Short Title: Short title: *Melinis minutiflora* seed rain

Seed rain of molasses grass (*Melinis minutiflora*) in the Cerrado

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Abstract

Seed rain is an important pathway for the introduction, maintenance and expansion of invasive species. In Brazil an important invasive species is molasses grass *Melinis minutiflora* (P. Beauv.) and to quantify the importance of primary dispersal we collected seed rain of *M. minutiflora* in three consecutive years in four different treatments in a Cerrado community of Central Brazil. Two control treatments were used in plots of native Cerrado, the first in areas with low coverage of *M. minutiflora* (LC) and the second (HC) under tussocks of *M. minutiflora* (HC). The third treatment was in plots that were burned once in and then allowed to naturally recover (FM) and the fourth treatment was in plots that were burned once and then maintained free of regeneration of *Melinis* through topical spraying with a herbicide and manual removal of new sprouts (IMM). Seed rain of *Melinis* was collected using plastic trays placed on the ground in each treatment (N = 16 in each treatment) at three dates during the dispersal period of *Melinis*. The initial coverage of *M. minutiflora* in the study area was approximately 50% varying between 13 and 75% in different plots. Seed rain was variable between years ranging from 856 to 23059 viable caryopses/m2. There were significant differences in the number of viable caryopses collected in each treatment, both among collection dates within the same year (F =) and treatments (F =) with a high variability among collection trays in all collections. The FM plots had a large reduction in seed rain in the first year but attained values similar to the LC plots after two years. The IMM plots had most no viable caryopses on all collection dates. The percentage of fertile caryopses was approximately 30% in all collections. The data indicated that dispersal limitation was high in all treatments so primary dispersal is probably not the cause of extensive spread of this invasive species.

Key Words: biological invasion, Brazil, seed dispersal

Management Implications

Melinis minutiflora has been considered to be a highly invasive species in conservation areas in Brazil, but there have been few studies on its capacity to colonize new areas. This study indicates that this species has strong primary dispersal limitation and as such has limited capacity to spread from areas where it is established although once established it produces a large quantity of viable caryopses. The use of a single fire to control *M. minutiflora* does not appear to be effective as a long-term strategy but the use of herbicides combined with cutting should be effective in the reduction of its density and persistence in the plant community.

Introduction

Seed dispersal has been studied in many plant species in many different communities (Schupp et al. 2010). Different vectors are important in seed dispersal, ranging from wind to animals, and the shape, weight, and location of the seed on the plant has an influence on the probable type of vector (Tamme et al. 2014; Thomson et al. 2011; Willson and Traveset 2000). Measurement of the dispersal distance of seeds or diaspores in natural communities is not an easy task and has been done through direct or indirect methods, see Bullock et al. (2006) for a review of methods. Some authors have constructed mathematical models to compare actual and theoretical distributions (for example, Adams et al. 2015; Greene and Johnson 1989). The importance of seed rain on plant community assemblage (Myers and Harms 2009; Marteinsdóttir 2014) and in restoration of plant communities (Arruda et al. 2018; Kettenring and Galatowitsch 2011; Schott and Hamberg 1997; dos Santos et al. 2020) have been shown as important lines of research.

Brazil is home to a vast array of plant species and a large number are present in the Cerrado, the second largest biome in Brazil, occupying over 1.8 million km^2. The Cerrado has a rich flora, with more than 12000 taxa, distributed in 171 families and 1454 genera (Mendonça et al. 2008). However, studies of dispersal of Cerrado fruits and seeds are relatively recent and most of these studies have focused on community analyses (Ishara and Maimoni-Rodella 2011; Mariano et al. 2019; Olivera and Moreira 1992; Reis et al 2012; Silberbauer-Gottsberger 1984; Vieira et al. 2002) although there are some studies on individual species (Farias et al. 2015; Golin et al. 2011). The dispersal strategies of Cerrado species has also been recently evaluated from an evolutionary standpoint by Kuhlmann and Ribeiro (2016).

