

EVALUATION OF DIRECT SEEDING AND SEEDLING PLANTING OF TWO NEOTROPICAL TREE SPECIES WITH THE USE OF NATURAL INPUTS¹

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ABSTRACT – Direct seeding of native tree species could be a low cost alternative for forest restoration. The paper aimed at evaluate direct seeding of two species from Southern Brazil, *Schinus terebinthifolius* Raddi and *Citharexylum solanaceum* Chamisso, comparing with seedling planting. The effects and costs of forest topsoil and forest litter addition were also evaluated in the direct seeding. The experiment was accomplished during 2009/2010. The treatments of direct seeding were *CONTROL* – control without seeding, *TSEED* – only seeding, *TLITTER* - seeding with forest litter cover, *TTOPSOIL* - seeding with forest topsoil, *TBOTH* - seeding with forest litter and with forest topsoil, *LTCONTROL* – control with forest litter and forest topsoil. The species *C. solanaceum* did not germinate at field. The species *S. terebinthifolius* had higher germination in the *TBOTH*, either at 30 days (21.6%) and 360 days (9.0%), which correspond to a density of 9,000 plants · ha⁻¹ after 360 days. The litter singly contributed less to the survival than the forest soil, however a synergic effect between the two inputs was observed. The *TBOTH* presented a higher growth (42 cm of plant height at 360 days). The costs of direct seeding with inputs (singly or combined) were higher than the conventional seedling planting in relation to the area unity. However, the cost of direct seeding without addition of inputs was higher considering the cost per survivor seedlings. Planted seedling of *S. terebinthifolius* reached 88.5 cm of height after 360 days. Seedlings of *S. terebinthifolius* generated by direct seeding reached the average of 5.1 and 42.0 cm of height in the *TSEED* and *TBOTH* treatments, respectively.

Keywords: *Forest restoration; Soil transposition; Financial costs of restoration.*

AVALIAÇÃO DA SEMEADURA DIRETA DE DUAS ESPÉCIES DE ÁRVORES NEOTROPICAIS COM O USO DE INSUMOS NATURAIS

RESUMO – A sementeira direta de espécies arbóreas nativas pode ser uma alternativa de baixo custo para a restauração florestal. O trabalho teve como objetivo avaliar a sementeira direta de duas espécies do Sul do Brasil, *Schinus terebinthifolius* Raddi e *Citharexylum solanaceum* Chamisso, comparando com um plantio de mudas. Os efeitos e os custos da adição de solo florestal e serapilheira também foram avaliados na sementeira direta. O experimento foi realizado durante 2009/2010. Os tratamentos de sementeira direta foram *CONTROL* - controle sem sementeira, *TSEED* - somente sementeira, *TLITTER* - sementeira com serapilheira, *TTOPSOIL* - sementeira com solo florestal, *TBOTH* - sementeira com serapilheira e com solo florestal, *LTCONTROL* - controle com serapilheira e solo florestal. A espécie *C. solanaceum* não germinou no campo. A espécie *S. terebinthifolius* apresentou maior germinação na *TBOTH* com 30 dias (21,6%) e 360 dias (9,0%), correspondendo a uma densidade de 9.000 plantas/ha aos 360 dias. A sementeira com serapilheira isoladamente contribuiu menos para a sobrevivência do que o solo florestal, no entanto, um efeito sinérgico entre os dois tratamentos foi observado. O *TBOTH* proporcionou maior crescimento (42 cm de altura em 360 dias). Os custos da sementeira direta com insumos (isoladamente ou combinado) foram maiores do que o plantio de mudas convencional por unidade de área. Entretanto, o custo por muda sobrevivente foi maior na sementeira direta sem insumos.



Mudas plantadas de S. terebinthifolius atingiram 88,5 cm de altura após 360 dias. Plântulas de S. terebinthifolius geradas a partir da semeadura direta atingiram a média de 5,1 e 42,0 cm para nos tratamentos de semeadura direta TSEED e T BOTH, respectivamente.

Palavras-chave: Restauração florestal; Transposição do solo; Custos financeiros de restauração.

