Integration of chemical control and burning practices for the management of gamba grass (*Andropogon gayanus*) in northern Australia

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Summary Gamba grass (*Andropogon gayanus*) is an invasive grass species in the semi-arid tropics. There has been abundant research conducted into the impacts of gamba grass, which has identified it as a habitat transforming species, primarily due to its ability to modify intensity and seasonality of fire regimes. However, there has been little work to develop practical management options integral with gamba grass ecology. A long-term study site was initiated in 2013 evaluating gamba grass management in a native savanna environment to develop a multi-season best-practice strategy. Herbicide application and burning at different times of the year were imposed. The current practice of glyphosate application in the wet season was effectively extended into the dry season, attributed to ecophysiological traits which increase gamba grass resource use efficiency. Seed viability was also reduced with early dry season glyphosate application. The efficacy of chemical control was enhanced when applied post-burning to regenerating vegetative growth. Burning without follow-up herbicide application provides a competitive advantage to gamba grass over native species, and exacerbates the grass-fire feedback to accelerate gamba grass invasion. Land managers should incorporate both burning and chemical control, and this paper discusses advantages and disadvantages for consideration in the development of best-practice strategies.

Keywords Fire regimes, invasive grass species, glyphosate.

INTRODUCTION

Gamba grass (*Andropogon gayanus* Kunth) was introduced to northern Australia as an improved pasture species, but is now considered invasive, and was listed as a declared weed in the Northern Territory (NT) in 2008. It is acknowledged as habitat transforming, primarily due to its ability to modify intensity and seasonality of fire regimes, and numerous studies have been conducted in the NT on the ecological impacts of this species (Rossiter *et al*. 2004, Setterfield *et al*. 2014). However, there has been minimal work evaluating integration of on-ground control methods and the interaction with gamba grass ecology, especially in native habitats.

Weed management is rarely prescriptive; numerous confounding factors ranging from environmental to economic to ecological will influence control decisions and efficacy of control actions. Herbicide application and burning are two key tools for gamba grass management. Manipulating timing of both these practices within the wet season (WS) and the dry season (DS), and the corresponding integration of the two, may enhance control outcomes. The ecology of gamba grass needs to be considered when integrating control options and is essential for cost-effective and strategic gamba grass management.

A long-term reduction in cover and density of infestations needs to incorporate control options for mature perennial tussocks, as well as a reduction in the seedbank and potential for spread. It is beyond the scope of this paper to address the decision-making for prioritisation of management areas; this is addressed to some extent by Adams and Setterfield (2012).

The focus of this paper is to discuss results derived from on-ground gamba control actions over three years at a site near Darwin, and present the advantages and disadvantages of different timing of herbicide application and of burning practices. This study provides factors to be considered from a practitioner's perspective in the development of a multi-season gamba grass management strategy.

MATERIALS AND METHODS

A study was initiated in 2013–14 WS to evaluate gamba grass management in Charles Darwin National Park (CDNP) in Darwin, Northern Territory (NT). This represents a native savanna environment consistent with that discussed by Ens *et al.* (2015) and possesses environmental, conservation and recreational values threatened by gamba grass. Sites were selected within CDNP characterized by dense infestations (>10 t biomass ha^{-1}) of gamba grass and were treated at a range of times over concurrent years, categorised here as either early WS (November-January) or early DS (April-June).

The current herbicide recommendation for gamba grass was followed; foliar application of 1% solution glyphosate (360 g L^{-1}) during the active growth period, applied using a QuikSpray® unit consistent with commercial operator practice. Sprayed (2014–15 WS) and non-sprayed control plots were subject to a WS burn on the 7th Jan 2016. Post-burn glyphosate application versus a non-sprayed control was then imposed within the burnt plots two months after burning. Herbicide treatment effect was measured as percent brown-out of total cover two weeks after application, and two months after commencement of the following wet season to assess regeneration. WS burn effect was evaluated as percent regeneration of total cover, two months after fire. Photo monitoring points were established to assess long-term trends in gamba grass infestations and native species regeneration. Constraints and advantages to different on-ground control actions were also documented.