Over the last several decades, the scientific community has shown increasing preoccupation with biological invasions (Latombe et al. 2017; Simberloff et al. 2013) and invasions by plants or animals have caused significant alterations to natural ecosystems (see revisions by Ehrenfeld 2010; Sharma et al. 2005; Vilà et al. 2011; Williams and Baruch 2000). Brazil is no exception and in several conservation areas the invasion by alien grasses, especially molasses grass (*Melinis minutiflora (P. beauv.)*)*, signal grass* (*Urochloa) decumbens. Staph. R Webster*), and jaraguá (*Hypharrenia rufa* (*Nees*) *Staph*) has been considered to be a serious threat to the diversity of these areas (Damasceno et al. 2018; Klink and Machado 2005; Pivello et al. 1999; Sampaio and Schmidt 2013). These grass species were introduced into Brazil in commercial ventures for forage or accidentally and according to some authors (Baruch et al. 1985; Pivello et al. 1999) due to their highly competitive ability have been able to spread. DiVittorio et al. (2007) showed that dispersal was important in the maintenance of several exotic species in a temperate grassland. Other studies on the dispersal of invasive grasses have been done by Quinn et al (2011) and Saura-Mas and Lloret (2005).

Previous studies *Melinis minutiflora* in Brazil have been done with different objectives. These studies include competition (Zenni et al. 2019), control methods (Martins et al. 2017; Sato et al. 2015), effect of fire (Damasceno and Fidelis 2020; Gorgone-Barbosa et al. 2020), forage quality (Bauer et al. 2008; Gomide et al. 1969), germination and seed quality (Carmona and Martins 2010), growth and productivity (Eller and Oliveira 2017), impacts on the surrounding plant community (César et al. 2014; Hoffmann and Haridasan 2008), reproduction (Silveira and Moraes 1996), and species distribution models (de Souza et al. 2017; Sciamarelli et al. 2011) among others. However, to our knowledge, there is only one other study quantifying dispersal of caryopses of *M. minutiflora* either in the Brazilian Cerrado or elsewhere in the world (Xavier et al 2021).

The objectives of this three year study were: 1) to quantify seed rain of *M. minutiflora* in a Cerrado community, 2) compare seed rain of *M. minutiflora* among years, 3) to evaluate if there were differences in the percentage of fertile caryopses of *M. minutiflora* in the seed rain during the same year and between years, 4) to evaluate the effect of different management techniques on seed rain of *M*. m*inutiflora* and 5) to calculate dispersal limitation.

Materials and Methods

Site description

The study area (15º 43' 53.3"S and 47º 55' 35.4"W) is located in Special Use Zone of the National Park of Brasilia, Brasília, DF, Brazil. The regional climate is the Aw type with rainy summers and dry winters. The study area is rectangular (50 x 70 m), subdivided into four blocks each containing six 10 x 10 m plots with a 1 m buffer zone between adjacent plots. For a detailed description of the study area and treatments applied in each plot see Martins et al. (2017).

Data collection

The aboveground coverage of all vegetation, and specifically *M. minutiflora,* in the study area was visually estimated in April 2003, April 2004 and April 2005. In each 10 x 10 m plot coverage data were collected in 15 quadrats (1 x 1 m), placing 5 quadrats along each of 3 parallel lines. Using the lower left corner of the plot as the origin the starting point of each line along the base line was determined using a random number table (min = 0 and max = 9) and the position of the five quadrats along each line was also determined using a random number table (min = 0 and max = 9). The position of the lines and the quadrats used for estimation of aerial coverage was variable among plots and among years.

Seed rain of *M. minutiflora* was collected in 16 of the 24 plots in the study area (Fig. 1). Seed rain was collected using open topped plastic trays measuring 28 x 18 x 5 cm (504 cm^2 of collection area) placed on the soil surface. The raw values can be converted into the number per m^2 by multiplying the raw value by 19.84. The bottom of the trays was not perforated. Four trays were used in each plot where collection of seed rain was done. Two types of control plots were used and placement of the seed collection trays in these plots was subjective. In four control plots (LC = low coverage) the trays were placed in areas where *M. minutiflora* was not present or with few nearby individuals (> 1 m distant). In the other four control plots (HC = high coverage) the trays were placed underneath tussocks of *M. minutiflora.* In the Fire May plots (FM) and the IMM plots (IMM) the trays were placed equidistantly along a straight line connecting two opposite corners of the plot from the lower left to upper right. The FM plots were burned in May 2003 and then allowed to regenerate naturally. The IMM plots were also burned in May 2003 and were maintained free of regeneration of *M. minutiflora* by spot spraying with glyphosate (Roundup®, 480 g ai L^{-1}, Monsanto) in January and April 2004 and manual removal of any new individuals or resprouts from January to March 2005.

