African lovegrass in Australia: a valuable pasture species or embarrassing invader?

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Abstract

For almost 100 years, *Eragrostis curvula* (African or weeping lovegrass), a C_4 perennial grass native to southern Africa, has been sown throughout Australia for pasture improvement and soil conservation. Although easy to establish, particularly in regions of low productivity, it has been found to be unpalatable, low in nutritional value and difficult to contain. Despite the occurrence of significant populations of African lovegrass across Australia, it has not been declared a weed in all regions. In this paper, research within Australia and overseas is summarised to illustrate the invasive nature of this species and to highlight the urgent need for a coordinated effort to better manage existing populations. Research and management efforts need to focus on developing guidelines to reduce African lovegrass populations by either replacing it with more desirable species or increasing its palatability and nutritive value. Urgent action must be taken to reduce further spread.

Introduction

From the early 1900s to the early 1980s, numerous agronomic types of African lovegrass (*Eragrostis curvula*) were introduced across Australia (Johnston *et al.* 1984). Although regarded as a productive and useful pasture species in summer-rainfall regions of southern Africa, USA and Argentina (Voight *et al.* 1970; Di Renzo *et al.* 2000; Guevara *et al.* 2005), African lovegrass has not met original expectations for pasture improvement in Australia. Instead, it is often unpalatable to stock and low in crude protein concentration and has invaded pasture communities, woodlands, riparian areas and roadsides (Campbell 1983). At the peak of experimental testing of different lines, Leigh and Davidson (1968) described African lovegrass as a 'perplexing' species that was 'probably the most unpalatable species ever recommended as a pasture, but it has all the vigour of a weed. With appropriate husbandry it might be a valuable pasture; without this it might be an embarrassment.'

The fundamental problem is that, with intensive management, African lovegrass can be a valuable pasture species (as is the case in South Africa, USA and Argentina), but without intensive management, it can reduce the value of pasture and degrade natural habitats. As it can readily escape and establish, particularly within disturbed and/or degraded pastures and grasslands (Auld and Scarsbrick 1970; Campbell 1983; Batianoff and Butler 2002), African lovegrass presents a social, environmental and economic conflict. Some pastoralists and other land managers have introduced it intentionally (generally for soil stabilisation), while others have had it inflicted on them, particularly when its initial arrival and establishment went undetected. This is why strategies for early detection and management to reduce populations need to be developed and then effectively communicated to landholders whose properties are at risk or are already affected.

This review paper synthesises what is currently known about the introduction and spread of African lovegrass in Australia and describes research from other countries that is relevant to the Australian experience. It is organised into 3 sections, which correspond to the 3 stages identified as essential for a plant invasion to occur (Lockwood *et al.* 2005). The first section describes the circumstances and traits (species and environmental) that led to the arrival of African lovegrass and then its current status as a weed. The second details the abiotic and

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biotic conditions that contribute to its establishment and persistence, and the third discusses the physiological traits which have contributed to its unwanted spread. Finally, an argument is made that one of the most ‘perplexing’ aspects of this grass species is that it is not universally declared a weed within Australia.

Arrival and current legislative status in Australia

An exotic plant can become a problem only if its seeds arrive by chance or intentionally at a new location where it is not wanted (Lockwood *et al.* 2005). Many of today’s serious weed species have been intentionally introduced into areas because they were, at the time, considered desirable (Cook and Dias 2006). The Australian Commonwealth Plant Introduction Scheme was initiated in 1929 and led to the introduction of over 5000 species of grasses, legumes and other forage and browse plants (Cook and Dias 2006). While some introductions have been successful, many have not. Lonsdale (1994) suggests that, in tropical Australia, 13% of introductions have become a problem, with only 5% being considered useful for agriculture. Low (1997) indicates that 5 out of 18 of Australia’s current worst tropical environmental weeds were intentionally introduced as pasture grasses. African lovegrass was also intentionally introduced and is now a serious problem (Campbell 1983).

