Control of African lovegrass by flupropanate in a flora conservation context

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Article type: Research paper

Word Count: Abstract - 250 Main text (incl. references) - 3332

Number of Tables: 1

Number of figures: 4

Abstract

Context. Managing widespread invasive plants to support biodiversity conservation is a significant challenge in many ecosystems, and requires weed control methods that have acceptable impacts on co-occurring native species. African lovegrass (*Eragrostis curvula*) is a perennial grass that has become invasive in many regions globally. There is a lack of effective control options, particularly in diverse native vegetation where application of broad-spectrum herbicide has risks of unacceptable off-target impacts. **Aims.** We tested the effectiveness of flupropanate (sodium 2,2,3,3-tetra-fluoropropionate) in controlling African lovegrass in a conservation context in Mediterranean-climate south-western Australia, testing two application rates and measuring target and off-target impact. **Methods.** Cover of plant species and their condition (alive or dead) was measured in replicate plots in an 'before-after-control-impact' design. A small sample of endangered *Grevillea curviloba* individuals were deliberately treated with flupropanate. **Key results.** Flupropanate significantly reduced African lovegrass cover, with greater reduction at the higher application rate. No significant off-target effects could be detected at a community (excluding African lovegrass) or plant functional group level nor in the deliberate exposure of *Grevillea curviloba*. However, there was a suggestion of increased mortality in one native species incidentally exposed to flupropanate. **Conclusions.** Land managers in south-western Australia can have confidence that flupropanate will be effective in controlling African lovegrass in conservation contexts, and specifically where infestations co-occur with *G. curviloba*. **Implications.** Evidence of off-target impacts emerging from this and other studies indicates that robust testing of the susceptibility of conservation-listed flora to flupropanate should precede any application in their habitat.

Keywords: grass weeds; selective herbicide; off-target impact; threatened flora; weed management

Introduction

Weed invasions have substantial impacts on biodiversity (Pyšek et al. 2012). Effective control methods are thus needed to address weed threats. In a biodiversity conservation context for the management of widespread weeds, acceptably low off-target impacts of weed control methods are required for management investment to achieve the desired conservation outcomes (Farmillo and Moxham 2023).

African lovegrass (*Eragrostis curvula* (Schrad.) Nees), a long-lived tussock grass with a native range of southern Africa, has become a significant weed globally including in Australia and North America (Roberts et al. 2020). It has been introduced widely through seed contamination and deliberately as a pasture species and for soil stabilization, but has spread further to become a weed in both agricultural and environmental settings (Firn 2009; van Klinken et al. 2017). As a perennial grass using the C4 photosynthetic pathway, African lovegrass grows actively through the warmer months of the year. African lovegrass has the capacity to resprout strongly from the base of tussocks following fire and other disturbances, and its spread is primarily via dispersal of seed by machinery, wind and externally on animals.

The most common method for control of African lovegrass in conservation settings is application of the non-selective herbicide glyphosate, although mechanical removal can be effective for low-density infestations, and preventing spread is also an important African lovegrass management strategy (Firn 2009; Blakely et al. 2022). African lovegrass control in conservation settings is challenging as there are risks of off-target impacts in the use of broad-spectrum herbicides. As an alternative to glyphosate, flupropanate (sodium 2,2,3,3-tetra-fluoropropionate; marketed under several product names) has been demonstrated to be effective for African lovegrass control in some eastern Australian agricultural and environmental situations (Campbell and Nicol 1998). While flupropanate may have potentially less uniform impact on co-occurring vegetation than glyphosate (Campbell et al. 2002), off-target impacts on vegetation ranging from tree seedlings to desirable pasture species have been recorded (McLaren et al. 2008; Lusk et al. 2017; Blakely et al. 2022). Flupropanate has a low contact activity, so it is mainly absorbed into the soil and taken up by plant roots after rain post-application. Flupropanate effectiveness is thought to be dependent on both temperature (acting faster with warmer conditions) and rainfall (requiring wet conditions for activation) (Lusk et al. 2017). Some soil residual effects are typical but may be short-lived (Bourdôt et al. 2017).

