Seed characterization and direct sowing of native grass species as a management tool

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Abstract

There is insufficient information about germination, seed biology and seedling establishment of native grass species of the *cerrado* (Brazilian savannah) to recommend their use in restoration of disturbed areas. We evaluated the production, percentage of fertile seeds, germination, seedling growth and establishment in the field of eighteen native grass species and one exotic invasive species (*Melinis minutiflora*) and also the effects of different storage periods on germination. The percentage of fertile seeds varied from 6·0 to 94·2% among native species. Ten species produced a minimum of 800 fertile seeds per gram. Germination rate was in the range of 11·0 to 98·8%. Storage for 1 year reduced the germination rate in one species, did not affect germination of three species and increased germination (by 2–10 times) in 14 species. After 2 years of storage, six species showed reductions in germination. Three different patterns of resource allocation were observed and might provide mechanisms for increasing seedling establishment under different environmental conditions. In the field, only two species flowered in the first year after sowing and an additional eight in the second year of observation. *Melinis minutiflora* is an aggressive species with more than three times the fertile seed production of native species (2820 seeds per gram), high germination rate (55%) and a high number of germinable seeds (1551 per gram). Despite the wide variation in seed characteristics and the delay in flowering, it is concluded that most native grass species can be used in projects aiming at the restoration and management of degraded areas.

Keywords: cerrado, invasive species, germination, restoration, seed storage, Brazil

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Introduction

In recent decades, as a consequence of agricultural and cattle-ranching activities, the Brazilian savannah or cerrado (Allen *et al.*, 2011) has undergone fragmentation of habitats, loss of biodiversity, invasion of exotic species and changes in the fire regime and carbon cycle (Ratter *et al.*, 1997; Klink and Machado, 2005). This situation has increased concern regarding the maintenance of biodiversity and/or the restoration of degraded areas, leading to the development of management techniques that can be easily used to help restore degraded ecosystems (Davies *et al.*, 1995; Murphy and Lovett-Doust, 2004; Zahawi and Holl, 2009) such as direct sowing (Martins *et al.*, 2001; Atkinson, 2009). The use of seeds has been shown to be effective in recovering the species composition and functional groups of the herbaceous vegetation, increasing diversity and controlling exotic invasive species (Moraes and Williams, 1992; Ambrose and Wilson, 2003; Prober *et al.*, 2005; Foster *et al.*, 2007). Characterization and investigation of the attributes of seeds are essential to obtain high-quality seeds for biodiversity management, recovery of degraded areas or production (Carmona *et al.*, 1999; Cole *et al.*, 2005; Prober *et al.*, 2005; Foster *et al.*, 2007).

Close to 300 species of native grasses exist in the cerrado region, and the species of the herbaceous layer represent 60 to 80% of the 12 000 known native species (Mendonça *et al.*, 2008). However, nearly all efforts to restore degraded cerrado areas use only woody plants or exotic grass species such as *Melinis minutiflora* P. Beauv. and *Brachiaria* spp. (Carneiro *et al.*, 2001; Silva *et al.*, 2006; Silva and Corrêa, 2008), mostly because of lack of information on the reproductive phenology of the native grass species (Almeida, 1995; Martins *et al.*, 1997; Munhoz and Felfili, 2005, 2006), their seed production (Carmona *et al.*, 1999), germination (Carmona *et al.*, 1998; Zaidan and Carreira, 2008) and seedling response to the factors that may affect their establishment (soil fertility, precipitation, fire, competition and herbivory), as discussed by Lindsay and Cunningham (2011) and Cole *et al.* (2005).

To evaluate the potential use of seeds of native cerrado grasses in the recovery of degraded areas, this study characterized (i) the number and mass of fertile seeds, (ii) germination, (iii) mean germination time, (iv) seedling establishment of eighteen native grasses and (v) compared their characteristics with those of *M. minutiflora*, an invasive African grass in the cerrado (Pivello *et al.*, 1999; Freitas and Pivello, 2005).