The first samples of African lovegrass at the NSW National Herbarium date back to 1900. By 1968 more than 115 introductions of African lovegrass took place across Australia, 112 via the Commonwealth Plant Introduction Scheme and 3 by the Soil Conservation Service of NSW (Leigh and Davidson 1968). In NSW alone, more than 100 lines of African lovegrass were evaluated experimentally for pasture improvement and roadside soil conservation (Leigh and Davidson 1968; Campbell 1983). Research comparing the performance of different lines has found a high amount of variability within the species *Eragrostis curvula*, but not enough to warrant the formation of new species (Leigh 1967). To aid identification and the selection of lines, agronomic types were described, based largely on gross morphological differences (Leigh 1967; Leigh and Davidson 1968). However, there is considerable overlap in characteristics between groups, which can make identification difficult; therefore, the types are often referred to collectively as a complex (Jacobs 1982).

The complex is comprised of 7 types: Curvula, Conferta, Short Chloromelas, Tall Chloromelas, Robusta Green, Robusta Blue and Robusta Intermediate (Leigh and Davidson 1968; Jacobs 1982). Jacobs (1982) re-examined the different agronomic types and described their categorisation as misleading because of the extensive overlap in morphological traits, although Conferta was consistently found to be a distinctly separate type. Prior to the early 1980s, the Conferta type, of which Consol is a cultivar, had not been widely introduced into Australia. Research and practice have found this cultivar to be more palatable and, thus far, to not have the same weedy characteristics as other introduced lines (Johnston and Cregan 1979; Anon 1982; Johnston *et al.* 1984; Johnston 1988a, 1988b; Johnston and Shoemark 1997).

Palatability tests on several of the naturalised types within NSW found that the most widely introduced type, Curvula, was both the most productive and the least palatable, while naturalised populations of Short Chloromelas and Robusta Intermediate near Wagga Wagga, NSW also had low palatability (Johnston 1988b). The least palatable line of Curvula, 809 (Davidson 1965; Leigh 1967; Dahl and Cotter 1984), originated from Ermelo, and was one of the first lines established and distributed worldwide from the Rietvlei Agricultural Research Station, southern Africa (Leigh 1967; Leigh and Davidson 1968).

In the 1960s in Queensland, trials were established in the Lockyer Valley, Samford, Gayndah, Biloela, Charleville and Townsville to test the performance of different lines of African lovegrass for pasture improvement (Leigh and Davidson 1968; Strickland 1973). Today naturalised populations of lovegrass are found in all shires of south-east Queensland. Localised populations have also been reported in several shires scattered along the coast from Brisbane to Rockhampton, a few west of Roma and a few close to Townsville and Charters Towers (Department of Natural Resources and Mines 2003).

Although all agronomic types, with the exception of Consol, are now considered undesirable plants within Australia, declaration of the complex as noxious weeds has not occurred in all States and regions. African lovegrass is classified as: a locally controlled weed (Category C4) in NSW and is declared in 33 council areas in the State; a Category 2 weed in South Australia (excluding Consol); a declared pest plant in the ACT (Category C3) and Tasmania (Category D); while in Victoria it is a Regionally Prohibited Weed (Category PS/C2) in 5 out of 11 regions (Carr *et al.* 1992). Victorian authorities have also placed it in the very serious threat category (Carr *et al.* 1992). In Western Australia, African lovegrass is classified as unassessed, meaning it is not officially permitted or prohibited, but until a decision is made, it remains prohibited. In Queensland, African lovegrass has yet to be declared a weed, although several scientific articles have specifically named African lovegrass (*inter alia*) as a weed of concern in Queensland because of its ability to invade and dominate disturbed and/or degraded pastures and grasslands (Fensham 1998; Batianoff and Butler 2002; Martin 2003).

