saw girdling is one of many ways to girdle trees (Smith 1986, Lamprecht 1990). Chain-saw girdling was employed here due to the rapid speed in which girdles can be applied. This rapid speed will probably result in relatively low costs compared with manual girdling operations. Although trees with convoluted stems are difficult to girdle effectively, chain-saw girdling is more effective on these trees than manual girdling with axes or hatchets, due to the ability of chain-sawyers to access convoluted portions of the stems with narrow passages by making plunging cuts with the saw. Some of these areas may be inaccessible to workers using axes or hatchets.

The main disadvantage with chain-saw girdling is the narrow band of the girdle, which allows for rapid reclosure of the girdle cut in trees that grow new callus tissue. Wider girdling bands may increase the efficacy of treatments (Negreros-Castillo & Hall 1994). However, we have seen damaged trees in Bolivian forests reclosing large wounds with callus tissues, such as those caused by skidder collisions, indicating that wider girdles may not necessarily prevent reclosure by callus tissue. In any case, wider bands are likely to be more necessary when herbicide application does not follow girdling. Possible options for those species that are difficult to control with girdling treatments, such as *A. cardenasii*, include more concentrated herbicide solutions or large volumes of herbicide applied to wider or more numerous girdling bands. Species that exude latex upon girdling, such as *P. laevis*, were difficult to control in general. Latex exudation is likely to drastically reduce penetration of herbicide into girdled trees.

While it appears that girdling with 2,4-D is the most effective and least expensive method for controlling undesirable trees of the three options tested in this study, further refinement of treatments needs testing. Studies that determine optimal concentration of herbicide applied and optimum season of application are recommended, as well as methods for treating species that are difficult to control.

Acknowledgements

The authors thank Amazonic Sustainable Enterprises Inc. and Agroindustria Forestal La Chonta Ltda. for their co-operation in this study. This study was conducted by Proyecto Bolfor, a sustainable forest management project in Bolivia funded by the US Agency for International Development and administered by Chemonics International.

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