RESULTS AND DISCUSSION

Timing of herbicide application The effect of seasonal timing of glyphosate application on native plant communities was considered by Brooks *et al.* (2006). However, this was not quantified for the target species, gamba grass, itself. The majority of land managers currently finish spraying gamba grass once it has commenced seeding, coinciding with rapid bolting of reproductive tillers up to 4 m in height, usually in April-May.

Foliar glyphosate application was an effective method to control gamba grass in CDNP, with total brown-out observed within two weeks of herbicide application, even in very dense infestations (>15 t ha^{-1}), irrespective of time of application. However, the time of the season at which treatment occurred, imposed different advantages and disadvantages both operationally and ecologically (Table 1).

Gamba grass without prior burning treatment was characterised at the commencement of the WS by tall (>3 m) rank material remaining from the reproductive tillers from the previous WS. Stimulation of active vegetative growth at the start of the WS, commenced as a green collar of leaf around the base of the plant surrounding tall rank growth; this was not conducive to foliar herbicide uptake. Early WS application resulted in isolated tussock regeneration and seedling recruitment later within that WS, requiring follow-up with consequent additional mobilisation costs (spray team to access site). Collateral damage of native species was also observed, effectively limiting the opportunity for seed production and subsequent recruitment desirable for habitat restoration, although the degree of damage was gamba grass density dependent.

Early DS glyphosate application during- and post-seeding continued to be effective on gamba grass (100% brown-out). Gamba grass possesses a number of ecophysiological traits such as carbon assimilation in the dry season, for greater resource use efficiency. These traits extend its growing season and provide a competitive advantage over native species in savanna habitats (Ens *et al*. 2015). This extended growth period also provides the opportunity to extend the current practice of foliar application only in the WS to later into the DS.

Little or no off-target damage was observed at early DS, coinciding with senescence of surrounding native species, suggesting they were not receptive to herbicide uptake at that time. Brooks *et al.* (2006) concluded that glyphosate produced off-target damage when treated in April; delaying application until further into the DS may mitigate this effect, whilst also maintaining effectiveness of control on gamba grass.

Follow-up gamba grass control in the subsequent year was required irrespective of time of spraying, due either to regeneration of perennial tussocks, or seedbank recruitment.

Timing of burning Fire is intrinsic to the ecology of northern Australia, and the effect of timing of burning has been examined extensively for native savanna species. However, the effects of fire on gamba grass at different phenological stages and conducted at different times of the year, is less documented.

Manipulation of timing of burning is difficult due to the resource intense nature of conducting a controlled burn, and the difficulties in preventing wildfires. Current practices for gamba grass burning are primarily for risk mitigation, generally in the early DS, rather than for strategic weed control. Fires from August-October (late DS) are often wildfires (non-controlled).

A significant advantage of WS burning was the removal of rank gamba grass growth and promotion of vegetative production. This effectively manipulated proportion of green leaf to rank stalk and increased efficiency of subsequent glyphosate herbicide uptake. However, if follow-up spraying was not conducted, burning provided gamba grass with a competitive advantage, and the cycle repeated itself for the following season. Table 1 discusses the advantages and disadvantages of different seasonal burning times.

Irrespective of timing of burning, gamba grass regenerated to original cover by the end of the WS if follow-up herbicide application did not occur.

Integration Chemical control and fire are both recognised as control options for a range of weeds in northern Australia, where fire can increase mortality of species such as rubbervine and bellyache bush (Vitelli and Pitt 2006). However, fire provides a competitive advantage to gamba grass, initiating a grass-fire

Table 1. Considerations for spraying and burning at different times for gamba grass management.