Materials and methods

The study evaluated seeds of eighteen native cerrado grasses: *Andropogon leucostachyus* Kunth, *Aristida recurvata* Kunth, *Aristida riparia* Trin., *Aristida setifolia* Kunth, *Aristida torta* (Nees) Kunth, *Axonopus barbigerus* (Kunth) Hitchc., *Axonopus brasiliensis* (Spreng.) Kuhlm., *Ctenium chapadense* (Trin.) Doell, *Echinolaena inflexa* (Poir.) Chase, *Gymnopogon spicatus* (Spreng.) Kuntze, *Paspalum carinatum* Humb. & Bonpl. ex Flüggé, *Paspalum gardnerianum* Nees, *Paspalum reduncum* Nees ex Steud., *Paspalum stellatum* Humb. and Bonpl. ex Flüggé, *Paspalum trachycoleon* Steud., *Schizachyrium microstachyum* (Ham.) Roseng., B.R.Arrill. & Izag., *Thrasya glaziouvii* A. G. Burman, *and Tristachya leiostachya* Nees; and one exotic species, *Melinis minutiflora* P. Beauv. (APG III, 2009). These species are widely distributed and common in the cerrado (Clayton *et al.*, 2006).

The seeds were collected in the IBGE Ecological Reserve (Reserva Ecológica do IBGE, Instituto Brasileiro de Geografia e Estatística, 35 km south of Brasília; 15°56ʹS and 47°52ʹW). The reserve covers 1300 ha and includes the most common cerrado physiognomies. The climate is seasonal (CWA in Köppen classification) with a well-defined rainy season (October to April). The mean annual precipitation is 1453 mm, and the mean temperature is 21°C (IBGE, 2004).

The seeds were harvested manually from April to June 2008, 2009 and 2010. To ensure the harvest of the largest number of mature seeds, only panicles showing one-third of the seeds already dispersed were collected (Carmona *et al.*, 1999; Scheffer-Basso *et al.*, 2007). The seeds were hand-sorted, stored in paper bags and kept at room temperature (~25°C) until use. For each species, the number of fertile seeds per gram was calculated from five groups of 100 seeds. Each seed was manually tested to verify the presence of an embryo (Brasil, 2009).

Four groups of 100 fertile seeds were used to estimate the germination rate and mean germination time. Seeds were placed in Petri dishes with filter paper moistened with distilled water. The dishes were kept at room temperature under white light with a 12-h photoperiod. The samples were moistened daily or when required. The geotropic curvature of the radicle was used as the germination criterion (Labouriau, 1983), and the number of germinated seeds was counted daily

for 1 month. The same procedures were used to estimate the effect of storage for one and 2 years.

Five days after germination, seedlings were transferred to plastic bags containing a mixture of 0·66 of cerrado soil and 0·33 of sand (Silva and Klink, 1997). The seedlings were kept in laboratory conditions for 1 month and then transferred to a greenhouse until harvest. In the first 2 months, three to five seedlings per species (according to availability) were collected every 15 d. The remaining seedlings were harvested at the end of the third month of growth. To evaluate the allocation of resources, above- and below-ground biomass components were oven-dried at 70°C until constant mass and weighed. Because of the small number of seedlings obtained for *C. chapadense, P. carinatum, P. gardnerianum* and *P. trachycoleon,* these species were not evaluated for the root/shoot ratio.

Field establishment of seedlings was observed in the IBGE Ecological Reserve in an area 5 × 5 m where all vegetation had been removed to prevent competition with adult plants (Silva and Castro, 1989). Soil was removed to a depth of 2 cm, to prevent germination from the seed bank (Andrade *et al.*, 2002). In December 2009, mid-rainy season, a seed mix (4·5 g m^{-2}) composed of seeds of fourteen native grasses (*A. recurvata, A. riparia, A. setifolia, A. torta, Axonopus aureus* P. Beauv., *A. barbigerus, E. inflexa, G. spicatus, P. gardnerianum, P. reduncum, P. stellatum, Paspalum polypyhyllum* Nees ex Trin., *S. microstachyum* and *Schizachyrium sanguineum* (Retx.) Alston.) was sown in the area. The seeds used in the mix were collected between April and August 2009; they comprised 78% of the species that had been tested for germination. The mass of seeds used in the mix was within the range of fallen diaspores per year in cerrado soil (Leal and Oliveira, 1998). Germination, seedling establishment and the time needed for flowering were monitored, at 15-d intervals, in five plots of 0·5 × 0·5 m randomly distributed in the area. All individuals present in the plots at the beginning of the dry seasons (June) of 2010 and 2011 were considered as established.