Establishment and persistence

When an invasive or any colonising plant species arrives in a new area, conditions have to be suitable for its establishment and, subsequently, its persistence for it to be a problem. These include abiotic factors such as light, nutrients and water, and biotic factors such as competition from the existing community (Mack *et al.* 2000; Davis *et al.* 2005). Based on research conducted within Australia, USA and southern Africa, African lovegrass has the capacity to survive under a wide range of environmental conditions and disturbance regimes. Evidence suggests that it is a strong survivor when grown on infertile sandy soils in areas with a mean annual rainfall of 300–700 mm (Leigh and Davidson 1968). Once established, it has the capacity to respond to increased nutrient availability arising from disturbance or the addition of fertilisers (Davidson 1964; Squires and Myers 1970; McMurphy and Denmen 1970; Dahl and Cotter 1984; Masters and Britton 1990). Several conditions appear to promote its establishment and persistence: grazing and nutrient addition, the lack of competition from other grasses (conflicting views and evidence on the competitive ability of African lovegrass will be discussed), water stress and acid soils and mine spoils.

Grazing and nutrient addition

In the native home range of African lovegrass, southern Africa, heavy grazing and nutrient addition have been found to promote its persistence (Davidson 1965; Gillard 1969). African lovegrass is described as a subclimax or seral species (Jong and Roux 1955; Gillard 1969). Such species become established in-between ruderal (early-colonising) and climax (late-colonising) species. In a long-term restoration project in the Highveld region of South Africa, where treatments were applied to the soil to break up the crust layer, African lovegrass was dominant within the pasture in the first 3 years after treatment (Snyman 2003). After 10 years, however, it was almost completely absent regardless of the treatment type (hollow-dyker plough, furrows ripper/subsoiler, walking-stick planter) and soil type (sand or clay), possibly owing to strong competition from other species such as digit grass (*Digitaria eriantha*).

In several South African studies, African lovegrass showed a growth response to fluctuations in nutrients within grazed pastures (Jong and Roux 1955; Davidson 1965). Davidson (1964; 1965) suggested that its persistence might be explained by its capacity to quickly capture nutrients such as nitrogen in cattle dung and urine. Climax grasses at the Frankenwald field station, South Africa were killed by excretal N, with African lovegrass and couch grass (*Cynodon dactylon*) establishing in their place. Supporting evidence was also found in a long-term study (more than 50 years) in Pietermaritzburg, South Africa, that measured the response of a southern tall grass veld to the addition of different types of fertilisers (Fynn and O'Connor 2005). While density of other endemic native grass species (*Themeda triandra*, *Heteropogon contortus* and *Tristachya leucothrix*) decreased following nitrogen addition, African lovegrass increased in abundance, particularly when soil phosphorus remained limited and in the absence of lime addition.

In the USA, where African lovegrass is generally valued as forage, particularly within the south-west region, intensive management practices are used to increase its palatability (Klett *et al.* 1971; Shoop *et al.* 1976; Masters and Britton 1990). In Oklahoma, African lovegrass produced 3–5 times more usable forage than in its native home range (Shoop *et al.* 1976). Fertilisers, controlled rotational grazing, burning and in some instances irrigation have been used, often in combination, to increase its palatability and nutritional value. In a 20-year study of the effects of N fertilisation (urea or ammonium nitrate applied at a rate of 37 kg N/ha/yr), Berg (1986) found that the growth of African lovegrass was not hindered by soil pH values of 5.3, with no response to liming. In a separate study, yield of African lovegrass increased by 20% following the addition of a single application of 90 kg/ha P on light soils in Oklahoma (Taliaferro *et al.* 1975).

African lovegrass is grazed readily when the tissue is young, but palatability decreases sharply with maturity (Klett *et al.* 1971; Shoop *et al.* 1976; Masters and Britton 1990). In the USA, controlled rotational grazing is used to keep mature tissue from developing and prescribed burning reduces carry-over and litter production and increases the crude protein concentration in new tissue (Klett *et al.* 1971; Shoop *et al.* 1976; Masters and Britton 1990; McFarland and Mitchell 2000). Burning can increase the density of tillers by 61%, stimulate flowering and increase seed production (McFarland and Mitchell 2000).