African lovegrass is regarded as among the highest impact grass environmental weeds in Australia (van Klinken et al. 2017). African lovegrass is competitively superior to native grasses under a range of environmental conditions and higher African lovegrass biomass is associated with lower richness of co-occurring species (Firn et al. 2010; Firn et al. 2017). In a weed prioritization for the Department of Biodiversity, Conservation and Attractions' (DBCA) Swan Region in south-western Australia, African lovegrass was ranked with high ecological impact and rapid invasiveness (https://www.dbca.wa.gov.au/management/threat-management/weeds). The Swan Coastal Plain, which forms part of the Southwest Australian Floristic Region biodiversity hotspot, supports an exceptional concentration of threatened flora, particularly on the relatively older (late Pliocene–middle Pleistocene) Bassendean sands and Guildford sediments (Gosper et al. 2021a, 2022) on the eastern side of the plain.

Levels of weed invasion are relatively high on the comparatively fertile Guildford sediments (Gosper et al. 2021b), with African lovegrass particularly problematic on the heavier soils typical of this formation. African lovegrass invasion impacts a range of threatened flora including *Grevillea curviloba* (Western Australian conservation status of endangered; Figure 1), *Darwinia foetida* (endangered), *Synaphea* sp. Fairbridge Farm (D. Papenfus 696) (critically endangered), *Synaphea* sp. Pinjarra (R. Davis 6578) (critically endangered) and *Synaphea* sp. Pinjarra Plain (A.S. George 17182) (endangered), and threatened ecological communities, such as *Corymbia calophylla – Kingia australis* woodlands on heavy soils (critically endangered) and *Corymbia calophylla – Xanthorrhoea preissii* woodlands and shrublands (endangered).

The aims of this study were to build on previous research by testing the efficacy of flupropanate to control African lovegrass in a different climatic and land use context, specifically to:

- Determine if flupropanate remains effective in controlling African lovegrass in a strongly Mediterranean climate, where herbicide effectiveness could plausibly be reduced by lower water availability over the warmer months of optimal African lovegrass growth.
- Document any off-target effects on co-occurring native flora when flupropanate is applied to control African lovegrass for conservation outcomes.

Materials and methods

Study site and treatments

An area near Bullsbrook, north-east of Perth in southwest Western Australia, was chosen for the study, having an extensive African lovegrass infestation adjoining and in similar habitat (soils, remnant vegetation) to key threatened flora in which African lovegrass control is required. The site, in a narrow (less than 100m wide) and linear rail easement vested in the Perth Transport Authority and the City of Swan, had been historically cleared of large trees, but retained scattered mature native shrubs, over a mixed ground layer of dense African lovegrass, invasive perennial veldt grass (*Ehrharta calycina*), invasive annual grasses, and native and invasive herbs, geophytes and graminoids.

The experiment was set up as a repeated measures 'before-after-control-impact' design. Three sets of replicate 10 × 10m plots were established and sampled in 2019 prior to application of each of three treatments; a no herbicide control, and a lower (1.5mL L^{-1}) and higher (3.0mL L^{-1}) flupropanate application rate. Plot corners were marked with steel droppers and recorded with GPS. Liquid herbicide (mixed with dye) was applied by a ground-based operator with backpack-based spray equipment as it would be in a management scenario, by targeted spot spray to runoff of live African lovegrass plants. Due to high African lovegrass density, exposure of co-occurring native and other invasive flora to flupropanate was inevitable and because flupropanate uptake is primarily via the roots, even larger shrubs and small trees may have been exposed. Treatments were applied in late spring (November) 2019, when African lovegrass was actively growing (Roberts et al. 2021), with follow-up spot spraying applied as required in November 2020.