The data were tested for normality and homogeneity. Because the data violated the normality assumption, Kruskal–Wallis and *a posteriori* Dunn's test ($\alpha = 0.05$) were used. A principal components analysis (PCA) was carried out to explore and highlight the relationships between species and germination, mean germination time, seed mass and number of fertile seeds.

Results

The percentage of fertile seeds ranged from 6·0% (*A. barbigerus*) to 94·2% (*G. spicatus*). Only *A. riparia, A. torta* and *G. spicatus* showed more than 80% fertile seeds; for *A. leucostachyus, A. recurvata, A. setifolia,*

Table 1 Percentage of fertile seeds, number of seeds per gram, germination and potentially germinable seeds per gram (±SD) for eighteen native grass species common in the Brazilian cerrado) and for the exotic invasive grass *Melinis minutiflora*.

Species	Fertile seeds (%)	Fertile seeds per gram	Germination (%)	Germinable seeds per gram
Andropogon leucostachyus	60·6 ± 2·0	1555 ± 242	27·8 ± 8·2	432
Aristida recurvata	63·2 ± 5·1	1898 ± 195	48·7 ± 10·2	924
Aristida riparia	90·4 ± 3·8	858 ± 54	56·7 ± 28·7	486
Aristida setifolia	73·8 ± 4·8	1624 ± 152	11·2 ± 5·6	182
Aristida torta	89·8 ± 3·9	1411 ± 78	53·8 ± 11·2	759
Axonopus barbigerus	6·0 ± 2·0	338 ± 110	95·0 ± 6·0	321
Axonopus brasiliensis	20·0 ± 8·2	349 ± 61	3·6 ± 1·0	13
Ctenium chapadense	75·8 ± 2·5	1517 ± 56	23·0 ± 6·3	349
Echinolaena inflexa	30·2 ± 7·3	137 ± 12	48·2 ± 9·1	66
Gymnopogon spicatus	94·2 ± 2·3	5468 ± 172	32·2 ± 14·2	1761
Melinis minutiflora	15·8 ± 3·3	2820 ± 332	55·0 ± 12·3	1551
Paspalum carinatum	7·8 ± 1·6	424 ± 85	21·2 ± 7·6	90
Paspalum gardnerianum	15·2 ± 5·7	324 ± 77	9·2 ± 6·0	30
Paspalum reduncum	7·2 ± 1·3	594 ± 89	55·0 ± 20·6	327
Paspalum stellatum	21·2 ± 2·7	272 ± 26	68·0 ± 7·5	185
Paspalum trachycoleon	26·6 ± 2·3	1307 ± 85	95·2 ± 10·2	1244
Schizachyrium microstachyum	55·6 ± 2·9	1389 ± 112	98·8 ± 1·9	1372
Thrasya glaziouvii	34·8 ± 3·1	920 ± 52	24·7 ± 1·7	227
Tristachya leiostachya	21·8 ± 4·0	8 ± 1	11·0 ± 5·8	1

C. chapadense and *S. microstachyum,* the range was from 20 to 80%; and the remainder showed <20% (Table 1). *Tristachya leiostachya* had the fewest fertile seeds per gram (eight) and *G. spicatus* the most (5468). Although *M. minutiflora* had a low percentage of fertile seeds (15·8%), the number of fertile seeds per gram was the second highest (2820; Table 1).

The germination rate was higher than 90% only for *S. microstachyum* (98·8%), *P. trachycoleum* (95·5%) and *A. barbigerus* (95·2%). The germinability ranged between 50 and 70% for *A. riparia, A. torta, P. stellatum* and *P. reduncum* and was lower than 50% for the other native species. For *M. minutiflora,* the germination rate was 55·0% (Table 1). Before storage, the longest mean germination time was observed for *A. setifolia* (74 d; Table 2) and the shortest for *A. barbigerus* and *S. microstachyum* (7 and 9 d), similar (*P* = 0·3865) to *M. minutiflora* (8 d).