In Australia, African lovegrass has also been found to respond positively to grazing and nutrient addition, particularly when irrigated. In the Mediterranean region of south-west Australia, a program to evaluate tropical grasses found African lovegrass to be highly productive and capable of supporting high stocking rates when irrigated, fertilised and rotationally grazed (Roberts and Carbon 1969). Squires and Myers (1970) found African lovegrass gave a higher total yield than *Paspalum dilatatum* when fertilised with N and irrigated in south-eastern Australia. When fertiliser was not added, however, African lovegrass had the lowest crude protein concentration of the 6 grass species studied.

Competitive ability

Opinions on the competitiveness of African lovegrass differ, as it has been described as both a good competitor and a poor competitor. This variation in assessments might reflect differences in environmental conditions, cultivar type and biotic interactions, which suggests African lovegrass has a high phenotypic and genetic plasticity. For example, Johnston (1989) recommended planting of African lovegrass to 'out-compete' another problem grass, spiny burrgrass (*Cenchrus longispinus*), as he found in a field trial that African lovegrass was better adapted to the infertile soils that characterised the study site and, therefore, able to grow more quickly. In a study in the USA, allelopathic chemicals from spiny burrgrass litter reduced African lovegrass germination by preventing the emergence of the radicle and, in some cases, preventing root development of Ermelo seedlings (Matizha and Dahl 1991). In this study in both field and lab studies, spiny burrgrass had a strong competitive effect on the vigour of African lovegrass seedlings. In its native range, African lovegrass proved more aggressive than wool grass (*Anthephora pubescens*), but wool grass was generally a poor competitor (Mynhardt *et al*. 1994).

Robinson and Whalley (1991) established a field trial specifically to compare the competitive ability (measured as yield and growth habit) of 3 agronomic types of African lovegrass (Curvula, Conferta and Chloromelas) and 3 temperate pasture grasses (*Festuca arundinacea*, *Dactylis glomerata* and *Phalaris aquatica*) in northern New South Wales. They found that all of the agronomic types of African lovegrass were more competitive than the other species during the summer. Sheep preferentially grazed on the other grasses rather than African lovegrass in April, with grazing being recorded on the most competitive type, Curvula, only after 8–12 hours of exposure.

In a more recent study, Ghebrehiwot *et al*. (2006) compared the competitive ability of African lovegrass and 3 other South African native grasses (*Themeda triandra*, *Aristida junciformis* and *Hyparrhenia hirta*) that differ in their characteristics and response to management in KwaZulu-Natal. While soil nutrient level determined the grass species with the highest competitive effect on *Themeda triandra*, the competitive effect of African lovegrass on *Themeda triandra*, although not the highest, remained intermediate and constant across nutrient levels.

Other studies, however, describe African lovegrass as establishing more readily when pastures are degraded and there is little biotic competition (Campbell 1983; Parsons and Cuthbertson 1992). Johnston and Shoemark (1997) suggested that, despite the ability of African lovegrass to dominate large tracts of land, it is not a highly competitive species when abiotic conditions are generally favourable for plant growth and therefore, other grasses are present as competition.

Water stress

African lovegrass has also been found to increase in density in grazed pastures and on light soils during times of drought (Ritman 1983), which suggests African lovegrass might not be a strong competitor, but instead tolerant of stress. Thus, conditions that render other species temporarily or permanently inactive might favour its establishment (Grime 1977). For example, in the Bega Valley, NSW, a population of African lovegrass, first noticed in 1945, was not considered a problem until 1982. It was found to have spread over an estimated 8300ha, following a number of dry years in the 1960s–1970s (Campbell 1983).