1. INTRODUCTION

The Atlantic Forest displays one of the greatest biodiversity and endemism reserves per unity area of the planet. The forest formations that belong to the Atlantic Forest were 15% of the Brazilian territory (Morellato and Haddad, 2000) and are nowadays reduced to near 7% of the original area (Myers et al., 2000). One third part of the remnant Atlantic Forest is in small forest fragments with less than 100 ha (Ribeiro et al., 2009). On the other hand, forest reduction still presents a great dimension. Brazil has been losing 2.9 million ha of forest per year and the net increment of planted forest (including commercial forestry) does not reach the 25 thousands ha per year (Brockhoff et al., 2008).

The restoration of degraded forests needs multiple human interventions and the utilization of adequate methods. To such interventions, a deeper understanding of the effectiveness of alternative methods to planting of seedlings is needed. These alternatives are based on knowledge of silviculture of the species and self-regeneration of the forest communities, with the consequent reduction of costs (Ferreira et al., 2003; Hüller et al., 2009).

Seedling planting with species of different successional groups is the most frequent method in forest recovering (Kageyama et al., 1989; Knowles and Parrotta, 1995; Shono et al., 2007). As the economic return of native tree plantings is usually low and their costs are relatively high, "restoration plantings are probably an option that can only be used in a relatively small number of situations" (Lamb et al., 2005). Meanwhile, alternatives such as direct seeding or spontaneous regeneration through secondary succession are promising to turn feasible the ecological and socio-economic dimensions of forest restoration (Engel and Parrotta, 2001; Reis et al., 2003).

Direct seeding tends to be an inexpensive method if compared to the seedling planting, requiring less equipment to the planting and greenhouse structure,

allowing restoring wide areas with easy procedures (Araki, 2005). However, high quality seeds in sufficient abundance are frequently unavailable (Mattei, 1993) and their response at field is unpredictable (Engel and Parrotta, 2001).

The success of direct seeding is also dependent on favorable conditions for rapid germination. Unlike the condition on the nursery, the lethal agents of the field conditions are not under control (Mattei and Rosenthal, 2002; Woods and Elliot, 2004). Therefore, auxiliary procedures also must be tested, for instance straw and forest litter addition, physical protectors, organic manure supply and weed management.

Inputs such as mulching (Stevenson and Smale, 2005) or forest soil have been evaluated (Requena et al., 2001). On the other hand, these additions could increase the costs of direct seeding and, in spite of bringing benefits; they could hinder economically the activity. The measurement of costs for implementation of different cultivation systems is indispensable to plan restoration.

The present investigation of direct seeding has included two native tree species from Southern Brazil, *Schinus terebinthifolius* Raddi and *Citharexylum solanaceum* Chamisso. The first is a pioneer tree species frequently found in riparian habitats but also in dry land. It has small seeds, with near 26,000 seeds · kg⁻¹ (Lorenzi, 1992). The second species is a pioneer and hygrophilous tree species, occurring rather in riparian forests. The species has near 19,000 seed · kg⁻¹ (Lorenzi, 1992). The study was conducted in order to compare the germination and growth potential of seeds of the two species at field using different treatments of direct seeding. The costs, survival and growth data were compared with results of seedling planting, in the same field conditions.

As underlying hypotheses, we have tested if: 1. direct seeding had lower costs than seedling plantation, 2. addition of forest soil and litter could benefit the direct seeding and 3. additional costs of the additives justify their application.

2. MATERIAL AND METHODS

2.1. Study area

The experiment was located at Conceição River margins in the Coronel Barros municipality, State of Rio Grande do Sul, Brazil (28° 22' 05,18" S; 54° 32' 09,89" W). The predominant soil class was Oxisol (USDA, 1999). The site was a crop area abandoned for 20 years, because it is part of permanent preservation area according to the Brazilian laws. Until the experiment the area has been used to crop cultivation (maize, wheat, soybeans). Some individuals of ligneous species, e. g. *Solanum mauritianum* Scop. and *Ateleia glazioviana* Baill., were observed during the evaluation.

The physic-chemical soil profile (Table 1) was provided by the Soil Laboratory of UNIJUÍ University (Ijuí-RS, Brazil).