Vegetation measurement

At each of the nine plots, species presence and condition (whether the whole plant was alive or dead) were recorded at 200 point intercepts with an 12mm pole distributed 0.25m apart in a grid pattern along five equally-spaced transects across the plot. This technique provided an objective measure of species abundance/cover as the number of intercepts with the species present, either alive and/or dead, out of 200. Any additional species present in the plot but not intercepted were also recorded and allocated a nominal cover value of 0.5. Vegetation measurements were completed in 2019 (pre-treatment), 2020 (~1 year after the first treatment in 2019) and 2021 (~1 year after second treatment in 2020) immediately prior to herbicide application. Consideration was given to normal modes of seasonal growth, so annual species, or annually active species such as geophytes, were regarded as 'alive' in vegetation measurements regardless of whether they had begun to senesce, due to senescing being the expected condition in late spring. Annual or annually active species in the post-treatment samples would have germinated or sprouted after the previous herbicide treatment, so their detection indicates that they were able to grow after treatment of their habitat, with the effect of treatments being assessed through changes in the number of intercepts. In contrast, any susceptibility of above-ground perennial species can be assessed through both changes in the quantity of live and dead intercepts.

Statistical analysis

Cover of plant species was aggregated into functional groups on the basis of growth form (annual, perennial groundcover (grass, herb and graminoid), and woody shrub) and status as native or invasive, using the information from Western Australian Herbarium (1988-2024) (Supplementary Material S1). Functional groupings did not include cover of African lovegrass.

Summed plot live vegetation intercepts (cover) for African lovegrass, invasive annuals, invasive perennial groundcovers, native perennial groundcovers and native woody shrubs were analyzed using the repeated measures ANOVA module in Statistica 7.1 (https://docs.tibco.com/products/tibco-statistica-14-0-0), with a fixed factor of treatment and the fixed repeated measure of sample year (2019, 2020, 2021). Cover of African lovegrass was log_{10} transformed.

Ordination was used to explore changes in species composition over time and with treatments. The cover data were filtered to live touches only, singletons were removed, and separate data files prepared including and excluding cover of African lovegrass. Data were square-root transformed and non-metric multidimensional scaling applied using the Bray-Curtis dissimilarity metric in PRIMER analysis software (version 6.1.11, https://www.primer-e.com/software). PERMANOVA, using a design a fixed factor of treatment, a random factor of site nested in treatment, and the fixed repeated measure of sample year (Anderson et al. 2008), was used to test for differences among herbicide treatments and time.

Targeted exposure of Grevillea curviloba

Grevillea curviloba is one of the threatened flora for which an effective non-broad spectrum herbicide for African lovegrass control would be highly valuable. To test the effect of exposure to flupropanate of *G. curviloba*, three potentially 'sacrificial' plants were sprayed with the high dose 3.0mL L^{-1} liquid flupropanate treatment, with three unsprayed controls. The 'sacrificial' plants were growing along a road verge and are periodically slashed (Figure 1), and hence are artificially maintained in a prostrate growth form. Sample plants were marked by a metal tag attached to a peg inserted into the ground near the base of the plant, and canopy dimensions (north-south and east-west) and condition were assessed, prior to spraying (November 2019) and at 1, 6, 12 and 24 months afterwards.

Results

Application of flupropanate resulted in a significant reduction in African lovegrass cover (Figure 2), demonstrated by a significant time × treatment interaction. The higher application rate resulted in a greater decline in African lovegrass cover in the first year post-treatment, and although a second application further reduced African lovegrass cover at both herbicide rates, the difference between application rates was maintained.

No effects of flupropanate treatment were detected for any of the invasive annual, invasive perennial groundcover, native perennial groundcover or native shrub functional groups (Table 1). For invasive annuals, there was a significant effect of Year, with greater cover in the two post-treatment years. While there were insufficient intercept data and a lack of replication across the sample plots for robust statistical analysis at the species level for native flora, there was a suggestion of an adverse impact to flupropanate in *Desmocladus virgatus* (Figure 3). There was both an increase in dead intercepts and a decline in live intercepts in the first year post-treatment in all flupropanate-treated plots where this species was recorded which was not apparent in the control plot with *D. virgatus*. Live cover of *D. virgatus* recovered somewhat following the second year of treatment.

