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Direct seeding reduces costs, but it is not promising for restoring tropical seasonal forests

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ABSTRACT

Direct seeding is a potential technique to restore forests; however, further studies are needed before its application on a large scale. We carried out a field experiment in a deforested area in southern Brazil to test the technical and economic feasibility of a direct seeding system with high tree species diversity to restore the tropical seasonal forest. We also compared species performances and tested the effects of seed size and successional group on tree seedling emergence and development. The trial was established at two different sowing times using 31 tree species. For two years after sowing we evaluated seedling emergence, establishment, survival and early growth of tree species, weed competition and costs for plantation establishment and early maintenance. Most species had low seedling emergence and establishment, but high survival rates, implying that low seedling emergence is the main barrier to community assembly that must be overcome. The most successful species had larger seeds, belonged to non-pioneer categories and had slower growth rates. Final costs after two years were lower than has been reported in the literature for most restoration planting using seedlings both in Brazil and elsewhere; however, seedling density was low. Although direct seeding may be a feasible alternative to decrease planting costs, the poor species performances and low seedling density may reduce its applicability. Thus, we recommend direct seeding only in association with the planting of pioneer species seedlings.

1. Introduction

Most methods of tropical forest restoration use high diversity plantings of nursery-raised seedlings, which has been the predominant approach in Brazil (Durigan et al., 2013; Rodrigues et al., 2009a; Sampaio et al., 2007) and many other tropical regions (Lamb et al., 2005). However, in many circumstances these approaches are too costly to be adopted at the large scales needed (Lamb et al., 2005). Techniques are required that kick-start natural succession and ecosystem development at a low cost and with minimal inputs, to ensure ecosystem resilience and stability, providing direct benefits for mankind (Engel and Parrotta, 2008).

A possible pathway to ecological restoration is the direct seeding technique, where seeds of forest species are sown directly on the site, instead of being outplanted as nursery-raised seedlings (Birkedal, 2010; Cole et al., 2011). Direct seeding has been considered a simple, convenient and inexpensive technique that is easily adopted by the owners of small and medium-sized plots (Camargo et al., 2002; Ceccon et al., 2016; Douglas et al., 2007; Engel and Parrotta, 2001; Knight et al., 1998). Nevertheless, many factors will affect the efficacy of the method, such as species and seed characteristics and environmental conditions (Doust et al., 2008; St-Denis et al., 2013; Wang et al., 2011). It is still necessary to improve its efficiency, applicability and effectiveness (Hossain et al., 2014; Pereira et al., 2013; St-Denis et al., 2013).

Many studies have been undertaken to investigate the success of direct seeding in the restoration of abandoned fields (Dodd and Power, 2007; Hooper et al., 2002; St-Denis et al., 2013). Considering that tree species richness of tropical forests is very high, the selection of the right species is essential to ensure that direct seeding can be applied effectively (Tunjai and Elliott, 2012). Furthermore, the lack of information on costs may limit the application of direct seeding systems on a broader scale. To date, only a few studies have analyzed direct seeding implantation and maintenance costs, and all of these focused on systems established with relatively low species richness (Cole et al., 2011; Douglas et al., 2007; Engel and Parrotta, 2001).

This paper investigates the technical and economic feasibility of a manual direct seeding system with high tree species diversity to restore the tropical seasonal forest in southeastern Brazil. We addressed the following questions: a) Is it possible to achieve high seedling density and species diversity using direct seeding? b) Are direct seeding methods more cost-effective than planting nursery-raised seedlings? c) Do seed size and successional group affect seedling emergence,

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Table 1
Soil chemical attributes of the study site (0–20 cm depth).

Depth (cm)	pH	O.M.[a]	Pextractable	H + Al	K	Ca	Mg	BS[b]	CEC[c]	V%[d]
	CaCl2	g/dm^3	mg/dm^3	mmolc/dm^3						
0–5	5.4	35	8	14	2.0	17	7	26	40	65
5–10	5.0	23	6	15	1.4	14	4	19	34	57
10–20	4.7	20	4	17	1.1	11	4	16	33	49

[a] Organic matter.
[b] Base sum.
[c] Cation exchange capacity.
[d] Base saturation.

establishment, survival and growth? d) How do the native species sowed differ in their field performance and which are most suited for direct seeding projects in the region?