The typical vegetation in the region is the Seasonal Semideciduous Forest. The climate is humid subtropical Cfa, according Köppen System (Moreno, 1961). The annual average temperature is 21.8 °C and the annual rainfall is 1,735 mm (Instituto Regional de Desenvolvimento Rural/UNIJUÍ, Augusto Pestana, Brazil). During the experiment, the highest mean maximal temperature was 34.5 °C (December 2009) and water stress conditions were observed only to March 2010 (Table 2).

The direct seeding has included seeds of *S. terebinthifolius* and *C. solanaceum*. For the second species, scarified seeds have also been evaluated. The seeds were submitted to scarification in a mechanical device equipped with a cylinder covered by sandpaper during 20 minutes under 1,200 rpm, following the indications of Zemetra et al. (1983). For both species potential germination was tested in laboratory and also in a nursery.

The experiment was established during September 2009, in a randomized design with six replications for each the six treatments and for each species.

The treatments were (Control) – control without seeding, (TSeed) – only seeding, (TLitter) – seeding with forest litter cover, (TTopsoil) – seeding with forest topsoil, (TBoth) – seeding with forest litter and with forest topsoil, (LTControl) – control with forest litter and forest topsoil.

The seeds were covered with 2-4 mm of soil in all treatments. The area was prepared through mechanical plowing.

Each plot of 2 x 2.5 m received 50 seeds, corresponding to 100,000 seeds/ha. The plots with litter addition were covered uniformly with 9.0 kg (fresh weight) of forest litter material, corresponding to 18,000 kg/ha. The forest soil was obtained from 0-20 cm deep and was added in the amount of 18 kg (fresh weight) per plot, corresponding to 36,000 kg/ha. The physic-chemical profile of the soil and the litter was determined (Table 1).

To comparison purposes the initial development and costs of seedling planting was carried out in the same site. The seedlings were produced in conical polypropylene tubes in a nursery. They are brought to the planting site with 20-30 cm of height with near three months age. The planting pits were 30x30x30 cm and were open manually 2x2 spaced, without any kind of fertilizers. Three hundred seedlings of each species were divided in 12 replications of 25 seedlings each.

The cultural operations have included the cut-and weed control. The weed control was performed six months after planting and seedling with the aid of a mechanical mowing.

The evaluation of costs was carried out through measurement of all operations costs and they are hectare based. In the manual operations, the values were calculated based on man/days costs, and for the mechanized operations the costs were calculated as hours/machine operation, according to the values usually practiced in the region. The valuation of the forest litter and forest soil was based on the values of workforce needed to gathering, transport and application.

2.2. Measurements and statistics

The survival has been measured with reference to the initial number of seeds. The costs were calculated in Reais (R\$) and transformed in US dollars (US\$) considering the proportion of R\$1.60/US\$1.00 which was the current value in the end of the experiment (September 2010).

The germination data were submitted to a one-way ANOVA after data transformation according to, $p' = \arcsen\sqrt{p}$ where p is the proportion of germinated seeds. The pair wise analysis was carried out through Duncan test ($P < 0.05$). The statistic analysis was executed with software SASM-Agri (Canteri et al., 2001) and WinSat (Machado and Conceição, 2003).

Table 1 – Physic-chemical of the soil in the experimental area, in the forest soil and the litter.
Tabela 1 – Físico-química do solo na área experimental, no solo florestal e na serapilheira.

| | Soil in the experimental area | | Forest soil | Litter |
|--|-------------------------------|----------|-------------|--------|
| | 0-15 cm | 15-30 cm | | |
| pH | 4.7 | 4.6 | 5.0 | ND |
| Actual CEC - (Cmol _c /dm ³) | 10.3 | 9.5 | 15.4 | ND |
| CEC at pH7 - (Cmol _c /dm ³) | 21.9 | 20.5 | 19.9 | ND |
| C - mg/dm ³ | ND | ND | ND | 454.1 |
| N - mg/dm ³ | ND | ND | ND | 2.16 |
| P - mg/dm ³ | 4.2 | <3.0 | 7.7 | 0.94 |
| K - mg/dm ³ | 93 | 44 | 312 | 2.53 |
| Al - (cmol _c /dm ³) | 0.7 | 1.3 | 0.2 | ND |
| Ca - (cmol _c /dm ³) | 7.2 | 6.6 | 10.8 | 42.4 |
| Mg - (cmol _c /dm ³) | 2.2 | 1.5 | 3.6 | 1.28 |
| OM (%) m/v | 3.4 | 3.0 | 4.4 | ND |

ND = not determined.