Several studies have found physiological characteristics in African lovegrass, which might account for this high tolerance to water stress, including leaf waxing and rolling (Tischler and Voigt 1990; Johnston *et al.* 2002), and a high level of water retention in its leaf tissue (Colom and Vazzana 2001). Not all types of African lovegrass have shown the same tolerance to water stress, with Consol and Robusta being more tolerant than Curvula (Tischler and Voigt 1990; Colom and Vazzana 2001). Balsamo *et al.* (2006) found that Curvula was more tolerant of moisture stress than two other species of *Eragrostis*, and that it developed high leaf tensile properties in response to drought, which might explain its low digestibility and palatability in drought-affected regions. As a pasture, two Australian studies found Consol to have a high water use efficiency (Johnston *et al.* 2002; Sandral *et al.* 2006), but Johnston and Shoemark (1997) found Consol to be vulnerable to competition by the fast-growing winter-annual, *Trifolium subterraneum.*

The root system of African lovegrass might explain its ability to tolerate dry conditions. It has a deep vertical root system with its primary roots reaching depths of over 4 m on sandy soils (Shoop and McIlvain 1970). Its horizontal roots can extend radially for more than a metre, suggesting that African lovegrass is particularly effective at using light falls of rain and is adept at physically preventing the establishment of neighbours (Shoop and McIlvain 1970). These authors suggest that African lovegrass can continue to grow until the last bit of moisture is left in the soil, whereas other grasses might have developed alternative survival mechanisms such as shutting down physiologically at these same low soil moisture levels.

Rethman *et al.* (1997) found that, when compared with 4 other grass species at low soil moisture availability (20% field capacity), African lovegrass showed one of the highest above-ground biomass levels (226 g/tuft DM), but one of the lowest below-ground biomass levels (0.20 g DM/100 cm × 2.5 cm soil core). In a study of root development in African lovegrass, Montani *et al.* (1989) suggested that biomass data could be misleading if used as the sole indicator of soil activity, as fine roots with characteristically low biomass contribute significantly to water and nutrient uptake. By using a below-ground observation chamber to study the development of African lovegrass roots, these authors found that fine root development was highly seasonal and dependent on depth. The development of fine roots was highest during spring and autumn and fine roots were more abundant than primary roots at a depth of 25–50 cm, reaching equilibrium with primary roots at a depth of 60 cm into the soil profile.

Johnston and Shoemark (1997) found that Consol and Accession 4660 germinate readily when soil moisture is favourable, but that germination is delayed when soil moisture is unfavourable. Once germinated, seedlings grow slowly for the first 6 weeks and then undergo more rapid development (Maze *et al.* 1993). Slow seedling growth is generally not a characteristic associated with weedy species (Baker 1964). These observations coupled with its small seed size suggest that African lovegrass is not highly competitive as a young seedling, needing a physical opening to become initially established.

Slow initial development could possibly be an advantage in areas where water and nutrient availability are driven by sporadic pulses of rainfall. This idea is supported by a short-term glasshouse study, where, under a continuous watering regime, fast-growing grass seedlings from more productive environments (semi-arid floodplains) were the strongest competitors (Novoplansky and Goldberg 2001). However, under a pulsed watering regime (210 ml of water every 21 days), slow-growing grass seedlings from the least productive environments (semi-arid, upland clay swales) were the strongest competitors (Novoplansky and Goldberg 2001). While further research is needed, it is possible that African lovegrass seedlings might be at an advantage in unproductive environments, because of an ability to temper their growth until conditions are more favourable.

Acid soils and mine spoils

African lovegrass has the capacity to survive extreme soil conditions including acidic soils and mine spoils high in aluminium (Al), manganese (Mn) and copper (Cu) (Fleming *et al.* 1974; Foy *et al.* 1980, 1987). Foy *et al.* (1987) found that 3 genotypes of African lovegrass performed better than 29 bluestem (*Brothriochloa* spp.) genotypes in unlimed soils with pH 4.1, which were also high in exchangeable aluminium. Foy *et al.* (1980) studied 19 different genotypes of African lovegrass and found all genotypes tolerated a soil pH of 4.7, while several genotypes were tolerant of acid mine spoil with pH as low as 3.5. They also found indications of a possible trade-off between tolerance of acidic and calcareous soils, as the genotypes that performed well on the highly acidic soils (pH = 3.5) developed an iron-related chlorosis on soils with pH of 7.8.