Seed rain was collected in 2003, 2004 and 2005 during the dispersal period of *M. minutiflora* and the location of all trays was the same in each year both in the control plots and in the FM and IMM plots. In all years the trays were placed in the field on May 2nd prior to flowering of *M. minutiflora* in this region except for the FM plots when the trays were placed three days after passage of the prescribed fire (May

5th 2003). The IMM plots were burned on May 6th 2003, but seed rain was not collected in these plots during 2003. Within each year, three collections of the seed rain were made: the first (t_1) on July 9th, the second (t_2) on July 23rd and the third (t_3) on September 25th. Although the number of days between each collection date within years was different (t_0 to t_1 = 68; t_1 to t_2 =14; and t_2 to t_3 = 64) the same intervals were maintained among years. On each collection date the contents of each tray were removed and placed in a separate numbered paper bag and taken to the laboratory where all bags were stored at room temperature until processing. The seeds collected from each tray were processed in two stages: 1) caryopses of *M. minutiflora* were manually separated from all other seeds and 2) the caryopses of *M. minutiflora* were then separated into to two groups, fertile (containing caryopses) and non-fertile (without caryopses) using a General Seed Blower following the procedure described in Carmona and Martins (2010). After separation the number of seeds of *M. minutiflora* in each group was counted. Viability of the caryopses was not tested. Dispersal limitation based on the number of fertile caryopses that were collected in the trays over the entire collection period within the year for each treatment in each year was calculated following Xavier et al (2021).

Statistical analyses

Comparisons of data on the coverage values was done using the mean value of the 15 values obtained in each plot for all vegetation and separately for *M. minutiflora*. Comparisons among percentages of coverage were done using PAST 4.0 (Hammer et al. 2000). No transformation of the data was done prior to this analysis. Comparisons of seed rain was done using only data for fertile caryopses, as was done by Forcella et al. (1996). Since tray placement was different among treatments, analyses of annual variation was done only using data from the LC and HC plots (objectives 1 and 2) and comparison of treatment effects were done between the FM and IMM plots (objective 4). These data were analyzed in the R environment. A Generalized Linear Model (GLM, with Poisson and Identity function) was used to answer questions about the number of viable seeds. A GLM model with binomial distribution was used to test for differences of viable caryopses among treatments (objective 3). Prior to analysis of coverage the values were arcsine transformed.

Results and Discussion

Dispersal of caryopses of Melinis minutiflora

Previous studies have indicated different modes of seed dispersal in *M. minutiflora.* D´Antonio et al. (2001) states that dispersal of *M. minutiflora* is anemochoric and this mode is also indicated by Hauser (2008) and CABI (2020). However, Barger et al. (2003) affirmed that since *M. minutiflora* does not possess a strong dispersal mechanism such as a plume for wind dispersal its ability to colonize new areas is limited. There are no studies on terminal velocity of any species in the genus *Melinis*, but Stokes (2010) under laboratory conditions collected data on distances of wind dispersal of *M*elinis *repens*, a congeneric species, and even at the highest velocity used the mean distance traveled by *M. repens* seeds was only around 1.5 m. Considering that caryopses of *M. minutiflora* are slightly lighter than those of *M. repens* (Ansong and Pickering 2016) the mean distance traveled would probably would not be much greater. Silberbauer-Gottsberger (1984) considered that epizoochory is the dispersal mechanism of *M. minutiflora* and this is also reinforced by data from Ansong and Pickering (2016) who showed that seeds of *M. minutiflora* were retained on different types of fabrics. Endozoochory is probably not an important factor in dispersal of *M. minutiflora* as was shown by Gardener et al. (1993).