Flupropanate application had a significant effect on plant community composition when all species were included, as evidenced by a significant treatment × time interaction in PERMANOVA (Figure 4a). In ordination, two of the three control plots remained highly similar in composition across all years, while all flupropanate-treated plots showed a consistent directional shift in location in multivariate space over time associated with lower African lovegrass cover. In contrast, using the same data except for excluding cover of the target weed African lovegrass, there were no significant effects of flupropanate application on community composition (Figure 4b). Plots did vary in composition (significant site nested in treatment effect), and over time, reflected in the associations of the perennial native shrubs *Acacia saligna* and *Xanthorrhoea* sp. and invasive annuals *Bromus diandrus* and *Avena barbata* with the location of sites in multivariate space respectively.

Intentional exposure of three *G. curviloba* individuals to flupropanate did not result in any mortality over the period of sampling, nor any obvious change in plant condition. Similarly, the three control (no herbicide) individuals also survived.

Discussion

African lovegrass was effectively controlled by flupropanate, as has been found previously (Campbell and Nicol 1998), indicating that the strongly Mediterranean climate of the study area did not affect the herbicide's effectiveness. Similarly to Bourdôt et al. (2017) with *Nassella trichotoma*, higher levels of weed control were achieved at the higher (3.0mL L^{-1}) flupropanate application rate. Land managers in south-western Australia can therefore have confidence that flupropanate will be effective in controlling African lovegrass in conservation contexts, and specifically where infestations co-occur with the endangered *G. curviloba*, which was not detectably impacted by deliberate exposure. Flupropanate resistance in African lovegrass has been recorded in NSW (Powells 2022), emphasizing the value of an integrated African lovegrass control program.

As co-occurring flora species were in general either too infrequently encountered or did not occur in most plots, robust statistical analysis of the effects of flupropanate at the species level was not possible, so species were aggregated into functional groups and considered at the community level. There were no significant effects of flupropanate application on non-target groups and at the community level (with African lovegrass excluded), noting these findings refer to the effects of incidental exposure of non-target species to herbicide rather than targeted exposure. The greater cover of invasive annuals in post-treatment years is potentially explained by annual weeds increasing in abundance following African lovegrass control, as has been found elsewhere following invasive perennial grass control with flupropanate (Lusk et al. 2017). However, the increased invasive annual cover in post-treatment years was also found in control plots (no time × treatment interaction), suggesting variable seasonal conditions may be a more parsimonious explanation.

However, there was an indication of increased mortality in *D. virgatus* with flupropanate application, although more robust testing is required for confirmation. *D. virgatus* (Restionaceae) is a rhizomatous, tufted, perennial herb, and as a low-growing plant would readily have been exposed to herbicide applied to co-occurring African lovegrass. As flupropanate application was directed towards observable live African lovegrass individuals, the partial recovery of *D. virgatus* following the second year of treatment could be explained by the high levels of African lovegrass mortality after the initial treatment leading to lower spatial coverage of flupropanate in the second treatment year, and hence a lower probability of *D. virgatus* being sprayed. A potential explanation of the lower cover of dead *D. virgatus* after the second treatment could be that dead *D. virgatus* material from the first treatment year may have decayed to the point of being incorporated into leaf litter. As some off-target effects of flupropanate were likely in this study and have been shown elsewhere (McLaren et al. 2008; Lusk et al. 2017), robust testing of conservation-listed flora's susceptibility to the herbicide should precede any application in their habitat.

DBCA is further testing the effectiveness of flupropanate for control of other weed species of the Swan Coastal Plain and monitoring for off-target impacts on native flora in intact occurrences of two critically endangered threatened ecological communities, *Banksia attenuata* and/or *Eucalyptus marginata* woodlands on the eastern side of the Swan Coastal Plain and *Corymbia calophylla – Kingia australis* woodlands on heavy soils. The investigation of the trajectory of vegetation composition after weed control by flupropanate in native vegetation in good or better condition will be valuable, as in pasture settings replacement of the target weed by other weeds and bare ground has been the (undesirable) outcome (Lusk et al. 2017). In this study, insufficient time had elapsed after treatment to discern any patterns of vegetation change, with the dead thatch of African lovegrass remaining the dominant cover on treated plots.