Time of season	Advantages	Disadvantages
Early WS (Dec–Feb)	**Gamba grass is actively vegetative:** • Uses smaller volume of herbicide and less time per plant or per unit area than when plants have matured **Allows integration of spraying with previous DS or current WS burn:** • Stimulates lush green re-growth for improved herbicide efficacy • Removes rank tiller material from previous WS for decreased interception (waste) of herbicide • Increased operator safety and easier application by not working in thick tall gamba (logs, snakes, caught up hoses etc) **Allows staggering of spray and burn times:** • Prioritise spray areas previously burnt and now re-growing; follow-up areas from previous season • Less hectic than DS for Fire Officers' burning workload • Rainfall settles smoke haze	**Gamba grass if not recently burnt:** • Dormant tillers not yet emerged; often requires follow-up spraying later that WS to target regenerating tillers plus new recruited seedlings • Rank tillers remaining from previous WS not susceptible to herbicide uptake • Spraying may cause collateral damage of desirable species **Hot and humid, it rains a lot:** • Logistics more difficult; rain delays • Discomfort; poor worker efficiency **To conduct a burn at this time:** • Requires a short break in WS • May require fire exclusion in preceding DS for fuel load to carry • Removal of ground cover may lead to erosion from intense WS rain • May require additional DS burn if follow-up herbicide application NOT conducted
Early DS (Apr–June)	**Gamba grass is reproductive:** • More distinct in the environment; easier to locate and to identify for spraying. **Extends the spray window:** • Decreases work load for next season • Glyphosate may induce seed sterility • High gamba grass mortality; tussock plus new seedlings susceptible to herbicide • Resultant dead gamba grass mat reduces probability of seed soil contact at seedfall **Less collateral spray damage of native species:** • Already seeded; allows later recruitment • Dense gamba grass infestations can effectively 'shield' understory species **Logistics:** • Accessibility; decreased risk of getting bogged spraying or burning • More hours per day spraying/burning; less risk of delay from rain • Better climate condition: worker efficacy **Integrate spraying with an early cool DS burn:** • Consistent with burning practices for native species, such as *Sorghum* spp. dominated woodland • Prioritise burnt areas for early subsequent WS spraying	**Gamba grass (unless recently burnt):** • Increased herbicide volume and spray time per plant or unit area • Increased operator risk from spray drift due to taller spray height • Allowing seed set increases risk of seed spread **To conduct a burn at this time:** • Removal of ground cover coinciding with time of seedfall from gamba grass provides post-fire suitable habitat for seed soil contact • Smoke haze and associated human health issues
Late DS (Aug–Oct)	**Decreased biomass of gamba grass and subsequent regeneration of green growth provides opportunity for early WS herbicide application**	**Later curing of gamba than native species:** • Intense fires; habitat transforming due to increased fuel load and temperatures • Wildfires versus prescribed burns

feedback which accelerates gamba grass growth and invasion (Ens *et al*. 2015). Fire needs to be combined with timely herbicide application to maximise control of both established perennial tussocks, as well as reducing the seedbank for strategic management.

Gamba grass seed viability is low under natural conditions (Flores *et al.* 2005). The effect of timing of glyphosate application and of burning on mature seed viability has not been assessed, but preliminary results (this author) indicate that glyphosate can decrease gamba grass seed viability when applied at flowering and seeding.

CONCLUSION

Herbicide application (foliar glyphosate) was effective in reducing gamba grass cover in sites selected within CDNP. Early DS application on reproductive gamba grass extended the seasonal spray window compared to the current practice of WS treatment prior to flowering. This provided a number of advantages for gamba grass management including reduced collateral damage of already senesced native species. Fire was predominantly used as a risk mitigation tool in the early DS rather than for weed control. The WS burn demonstrated advantages in reducing rank biomass of gamba grass which had not been previously sprayed, to enhance subsequent herbicide efficacy (WS burn/WS spray). Plots which had been sprayed previously, then were subject to a WS burn, resulted in no regenerating gamba grass to date (2014–15 WS spray/2015–16 WS burn). In plots which were burnt (WS or DS) but herbicide not subsequently applied, gamba grass re-established to its original cover by the end of the WS. These results support the integration of burning and herbicide application for gamba grass control. Fire alone will continue to exacerbate the gamba grass problem; land managers should conduct strategic DS or WS burns, and then prioritise these areas for subsequent spraying.

Results here are based on qualitative data. Future work could better quantify relationship between gamba grass ecology and treatment outcomes, and also incorporate other factors such as grazing and the use of residual herbicides. However, current results provide a platform to demonstrate principles of integrating and rotating herbicide and fire regimes to develop a multi-season gamba grass management strategy.

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