Coverage

All plots initially contained a variable mixture of native Cerrado vegetation and *M. minutiflora.* Prior to the start of data collection, the mean total aboveground coverage in all 24 plots varied from 87 to 98% (94.9±2.65) and the percentage of *M. minutiflora* in the total varied from 13 to 75% (47.75±18.20). There was no statistical difference between the median total coverage in the subset of 16 plots used in this experiment and the other 8 plots (U =60, p =0.824) and the median coverage of *M. minutiflora* was also not statistically different between these groups (U = 43.50, p = 0.220). Over the three years the median coverage of *M. minutiflora* in the control plots varied. In the FM plots both total coverage and coverage of *M. minutiflora* declined in 2004 but increased in 2005. In the IMM plots total coverage followed the same pattern as in the FM plots, but coverage of *M. minutiflora* was reduced after one year and was almost eliminated after two years (Fig. 2).

Seed rain of M. minutiflora

Different methods have been tested to quantify seed rain (for example, see Bullock et al. 2006; Chabrerie and Allard 2005; Forcella et al. 1996; Koelmann and Goetze 1998). The traps used in this study are larger than those generally used in studies of seed rain but are similar in size to those used by Saura-Mas and Lloret (2005). This type of trap has the advantage of being simple and easily replicable but also the disadvantage of possibly being affected by environmental factors, principally wind, rain and the possibility of seed removal by animals. In this study the farthest distance of a tray to the nearest potential seed source of *M. minutiflora* was approximately 6 m for trays near the center of the FM and IMM plots. Seed rain of *M. minutiflora* in the LC and HC plots was always statistically different (   ) as was expected from the placement of the traps but both treatments had the same pattern among years with a slight decrease in absolute number between 2003 and 2004 and a larger decrease in 2005 (Tab. 1). Interannual differences in seed rain have also been shown in different species in other studies (Pilipavičius 2006; Urbanska and Fattorini 2000; Webster et al. 2003). The observed decrease in seed rain of *M. minutiflora* apparently was not associated with differences in rainfall since there is no clear relation with accumulated rainfall in the January to April period, 620.7, 1055.3 and 820.6 mm respectively (INMET 2019) at the nearest automatic meteorological station (≈6.5 km). This time period was chosen since it covers the interval from the middle to the end of the rainy season prior to flowering of *M. minutiflora*. The accumulated rainfall over the seed rain collection period (May to September) was also variable among years (135.6, 7.4 and 65.7 mm respectively). Small scale spatial variation in seed rain between trays within the same plots was high in all collections as was indicated by the values of the coefficient of variation in all collections, generally over 100%, even in the HC plots.

Seed rain of fertile caryopses of M. minutifora

Seed rain was spatially variable over time within each year when compared by evaluating the number of trays with and without fertile caryopses at each collection date. Fertile caryopses were collected in all of the trays in all the collection dates only in the HC plots. In the LC plots almost all of the trays had fertile caryopses in the first and second collection but in third collection less than half of the trays contained fertile caryopses. In September 2003 the FM plots had a higher number of empty trays than in 2004 and 2005 in this treatment. In the IMM plots, the September collections were always lower from the other two in this treatment. In each year the total number of traps with fertile caryopses always decreased during the dispersal period except for the traps in the HC treatment which always had fertile caryopses.

Insert analyses?

Apparently the majority of fertile caryopses of *M. minutiflora* were collected close to the seed source. This is similar to results reported by Saura-Mas and Lloret (2005) in their study of pampas grass (*Cortaderia selloana* (Schult. & Schult.f.) Axch. & Gordon) where the majority of seeds were collected within 0.5 m of the focal individuals. The majority of dispersed seeds of the annual grass, *Vulpia ciliata ssp ambigua (Le Gall) Stace & Auquier*, were also collected close to the source plants (Carey and Watkinson 1993). A study by Quinn et al. (2011) with two species of the grass *Miscanthus* showed that the majority of seeds were collected within 5 m of the source, but in their study seeds were released at 1.75 m above the ground, approximately 1 m higher than the average height of *M. minutiflora*, and seeds of *Miscanthus* are better adapted for wind dispersal than those of *M. minutiflora*.