Supplementary Material - Taxa recorded from plots and their classification into functional groups based on life form and status as native or invasive

Acknowledgements - We thank Anne Harris and David Mitchell for assistance with conceptualization and fieldwork, and Sandra Williamson, Ebony Skey, Megan Young, John Dagnall, Amy Gaunt, Simon Caunter and Alan Jenkins for assistance with fieldwork. John Morrell from Arc Infrastructure and Brad Thompson from the City of Swan facilitated access to the study sites.

Declaration of funding - This project received no specific funding.

Author contributions – All authors conceptualized and designed the study, undertook data collection and revised the manuscript. CRG led data analysis and writing.

Conflict of interests - The authors declare no conflicts of interest.

Data availability - Raw data will be made publicly available through the Department of Biodiversity, Conservation and Attractions' Data Catalogue upon article acceptance. https://data.bio.wa.gov.au/

Permits - The work was conducted under section 40 authorization TFL 106-1920.

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Figure legends

Figure 1. (a) African lovegrass (*Eragrostis curvula*) invasion impacting a population of the endangered *Grevillea curviloba*; (b) habitat of roadside *G. curviloba* plants that were regularly slashed and which were tested for tolerance to flupropanate. Photos: Carl Gosper, Julia Cullity.

Figure 2. Effects treatment with flupropanate (control - untreated; low rate – 1.5mL L^{-1}; high rate – 3.0mL L^{-1}) on cover of live African lovegrass (*Eragrostis curvula*). ANOVA results (in text box) are based on $\log_{10}$ transformed cover values (the number of point intercepts out of 200 with the species per plot), which were converted to proportional cover for graphical presentation. *** P<0.001, ** P<0.01, * P<0.05.

Figure 3. Effects of treatment with flupropanate (control – untreated; low rate - 1.5mL L^{-1}; high rate – 3.0mL L^{-1}) on cover of *Desmocladus virgatus*, showing intercepts with live *Desmocladus* plants (green lines and symbols) and dead *Desmocladus* plants (cyan lines and symbols). *Desmocladus virgatus* was present in 4 of the 9 plots (two in the herbicide low treatment, with these data showing means ± SE) and occurred so infrequently that robust statistical analysis was not possible.

Figure 4. Effects treatment with flupropanate (▼ control - untreated; ▲ low rate – 1.5mL L^{-1}; ■ high rate – 3.0mL L^{-1}) on community composition based on plant cover (A) including all species; and (B) excluding cover of African lovegrass (*Eragrostis curvula*). Ordinations are non-metric multidimensional scaling with (A) stress 0.15, vector showing African lovegrass; (B) stress 0.13, vectors showing species with a Pearson's correlation > 0.8. PERMANOVA results (in text boxes) give pseudo-F values for effects of Treatment (Tr), sample Year (Yr),

Site nested in Treatment (S(Tr)) and the interactions of Tr × Yr. *** $P<0.001$, ** $P<0.01$, * $P<0.05$.

Table 1. Statistical analysis results of the effect of application of flupropanate at two applications rates on the cover of functional groups of plants (excluding African lovegrass), showing ANOVA F values. Treatment (Tr) is the effect of levels of flupropanate, Year (Yr) is the effect of sample year (pre-treatment, year 1 and 2 post-treatment), and Tr × Yr is the interaction between these effects.