The species showed different responses to the selected variables: germination, mean germination time, mass of 100 fertile seeds and number of fertile seeds per gram (Figure 1). PCA axes 1 and 2 explained 68·5% of the data variance, and the species were grouped in three sets. The first set included species with high germinability and short germination time (*A. barbigerus*, *P. reduncum*, *P. stellatum*, *P. trachycoleon* and *S. microstachyum*); the second consisted of *M. minutiflora* and *G. spicatus*, the species with the highest fertile seed production and germination values of 55·0 and 32·2%; and the third group included the remaining species with intermediate values for all variables. Also, *T. leiostachya* and *A. setifolia* showed characteristics that distinguished them from the other species. *Tristachya leiostachya* has heavy seeds, low germinability and low fertile seed production, and *A. setifolia* has lightweight seeds and a long germination time.

Seed storage for 1 year did not affect the germination of *A. recurvata* (*P* = 0·1120), *P. stellatum* (*P* = 0·0511) and *S. microstachyum* (*P* = 0·2454). There was a reduction (*P* = 0·0127) in the germination of *A. leucostachyus* and an increase of two to ten times for the other species (Table 2). *Melinis minutiflora* showed a 45% increase in germination. A second year of storage reduced (*P* < 0·05) the germination of *A. setifolia, A. riparia, A. brasiliensis, E. inflexa* and *T. leiostachya* (Table 2), and only *S. microstachyum* showed a lower germination rate than at the year of harvest (*P* = 0·0202, Table 2). *Aristida recurvata, G. spicatus, P. stellatum* and *S. microstachyum* showed rates similar to those found for the first year of storage (*P* > 0·05).

Table 2 Germination percentage values and mean germination time (±SD) for eighteen native grasses of the Brazillian cerrado and for the exotic invasive grass *Melinis minutiflora,* observed after harvest and after one and 2 years of storage.

Species	Germination (%)			Mean germination time (d)		
	Before storage	1 year	2 years	Before storage	1 year	2 years
Andropogon leucostachyus	27·8 ± 8·2a	2·2 ± 1·0b	0·7 ± 0·8b	14 ± 2a	11 ± 1b	13 ± 0a
Aristida recurvata	48·7 ± 10·2a	65·0 ± 14·7a	55·7 ± 3·0a	36 ± 4a	19 ± 2b	15 ± 1b
Aristida riparia	56·7 ± 28·7ab	73·2 ± 6·2a	41·0 ± 6·0b	31 ± 4a	14 ± 1b	11 ± 1b
Aristida torta	53·8 ± 11·2a	77·7 ± 14·2b	60·7 ± 5·5 ab	45 ± 7a	9 ± 1b	12 ± 1b
Aristida setifolia	11·2 ± 5·5a	69·7 ± 3·0b	19·7 ± 8·5a	74 ± 15a	8 ± 1b	9 ± 1b
Axonopus barbigerus	95·0 ± 6·0	–	–	7 ± 1	–	–
Axonopus brasiliensis	3·6 ± 1·0a	38·5 ± 10·7b	3·5 ± 2·7a	36 ± 11a	23 ± 1a	14 ± 1b
Ctenium chapadense	23·0 ± 6·3a	85·5 ± 3·3b	60·8 ± 12·5c	17 ± 1a	12 ± 1b	13 ± 1b
Echinolaena inflexa	48·2 ± 9·1a	85·0 ± 6·5b	21·2 ± 9·8a	19 ± 3a	9 ± 1b	11 ± 1ab
Gymnopogon spicatus	32·2 ± 14·2a	93·2 ± 5·4b	81·5 ± 10·4b	12 ± 6a	5 ± 1b	4 ± 1b
Melinis minutiflora	55·0 ± 12·3a	100·0 ± 14·5b	100·0 ± 15·5b	8 ± 1a	5 ± 1b	10 ± 0a
Paspalum carinatum	21·2 ± 7·6a	47·7 ± 8·7b	28·7 ± 3·5a	17 ± 3a	12 ± 1a	13 ± 1a
Paspalum gardnerianum	9·2 ± 6·0a	55·0 ± 20·0b	11·5 ± 21·6a	17 ± 2a	9 ± 1b	12 ± 2ab
Paspalum reduncum	55·0 ± 20·6a	100·0 ± 22·9b	0c	9 ± 1a	6 ± 1b	–
Paspalum stellatum	68·0 ± 7·5a	53·7 ± 8·0ab	25·0 ± 2·5b	9 ± 1a	15 ± 1b	11 ± 1a
Paspalum trachycoleon	95·2 ± 10·2a	72·7 ± 8·0b	42·5 ± 4·7c	10 ± 1a	8 ± 1b	11 ± 0a
Schizachyrium microstachyum	98·8 ± 1·9a	81·2 ± 15·3ab	77·2 ± 6·6b	9 ± 1a	8 ± 1a	7 ± 0b
Thrasia glaziouvii	24·7 ± 1·7a	47·2 ± 8·2b	0c	12 ± 1a	8 ± 1b	–
Tristachya leiostachya	11·0 ± 5·8a	25·0 ± 7·9b	1·0 ± 2·2c	25 ± 10a	10 ± 2a	14 ± 0a