Differences in percentage of fertile caryopses of Melinis minutiflora

Caryopses of *M. minutiflora* are formed synchronously (Loch and Souza 1999) and apparently can remain in the seedheads for several months. Although there are previous studies of the percentage of fertile caryopses in collections of *M. minutiflora* (Aires et al. 2013; Carmona and Martins 2010) there are no previous studies of differences of percentages of fertile caryopses in the seed rain of *M. minutiflora* over time within the same year. This study shows that fertile caryopses remain in the seedheads and that dispersal their dispersal is possible during several months after flowering and production of seeds although the vast majority are dispersed near the onset of the dispersal period. The maintenance of fertile seeds over time in seedheads has been reported for other invasive plant species and has been suggested for use in control measures (Bitafaran and Andreasen 2020; Walsh and Powles 2014). The retention of seeds aboveground by *M. minutiflora* would result in a reduction in seed rain and consequently the seed bank in the soil if the area was burned prior to their release. There was a reduction in the percentage of dispersed fertile caryopses over time within the same year, with a higher percentage collected near the beginning (33%) than at the end (23%) of the dispersal period ($H = 11.66$, $p = 0.003$) (Tab. 2). The percentage of fertile caryopses was statistically different among treatment, 27.8% in the LC plots, 35.6% in the HC plots and 27.0% in the FM plots ($H = 10.96$, $p = 0.004$). The percentage of fertile caryopses in the first collection date is comparable with other data on seed quality presented by Carmona and Martins (2010) who reported a range of values of fertile caryopses from 17.5 to 36.1% for seeds of *M. minutiflora* collected in three different sites in the Federal District of Brazil in June of 2004 and by Martins et al. (2019) for different sites in Brazil. However, the values in this study are slightly higher than those reported by Aires et al. (2013) for percentage of fertile caryopses of *M. minutiflora* collected in May and June in another preserved Cerrado in the Federal District of Brazil.

Seed rain and differences between management techniques

Analysis Roberto = There was a highly significant difference between the number of viable seeds in the FM and IMM treatments.

Comparing the FM and IMM plots in 2004 and 2005 the seed rain was always significantly lower in the IMM plots. The results of the GLM indicated highly significant differences between the FM and IMM treatments. The LC and FM plots had intermediate values compared to the HC and IMM plots but were statistically different only in 2003.

Dispersal limitation in Melinis minutiflora

The values for dispersal limitation in *M. minutiflora* were variable among years (Table 3) and all values indicated a higher restriction than found by Xavier et al (2021). The highest restriction was in the treatments in the natural areas and under tussocks of *Melinis*. The effect of fire on dispersal limitation was apparent in the first year of data collection but increased in subsequent years. Although the number of seeds reaching the trays in the IMM treatment was very small (< 5% of the values in the natural area) dispersal was occurring. Among the three collection dates within the same year, the values for dispersal limitation always decreased from the first to the last collection which might be related to increasing mean wind velocity over this period (Maggiotto et al 2013).

The presence of fertile caryopses in the FM plots in 2003 and in the IMM plots in 2004 and 2005 indicates that dispersal of caryopses of *M. minutiflora* is possible over distances of at least 6 m since there were no reproductive individuals within these plots. If all the fertile caryopses collected in the IMM plots in 2005 germinated this value was within the lower range of germination of *M. minutiflora* found by Sato et al. (2015) in areas that were subjected to annual mowing. Thus, our data support their suggestion that annual mowing could be an effective control measure for *M. minutiflora* since the possibility of reintroduction through seed rain is low.

Fertile caryopses of *M. minutiflora* can remain in the seedheads through the dispersal period although the majority are dispersed shortly after formation. The importance of tussocks of *M. minutiflora* for maintenance of its presence of was shown by the large difference in seed rain between the LC plots and the HC plots. Our results indicate that short distance dispersal is possible since there were fertile caryopses present in the trays in the IMM plots where the coverage of *M. minutiflora* was almost eliminated. However, we do not believe that primary dispersal is an important factor in a rapid spread of *M. minutiflora* as can be observed in the values of dispersal limitation. Thus, our data support the affirmation by Barger et al. (2003) that since *M. minutiflora* does not possess a strong dispersal mechanism such as a plume for wind dispersal its ability to colonize new areas is limited.