Table 2 – Weather conditions during the experiment (September 2009 to September 2010).
Tabela 2 – Condições climáticas durante o experimento (setembro de 2009 a setembro de 2010).

| month | Rainfall (mm) | Temperature | |
|----------------|---------------|-------------------|-------------------|
| | | Mean Minimum (°C) | Mean Maximum (°C) |
| September 2009 | 348.0 | 9.8 | 21.9 |
| October 2009 | 126.9 | 11.7 | 26.7 |
| November 2009 | 471.5 | 18.2 | 32.9 |
| December 2009 | 217.9 | 20.9 | 34.5 |
| January 2010 | 262.9 | 18.2 | 30.4 |
| February 2010 | 277.7 | 16.9 | 28.4 |
| March 2010 | 72.0 | 15.7 | 27.7 |
| April 2010 | 179.2 | 11.7 | 23.0 |
| May 2010 | 149.7 | 8.0 | 13.8 |
| June 2010 | 119.8 | 8.5 | 14.5 |
| July 2010 | 225.3 | 7.7 | 16.9 |
| August 2010 | 12.8 | 7.2 | 18.1 |
| September 2010 | 250.6 | 10.9 | 22.3 |

Source: IRDeR/UNIJUÍ-RS.

3. RESULTS

The germination of *S. terebinthifolius* was higher than of *C. solanaceum* in laboratory with 47.6% and 5.6%, respectively ($P < 0.05$, Duncan test). In the nursery, again germination of *S. terebinthifolius* was superior than of *C. solanaceum*, with 47.6% and 10.0%, respectively ($P < 0.05$, Duncan test). Scarification of *C. solanaceum* seeds increased significantly the germination only in the nursery, to 43.2%.

The species *C. solanaceum* did not germinate in any field conditions. For *S. terebinthifolius* the higher emergence was observed in TTOPSOIL and TBOTH at 30 days (21.3 and 21.6%). TBOTH remained the treatment with highest survival until the final evaluation at 360 days (Fig. 1).

The results of growth also point towards a superiority of the TBOTH, reaching 42 cm of height at 360 days (Table 3).

Among the direct seeding treatments the financial costs were positively correlated with the survival and growth values. On the other hand, the cost per survivor seedling after 360 days presented an inverse correlation with the costs (Table 4). The planted seedlings of *S. terebinthifolius* and *C. solanaceum* had 83.3 and 92.0 of survival after 360 days, and the average height was 88.5 cm and 77.5 cm, respectively.

The implementation and maintenance during the first year for direct seeding are more costly than for seedling planting, except the treatment without additives (TSEED). The treatments TTOPSOIL and TBOTH exhibited higher values of survival and growth and, concomitantly, the greater costs per unit area.

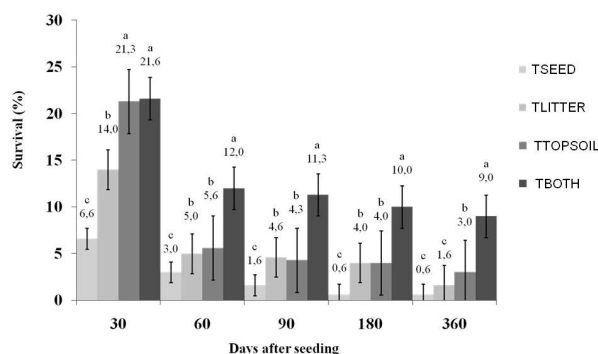


Figure 1 – (TSeed) – only seeding, (TLitter) - seeding with forest litter cover, (TTopsoil) - seeding with forest topsoil, (TBoth) - seeding with forest litter and with forest topsoil