[ab]The letters represents statistical differences in the variables between the years of storage. Comparisons were made in the same line not between species.
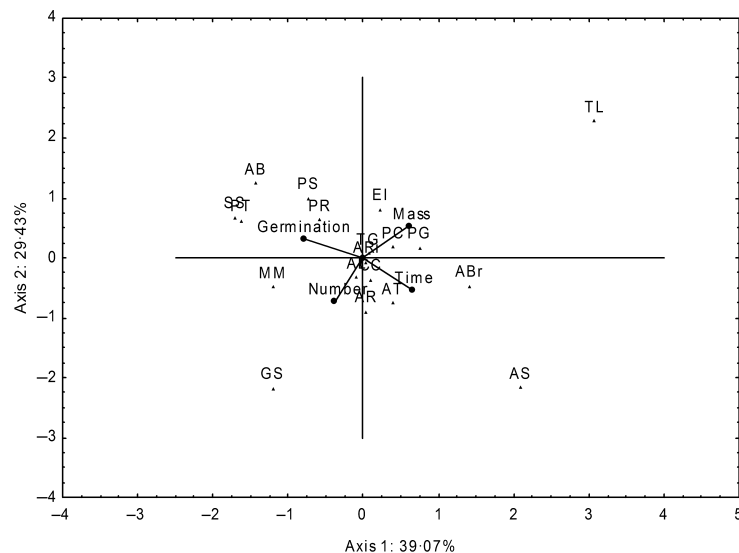
Figure 1 Principal components analysis. Input data were germination (germination), mean germination time (time), mass of 100 fertile seeds (mass) and number of fertile seeds per gram (number). AL, *Andropogon leucostachyus*; AB, *Axonopus barbigerus*; ABr, *Axonopus brasiliensis*; AR, *Aristida recurvata*; Ari, *Aristida riparia*; AS, *Aristida setifolia*; AT, *Aristida