Author contribution. CRM designed the experiment and collected the data. RBC did the statistical analyses in the R environment. All authors contributed to writing and discussion of the text.

Acknowledgements

To the Instituto Chico Mendes de Conservação da Biodiversidade and the Parque Nacional de Brasilia for authorization to perform this study

Funding

To WWF/Brazil (Project BTZ-NT-614/2002) and The Nature Conservancy Brazil (Donation No. 020/03) for financial support.

Competing Interests

The authors declare none.

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~~Table 1. Accumulated rainfall in Brasília, DF prior to the flowering season (January to April) and during the flowering season (May to September) of Melinis minutiflora in a cerrado near Brasilía, DF (INEMET 2019).~~

	~~January to April~~	~~May to September~~
	~~mm~~	~~mm~~
~~2003~~	~~620.7~~	~~135.6~~
~~2004~~	~~1055.3~~	~~7.4~~
~~2005~~	~~820.6~~	~~65.7~~

Table 1. Mean number of fertile caryopses (Mean ± 1 SD) of *Melinis minutiflora* collected in each treatment (N = 48) in each year in the Brazilian cerrado near Brasília, DF. The values in paretheses are the minimum and maximum number of fertile caryopses in the trays. Data were not collected in the Integrated Management May plots in 2003.

	2003	2004	2005	~~All years~~
Low coverage	163,69 ± 292.3 (0 - 1716)	104.04 ± 138.49 0 - 660	43.17 ± 66.31 0 - 363	~~2056.1 ± 3883.4~~
High coverage	1162,23 ± 1111.72 (22 - 4493)	1060.60 ± 1266.72 51 - 4736	728.15 ± 918.35 6 - 4360	~~19515.8 ± 22140.9~~
Fire May	1,19 ± 1.68 (0 - 6)	132.48 ± 294.19 0 - 1466	174.10 ± 362.60 0 - 1791	~~2121.2 ± 5619.6~~
Integrated Management May	-----	5.52 ± 12.02 0 - 59	4.35 ± 15.76 0 - 106	~~98.0 ± 276.9~~

Table 2. Mean percentage of fertile caryopses of *Melinis minutiflora* (Mean ± 1 SD) collected in the Brazilian Cerrado in each treatment during the entire collection period of each year. The number of trays with fertile caryopses is indicated in parentheses. Data were not collected in the Integrated Management May plots in 2003.

	2003	2004	2005	~~All years~~
Low coverage	27.74 ± 17.61 (48)	28.97 ± 13.94 (47)	23.19± 15.22 (45)	~~0.267 ± 0.158 (140)~~
High coverage	35.60 ± 13.91 (48)	46.25 ± 10.56 (48)	38.20 ± 17.15 (48)	~~0.400 ± 0.148 (144)~~
Fire May	26.98 ± 23.58 (24)	32.14 ± 17.57 (46)	27.67 ± 18.22 (39)	~~0.331 ± 0.502 (112)~~
Integrated Management May	-----	24.83 ± 22.53 (36)	20.77± 20.57 (30)	~~0.229 ± 0.216 (66)~~

Table 3. Dispersal limitation for fertile caryopses of *Melinis minutiflora* in a cerrado near Brasília. DF. The values in parentheses are the number of trays with at least one fertile caryopsis during each year in all three collections (Maximum number is 48).