	Tr	Yr	Tr × Yr
df	2,6	2,12	4,12
Functional group			
Invasive annuals	0.07	5.35*	1.45
Invasive perennial groundcovers	0.26	0.48	1.21
Native perennial groundcovers	0.07	0.21	0.70
Native woody shrubs	0.40	1.39	0.39

*** P<0.001, ** P<0.01, * P<0.05.


(a)
(b)

Fig. 1

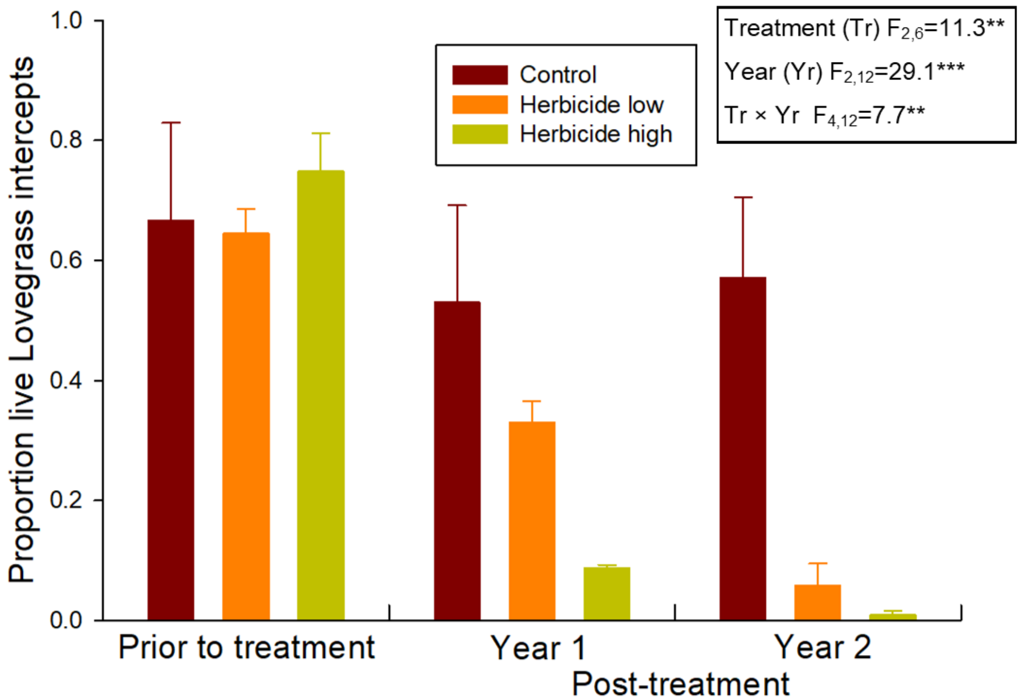
Treatment (Tr) $F_{2,6}$=11.3**
Year (Yr) $F_{2,12}$=29.1***
Tr × Yr $F_{4,12}$=7.7**
Control
Herbicide low
Herbicide high
Proportion live Lovegrass intercepts
1.0
0.8
0.6
0.4
0.2
0.0
Prior to treatment
Year 1
Year 2
Post-treatment