torta*; EI, *Echinolaena inflexa*; GS, *Gymnopogon spicatus*; MM, *Melinis minutiflora*; PC, *Paspalum carinatum*; PG, *Paspalum gardnerianum*; PS, *Paspalum stellatum*; PT, *Paspalum trachycoleon*; SS, *Schizachyrium microstachyum*; TG, *Thrasia glaziouvii*; TL, *Tristachya leiostachya*.
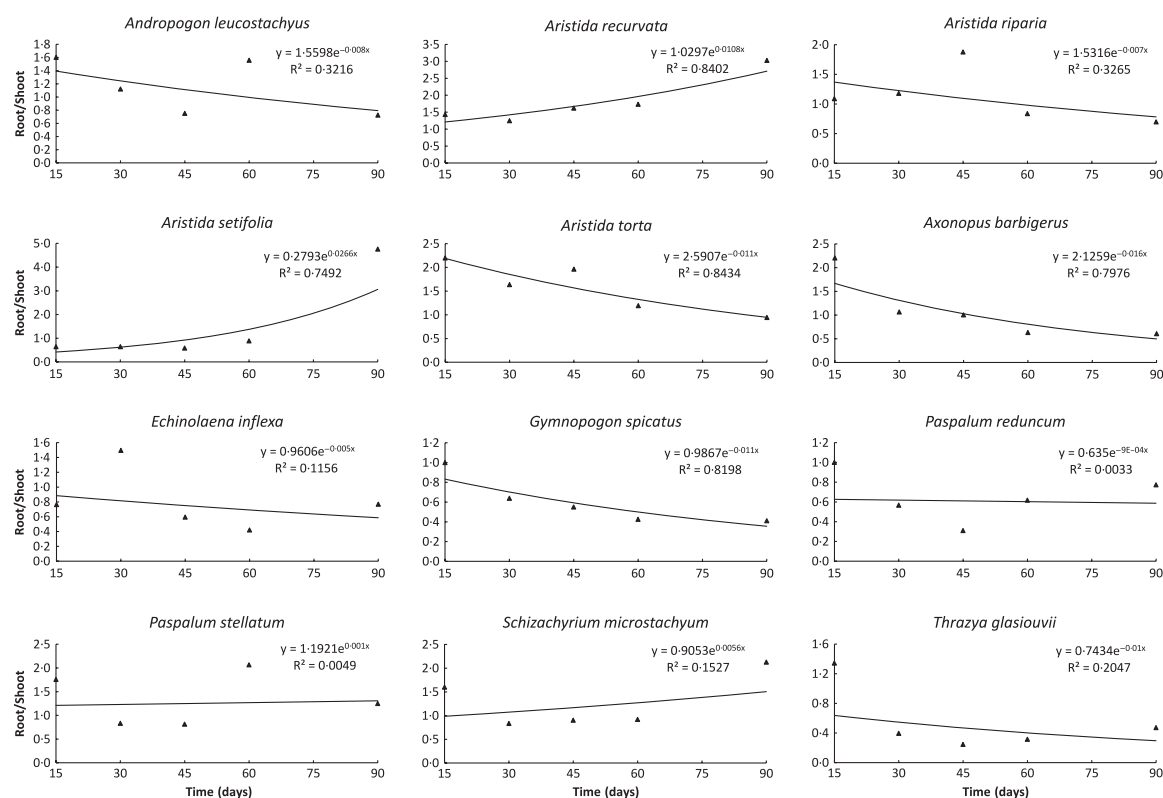
Figure 2 Root/shoot ratio during 90 d for twelve native grass species of the Brazilian cerrado.
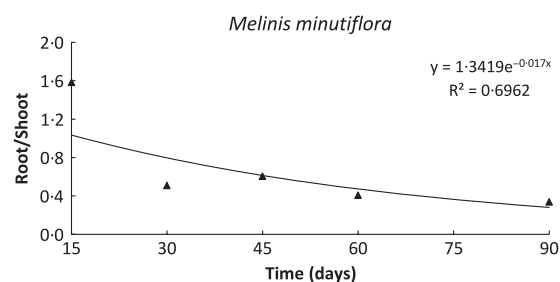
Figure 3 Root/shoot ratio during 90 d for *Melinis minutiflora*, an exotic invasive grass common in the Brazilian cerrado.