	2003	2004	2005
Low coverage	0.958 (46)	0.938 (45)	0.896 (43)
High coverage	1.000 (48)	1.000 (48)	1.000 (48)
Fire May	0.689 (23)	0.854 (41)	0.854 (34)
Integrated Management May	-----	0.607 (29)	0.528 (25)

1.1 IMM ▼	2.1 FS	3.1 IMS	4.1 CM ■
1.2 CM ■	2.2 IMS	3.2 CS ●	4.2 FM ▲
1.3 FM ▲	2.3 CS ●	3.3 FS	4.3 IMM ▼
1.4 IMS	2.4 FM ▲	3.4 CS ●	4.4 CM ■
1.5 FS	2.5 CM ■	3.5 FS	4.5 IMM ▼
1.6 CS ●	2.6 IMM ▼	3.6 IMS	4.6 FM ▲

Figure 1. Experimental design of the treatments used for studying *Melinis minutiflora* in the National Park of Brasilia, Brasilia, Brazil (CM = control May. CS = control September, FM = fire May, FS = fire September, IMM = integrated management May, IMS – integrated management September). Each block is 10 x 10 m. with a 1 m buffer zone between blocks. Data on seed rain were collected in the four CS plots in areas with low coverage of *M. minutiflora* (●), in the four CM plots under tussocks of *M. minutiflora* (■), in the four FM plots (▲) and in the four IMM plots (▼), The FS and IMS plots were not used for collection of seed rain.

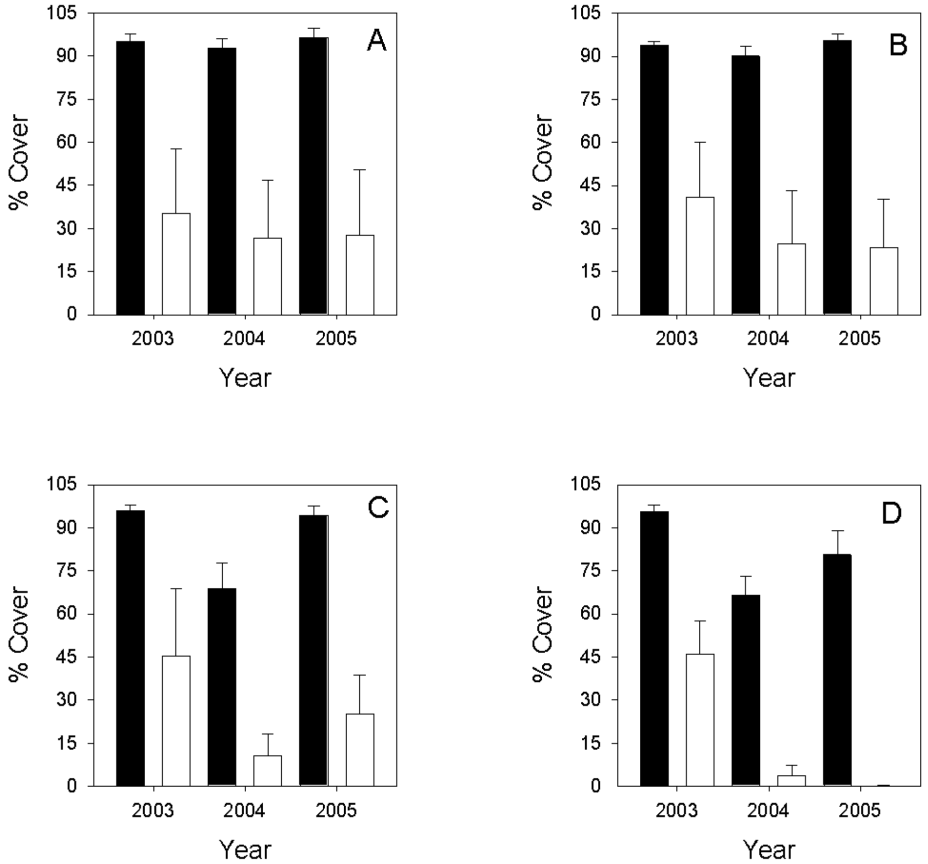

Figure 2. Means and standard deviations for total percent ground cover (filled bars) and percent cover of *M. minutiflora* (open bars) in April of each year in the plots where seed rain of *M. minutiflora* was collected. A = LC plots with trays placed in areas with low coverage of *M. minutiflora*, B = HC plots with trays placed under tussocks of *M. minutiflora*, C = fire May (FM) plots, and D = integrated management May (IMM) plots.