Fig. 2

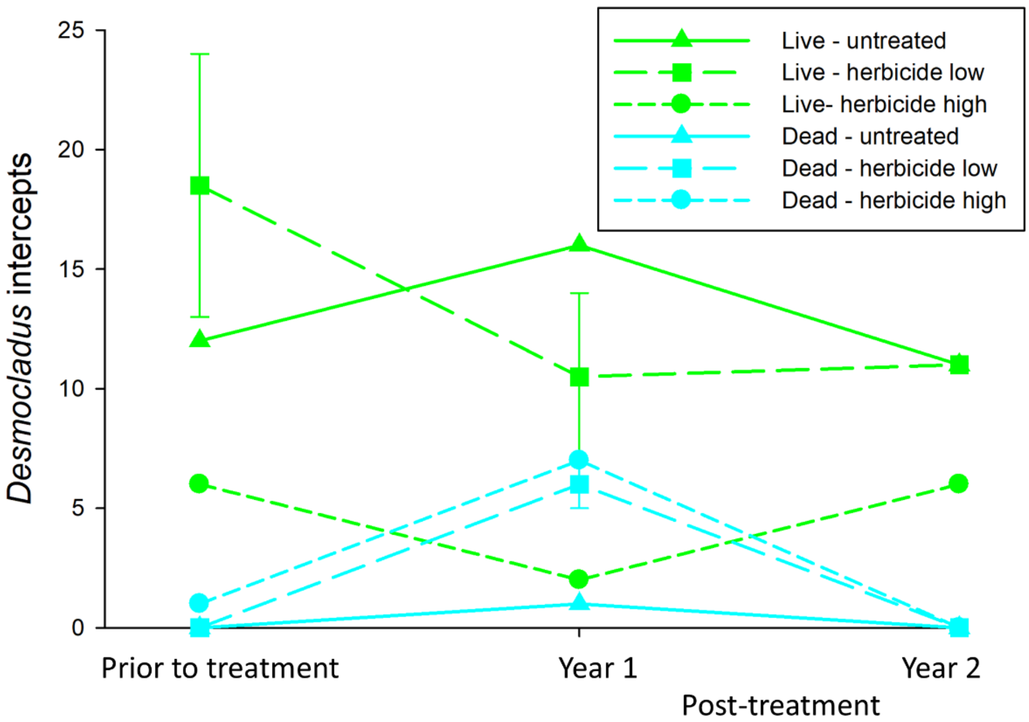
Live - untreated
Live - herbicide low
Live- herbicide high
Dead - untreated
Dead - herbicide low
Dead - herbicide high
Desmocladus intercepts
0
5
10
15
20
25
Prior to treatment
Year 1
Year 2
Post-treatment

Fig. 3

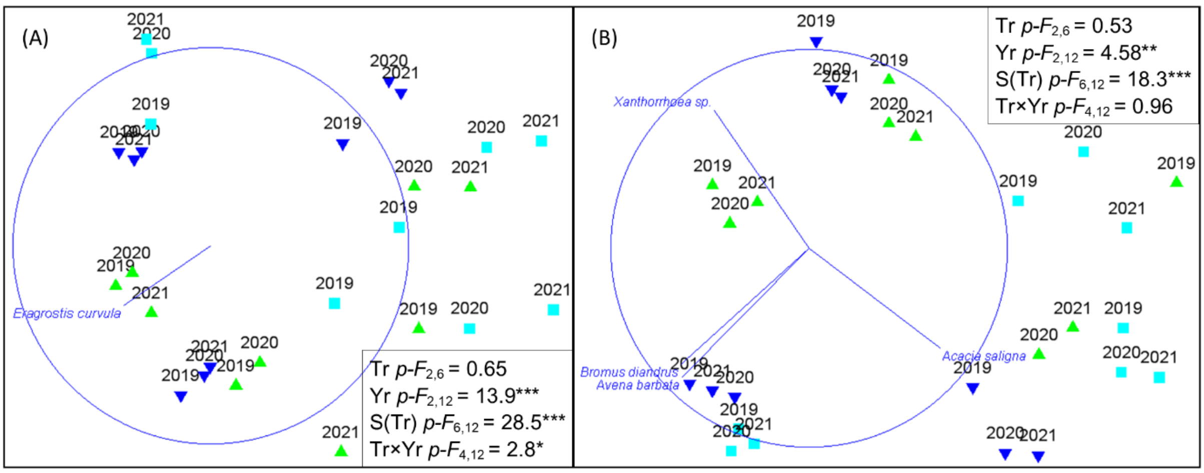
(A)
Eragrostis curvula
Tr p-$F_{2,6}$ = 0.65
Yr p-$F_{2,12}$ = 13.9***
S(Tr) p-$F_{6,12}$ = 28.5***
Tr×Yr p-$F_{4,12}$ = 2.8*
(B)
Xanthorrhoea sp.
Bromus diandrus
Avena barbata
Acacia saligna
Tr p-$F_{2,6}$ = 0.53
Yr p-$F_{2,12}$ = 4.58**
S(Tr) p-$F_{6,12}$ = 18.3***
Tr×Yr p-$F_{4,12}$ = 0.96

Fig. 4