Echinolaena inflexa, *G. spicatus*, *P. reduncum*, *T. glaziouvii* and *M. minutiflora* had a higher investment in above-ground biomass (Figures 2 and 3), while *A. barbigerus*, *A. recurvata* and *A. torta* had a larger root mass. No trend in resource allocation was observed for the remaining species (Figure 2).

In the field, germination started 15 d after sowing, and at the end of the first month, the median density of individual plants in the area was 1260 m^{-2}. The density decreased to 672 m^{-2} at the end of the first growing season (May 2010), and *G. spicatus* accounted

for 80% of these. *Gymnopogon spicatus* and *A. setifolia* flowered and dispersed their seeds at the onset of the dry season of 2010. In December 2010, the *G. spicatus* seeds dispersed in the area germinated, and only 112 individuals per square metre reached maturity at the end of the second growing season (December 2010 to May 2011). At that time, the area contained 223 individuals per square metre from the 2009–2010 growing season, and 54 of these flowered. The species that flowered were *A. riparia*, *A. setifolia*, *E. inflexa*, *G. spicatus*, *P. gardnerianum*, *P. reduncum*, *P. stellatum* and *S. microstachyum*.

Discussion

The high production of fertile seeds observed in *G. spicatus*, *A. leucostachyus*, *C. chapadense*, *S. microstachyum* and the *Aristida* species indicates there is an investment directed towards sexual reproduction and better-quality seeds. The lower production observed for the remaining species may be offset by the production of lighter-weight seeds and in higher quantities, as observed for *M. minutiflora*. This is especially true for most of the native species as the mean number of fertile seeds per gram directly compensates for the low

initial germination rates. Together, germination and the number of fertile seeds permit a more accurate prediction of the number of seeds that will potentially germinate (Table 1) and establish. *Melinis minutiflora* is an invasive species with a high number of seeds (Barger *et al.*, 2003; Martins *et al.*, 2009); however, considering the number of germinable seeds per gram (Table 1), the value obtained (1551) was lower than the estimate for *G. spicatus* (1761). This strategy is reinforced by the high number of *G. spicatus* seedlings that become established in the field after the first rainy season. Similar values of germinable seeds to that of *M. minutiflora* were also reached by *S. microstachyum* and *P. trachycoleon*, although with higher germinability and lower seed production (Table 1).

Along with high germination and production of fertile seeds, rapid and homogeneous germination reflects a strategy of immediate occupation of space. In the field, germination began about 15 d after sowing, and the maximum density of seedlings was observed after 30 d, matching the germination time found in the laboratory for most of the species. However, the initial delay in germination after imbibition, as observed for *A. setifolia*, prevents germination after occasional precipitation events that would lead to the rapid drying of the soil surface and consequently to high seedling mortality (Bell *et al.*, 1995; Scott *et al.*, 2010).

The number of fertile seeds, mean germination time, seed mass and germinability act together, forming distinct strategies for the species studied. The PCA showed the most influential variable for each species (Figure 1). *Melinis minutiflora* and *G. spicatus* showed a similar strategy of rapid germination and large numbers of lightweight seeds, tending to an 'r' selection (Pianka, 1970), as a trade-off for low germination or a high percentage of sterile seeds. *Axonopus barbigerus* and *S. microstachyum* have fewer seeds per gram, but higher germination rates, indicating higher seed quality (K strategy). Despite differences in germination rates and seed production, these four species all showed rapid germination, which can be associated with their phenology. The reproductive cycle of *A. barbigerus* begins in January, and seed dispersal is finished by October. *Schizachyrium microstachyum* begins flower production at the end of the rainy season (March), and seeds are dispersed at the beginning of the next rainy season in September (Almeida, 1995; Martins *et al.*, 2004). The flowering and seed dispersal of these species in the experimental plot support the hypothesis that seed dispersal at the beginning of the rainy season, together with rapid germination, characterizes a strategy of space occupation. In contrast, *T. leiostachya* produces few large seeds, with a low germination rate. These characteristics suggest that sexual reproduction is not its principal propagation mecha-

nism, although there is no information to support this hypothesis (França *et al.*, 2007). *Aristida setifolia* showed a fourth strategy: lightweight seeds with low and slow germination (longest mean germination time), suggesting scattered germination through the rainy season (Veenendaal *et al.*, 1996a).