2. Materials and methods

2.1. Study site

A direct seeding trial was established in an abandoned pasture located on a property within the campus of the São Paulo State University (UNESP) at Botucatu municipality, in the south-central region of the state of São Paulo (22°50′S; 48°24′W), Brazil. The site was dominated by invasive exotic grasses, mainly *Urochloa decumbens* (Stapf.) Webster and *Panicum maximum* Jacq. (Poaceae), and was situated next to a secondary forest fragment, which was classified as seasonal, semi-deciduous, tropical forest.

The soil is a moderately acidic and leached, sandy Oxisols of very low fertility (Table 1) and prone to severe laminar erosion. The average annual rainfall is 1494 mm, concentrated between October and March (Fig. 1). The mean annual temperature is 20.5 °C, with the minimum average occurring in July and maximum in February (Nogueira Júnior et al., 2011). The local topography is moderately hilly, with elevations ranging from 464 to 775 m.

2.2. Site preparation, maintenance and experimental design

The experiment was established at two different sowing times, January (first sowing time) and November (second sowing time) of 2009. The experimental trial had four replicates (80 m × 20 m), resulting in a total experimental area of 0.64 ha. Each sowing had a different range of species; the first sowing used 14 native forest species and the second one used 17 (Table 2).

The site was prepared one month before the first sowing with one mechanical application of post-emergence, non-residual herbicide (Roundup Original® 5.0 L.ha^{-1}, with the active ingredient glyphosate). After two weeks, the desiccated straw was mown and the sowing lines were prepared using a ripper pulled by a tractor, with 2 m spacing between lines.

For the first sowing time, the seeds were buried in spots manually along the planting lines, with 1 m spacing between spots (three seeds of the same species per spot). For the second sowing time, the seeds were placed evenly in the spots left by the first sowing germination failures. For both sowing times, the sowing depth was approximately 5–20 mm, depending on seed size. No thinning was carried out in cases where more than one seed germinated per spot in order to allow intraspecific competition and natural selection to operate.

The species were grouped into two broad classes: pioneers (typical of early succession phases, fast-growing trees with short lifespans, light-demanding seedlings, small and dormant or orthodox seeds) and non-pioneers (late secondary and climax species, mid to slow-growing trees with longer lifespans, shade-tolerant seedlings, larger and non-dormant or recalcitrant seeds), based on information from the literature (Martins et al., 2009; Silva et al., 2004) and personal observations. In each line, we sowed species belonging to only one group, in this way we had 10 lines per replicate: 5 with pioneer species and 5 with non-pioneer species. The species sequence in each line was randomized and this same sequence was repeated in all lines.

After sowing, weed control consisted of three manual applications per year (beginning and end of wet season and middle of dry season) of post-emergence, non-residual herbicide (Roundup Original® 5.0 L.ha^{-1}, active ingredient glyphosate), to ensure seedling survival and good early growth. During herbicide application, the seedlings were protected with polyethylene containers. Furthermore, ant traps containing formicide (Mirex-S® active ingredient sulfluramid) were set up at selected spots between the lines twice a year (according to visual ant presence) to reduce seed and seedling predation. The weed and ant control was carried out for two years after the first sowing; no further weed or ant control was applied after that period.

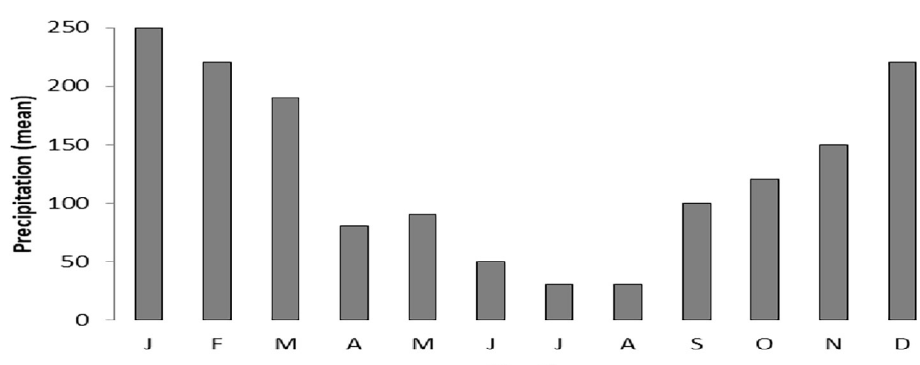

Fig. 1. Monthly precipitation in the study site. Mean precipitation measured from 1971 to 2013 at the Weather Station installed within the campus of the São Paulo State University (UNESP) at Botucatu (22°50′S; 48°25′W). Available on http://estacaolageado.fca.unesp.br/index.html. Accessed December 18, 2017.