Figura 1 – (TSeed) – somente sementes, (TLitter) - semeadura com adição de serapilheira, (TTopsoil) - semeadura com adição de solo superficial, (TBoth) - semeadura com adição de serapilheira e solo superficial

4. DISCUSSION

The survival of *S. terebinthifolius* at the first 30 days was higher in the treatments with addition of forest soil (TTOPSOIL) and addition of both forest litter and forest soil. It suggests that the added soil has a superior contribution in the early development than the forest litter, possibly representing a source of more soluble nutrients. From 90 days, the concomitant addition of litter and soil exhibited higher values of survival and the effect of soil addition singly had a gradual reduction. The concomitant addition of litter and forest soil presented a synergic effect to the survival, since the sum of the effects of these additives was lower than the benefit of the joint application. On the other hand, after 360 days the application of litter did not have significant differences in relation to the control, which does not justify their use singly.

Both forest litter and forest soil had physico-chemical features which potentially could facilitate the early growth of the seedlings. Forest soil presented high levels of Ca, K, and organic matter. On the other hand, the clay content was only 35%, reducing the possibility of soil compaction by the rain. Meanwhile, the litter had high level of C, N and Ca. Data suggest that the

litter addition could contribute to the survival if accompanied by a nutrient supply, in this case represented by the forest soil. On the other hand, addition of dead plant material to the soil increases the microbial activities and therefore the nitrogen consumption (Smettem et al., 1992), which requires compensation.

The survival of seedlings had an early critical period in the first 60 days after the seeding, during which the majority of the seedling losses have occurred. During such period, moisture and protection could be decisive (Ferreira et al., 2009). Nevertheless, the addition of forest litter which should promoted physical protection (Woods and Elliott, 2004) did have minor effects when compared to the addition of soil. Other studies have pointed out the ineffectiveness of litter addition (Stevenson and Smale, 2005).

Eighty two percent of the seedling losses have been observed between 30 and 360 days occurred until 90 days. As a general rule the survivorship of plants presents greatest levels of mortality in the beginning of the life cycle, decreasing gradually (Silvertown, 1987). Any techniques able to reduce the deaths in this early period could contribute significantly to optimize the direct seeding of the species.

For the height, again TBOTH had the higher values among the treatments. The height results of forest soil and forest litter singly was similar, and the sum of the two approximates to the value of TBOTH, delineating an additive effect.

The forest soil theoretically could have promoted emergence of other forest tree species from the seed bank (Reis et al., 2003; Braga et al., 2007). However, no other woody species have emerged through soil transposition in any treatments, which could have been caused by an unfavorable period of the year for the harvest of the soil, and further investigations are needed to validate the soil transposition as an effective method in that ecoregion.

The higher costs of TTOPSOIL and TBOTH treatments are especially due to the litter and forest soil operations. In the TBOTH (the more expensive) the litter addition represented 31% and the forest soil 33% of costs. Both have reached almost 2/3 of the total costs. The seed purchasing and soil preparation was only 10% and 3% of costs, respectively. The operations of seeding and input addition amounted to 10%, and the maintenance operations were 14% of total costs. If the only contribution of the inputs is nutrient addition,

Table 3 – Average height cm of seedlings of *S. terebinthifolius* as a function of time.**Tabela 3** – Altura média de plântulas de *S. terebinthifolius* como uma função do tempo.

| | Treatments | | | | | |
|----------|------------|--------|---------|----------|--------|---------|
| | CONTROL | TSEED | TLITTER | TTOPSOIL | TBOTH | CONTROL |
| 60 days | 0 | 2.4 b | 2.6 b | 2.8 b | 4.1 a | 0 |
| 90 days | 0 | 2.4 c | 4.4 b | 4.0 bc | 6.6 a | 0 |
| 180 days | 0 | 3.9 c | 15.4 b | 16.7 b | 24.7 a | 0 |
| 360 days | 0 | 5.07 c | 18.4 bc | 21.7 b | 42.0 a | 0 |

letters indicate differences in the Duncan test ($P < 5\%$).