After 1 year of storage, the species could be arranged by germination rates into three groups: species with decreased germination; species with unchanged germination compared with the values before storage; and those with increased germination rates. The reduction in germination rates could have been caused by loss of viability after storage, as observed for *A. leucostachyus* and *P. trachycoleon*, which indicates that these seeds may germinate immediately after they are dispersed, avoiding exposure to predation (Klink, 1996) and/or pathogens (Melo *et al.*, 2004). Increase in the germination rate may have resulted from dormancy loss (Carmona *et al.*, 1998; Adkins *et al.*, 2002; Borghetti and Ferreira, 2004). Adkins *et al.* (2002) showed that, despite the role of tegumentary (coat-imposed) dormancy in dicots, most tropical grasses show embryo (internal) dormancy with incompletely mature embryos at dispersal, requiring a post-development period for germination to occur. This mechanism is related to germination during more suitable seasons; for example, some species disperse seeds in the dry season, and the seeds then remain dormant until the rain begins, favouring germination and establishment in better conditions (Bell *et al.*, 1995; Veenendaal *et al.*, 1996a,b; Scott *et al.*, 2010). Species with unchanged germination rates after 1 year show little or no dormancy and are able to remain viable for longer periods (Zaidan and Carreira, 2008). Although some species are able to maintain high germination rates after storage in laboratory conditions, in field conditions, other factors can affect the viability of the seed bank. Seeds that do not germinate, or remain dormant, are exposed to pathogens, predation and removal by ants (Leal and Oliveira, 1998, 2000; Christianini *et al.*, 2007), factors that can reduce the density of viable seeds and thus favour more transient soil seed banks. The storage data and the cerrado transient soil seed bank (Andrade *et al.*, 2002) indicate that the loss of dormancy occurs between the dry and rainy seasons, with germination occurring at the onset of the rainy season when the conditions for establishment are better. On the other hand, the capacity to form a permanent soil seed bank, with 90% of seeds remaining viable for periods as long as 3 years and 40% for 8 years (Carmona and Martins, 2010), is one of the characteristics that benefits the invasive species *M. minutiflora*.

Considering that harvested seeds are not always used immediately, viability for longer than 1 year is important when choosing species for use in sowing,

seedling production or ecological restorations. In this group, *A. setifolia*, *G. spicatus* and *P. reduncum* can be recommended. Seeds that remain viable for 2 years are also recommended to reduce harvest and processing costs, allowing their use with high benefits during longer time intervals in studies aiming to revegetate large areas. Species that show a loss of germinability in less than 1 year (Table 2) are indicated for use in studies that aim for an immediate management, with increase in diversity, or during a period when the germinability is still high.

Three patterns in resource allocation were observed: (i) higher shoot biomass, (ii) higher root biomass and (iii) undifferentiated resource allocation. Considering that these species can occur in the same communities, resource allocation may be more related to phenology and seed characteristics. Steinaker *et al.* (2010) observed a temporal difference in biomass allocation in grass species in southern Canada. These species invest mainly in shoot biomass, and after 2–4 weeks, the allocation changes to the root portion. A similar pattern was observed for five of the thirteen species studied here, including the invasive *M. minutiflora*. Three species showed a main root resource allocation, and the remaining ones showed an undifferentiated allocation. Higher shoot investment in early development may be directed to avoid light competition. Other studies have shown that although light competition affects establishment, root competition plays a fundamental role for grass species because it involves a large number of resources, including water and at least twenty essential mineral nutrients (Snaydon and Howe, 1986; Silva and Castro, 1989; Casper and Jackson, 1997). *Aristida setifolia* and *G. spicatus* were the only species that produced seedlings in the experimental plot in both years of field observation. This may be associated with initial resource allocation to shoots (Figure 2) and directed to flowering and seed production after shorter periods than in the other species. About 57% of the species flowered only in the second year after sowing, indicating that initial investment mainly in roots favours establishment prior to reproduction. However, this late flowering also renews the soil seed bank and starts a natural revegetation process of the herbaceous vegetation.

Conclusions

The results presented indicate that there is potential for some native grass species to be used for restoration of degraded areas, due to their high seed production and high germination rates, as observed for *Aristida riparia*, *Axonopus barbigerus*, *Gymnopogon spicatus* and *Schizachyrium microstachyum*. The results of the study reinforce the importance of direct sowing of *G. spicatus*

and *A. setifolia* for successful restoration, due to their different strategies of resource allocation and more rapid growth, seed production and space occupation, compared with *Melinis minutiflora*.

Acknowledgments

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