Table 4 – Costs (US\$/ha) for each operation in direct seeding (CONTROL-TBOTH) and seedling planting (SP).**Tabela 4** – Custos (US\$/ha) para cada operação em semeadura direta (CONTROL-TBOTH) e plantio de mudas (SP).

| | CONTROL | TSEED | TLITTER | TTOPSOIL | TBOTH | SP |
|---------------------------------------|---------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Seedlings | - | - | - | - | - | 859.37 |
| Seeds | - | 360.00 | 360.00 | 360.00 | 360.00 | - |
| Soil preparation * | 127.31 | 127.31 | 127.31 | 127.31 | 127.31 | 257.80 |
| Workforce to seeding and planting ** | - | 159.12 | 159.12 | 159.12 | 159.12 | 214.84 |
| Litter gathering ** | - | - | 1,125.00 | - | 1,125.00 | - |
| Forest soil gathering ** | - | - | - | 1,200.00 | 1,200.00 | - |
| Weed control around seedlings ** | - | 254.62 | 254.62 | 254.62 | 254.62 | 343.75 |
| Ant control | 57.28 | 57.28 | 57.28 | 57.28 | 57.28 | 91.66 |
| Formicide | 55.55 | 55.55 | 55.55 | 55.55 | 55.55 | 80.00 |
| Litter and Forest soil application ** | - | - | 190.96 | 190.96 | 190.96 | - |
| Mowing ** | - | 127.33 | 127.33 | 127.33 | 127.33 | 114.58 |
| Results | | | | | | |
| Total costs | 240.15 | 1,141.23 | 2,457.20 | 2,532.20 | 3,657.20 | 1,897.64 |
| Density (seedlings/ha) after one year | | 600 | 1,600 | 3,000 | 9,000 | 2,108 |
| Cost of survival seedling | - | 1.90 | 1.54 | 0.84 | 0.41 | 0.90 |

Mechanical work = values calculated in hour/machine (HM).

Manual workforce = values calculated in man/day (HD).

other less expensive sources of nutrients must be tested. However, forest soil could be a source of mycorrhizae (Requena et al., 2001), and such biological effect needs further investigation.

In spite of the higher costs, TTOPSOIL and TBOTH exhibited the higher density of seedling, which was higher than the seedling planting. On the other hand, the cost per seedling was the lowest to the TBOTH. Considering that the densities of seedling in the treatments TTOPSOIL and TBOTH were excessive (3,000 and 9,000/ha, respectively), a reduction of inputs could produce a reduction of costs, optimizing the use of additives.

Engel and Parrotta (2001) had observed implantation values (including maintenance in the first two years) between US\$ 1,054 and 1,287 (updated values to 2011 according to the Consumer Price Index), where the major costs were seeds acquisition (US\$ 257) and workforce for the seeding operation (US\$ 165 to 231). The costs reported by these authors are similar to the costs of

TSEED treatment. However, the costs reported by Engel and Parrotta (2001) refer to the two first years and the seedling density obtained was not informed, making difficult the comparison.

The number of seedlings produced from the total seeds ranged between 0.6% (TSEED) and 9.0% (TBOTH). As a general rule, less than 10% of the seeds of tree species produce seedlings in direct seeding after one year except for species with big seeds (> 1.0 g) (Camargo et al., 2002; Araki, 2005; Escaio et al., 2012). To *Enterolobium contortisiliquum*, Engel and Parrotta (2001) reported 18% of seeds that resulted in seedlings after two years, which could be considered an exceptional outcome. In spite the low rates of early survival, the direct seeding of *S. terebinthifolius* could be used as a method of enrichment in degraded areas where the spontaneous regeneration is in initial phase and a faster colonization would be not decisive for inhibit growth of weeds.

5. CONCLUSIONS

The direct seeding could be considered viable for *S. terebinthifolius* but not for *C. solanaceum* without further studies on the germination viability of the second species.

The forest soil could be used as an additive with forest litter instead of singly; further studies could investigate the optimal amount of inputs to minimize the costs.

The costs of each survivor seedling of *S. terebinthifolius* were higher for the direct seeding without inputs and were reduced by the inputs addition.

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