Fleming *et al.* (1974) compared the tolerances of African lovegrass and tall fescue (*Festuca arundinacea*) for high concentrations of Al and Mn and acidity in separate experiments. They found that African lovegrass was tolerant of Al concentrations in nutrient solution as high as 4 ppm, suffering a decrease in above- and below-ground biomass of less than 20% at this level. However, at the same concentration of Al, the above- and below-ground biomass of tall fescue was reduced by 62% and 97%, respectively. Both African lovegrass and tall fescue were tolerant of low pH nutrient solutions and concentrations of Mn as high as 32 ppm. Although an accurate map of the current distribution of African lovegrass is not available, this high tolerance of acidity, Al and Mn concentrations might explain its ease of establishment and persistence within Australia. The initial range expansion of African lovegrass has been favoured by sandy acid soils derived from granite, as well as solodic soils derived from sandstone (Parsons and Cuthbertson 1992).

Spread

For an introduced plant species to become a serious problem, it has to be capable of spreading to new areas. The traits enabling a species to spread have been researched extensively, but a set of specific traits has proven difficult to pinpoint (Scott and Panetta 1993; Reichard and Hamilton 1997; Alpert *et al.* 2000). Alpert *et al.* (2000) suggested that specific traits might not exist, because of the high morphological and physiological variability within and between species, and within and between ecosystems. They suggested the following 2 general categories are important:

(1) traits that allow a species to arrive into a new area, and
(2) traits that allow a species to survive once present.

Generally, traits associated with rapid spread include: long fruiting periods, high seed production, small seed size, prolonged seed viability and non-specialised transport (Alpert *et al.* 2000).

Since its introduction, African lovegrass has spread into a range of different habitats, including pastures, conservation areas, roadsides and river banks. For example, Leigh and Davidson (1968) reported that there were 9 locations where African lovegrass had spread from experimental plots in NSW and become naturalised. By 1983, a survey of weed control bodies in that state found that its infestation range had expanded to 56 shires (Campbell 1983), and that roadsides, railways and intentional introduction into pastures located upstream had accelerated the spread onto private properties and conservation areas, where it was not intentionally introduced.

African lovegrass displays a number of reproductive traits that might explain its prolific spread. It can produce large amounts of seed, estimated at 600 kg/ha (Johnston and Cregan 1979), that are very small (5×10^6 seeds/kg) (Johnston and Shoemark 1997). It spends only a short period in the vegetative state before flowering (Shoop and McIlvain 1970) and is capable of producing flowers and seeds in all seasons within Australia, depending on rainfall availability (Lazarides 1997). Seed formation in African lovegrass does not require fertilisation, but instead occurs largely through apomixis, a type of asexual reproduction (Lazarides 1997). The seeds are dispersed in a number of ways including the activities associated with road construction (*e.g.* grading and seed contamination of central gravel pits), roadside slashing, on vehicles, in livestock dung and in contaminated soil (Parsons and Cuthbertson 1992).

Once in place, seeds can germinate under a wide range of temperatures and soil moisture availability (Cox 1984; Maze *et al.* 1993). Maze *et al.* (1993) studied the factors affecting the germination success of 6 perennial grasses, 5 natives (*Enteropogon ramosus*, *Elymus scabrus*, *Bothriochloa macra*, *Chloris truncata* and *Danthonia caespitosa*) and African lovegrass. African lovegrass germinated under a wider range of temperatures (generally any temperature >10°C) and soil moisture availability than most of the native grasses, except *Enteropogon ramosus*. Lovegrass was also found to have a short dormancy period, with a germination success rate of more than 90% up to 7 months after harvest and more than 50% germination at 60 months after harvest.

Like many tussock grasses (bunch grasses), African lovegrass can also spread vegetatively by tillering in response to disturbances such as grazing, slashing, burning and mowing (Campbell 1983; Masters and Britton 1990). What might set African lovegrass apart from other tussock grasses in terms of vegetative growth is its ability to tolerate shade, as it was found to re-grow once cut under low light, while other tussock grasses did not show the same capacity (Ghebrehiwot *et al.* 2006).

Discussion

Leigh and Davidson's (1968) description of African lovegrass as a 'perplexing species' seems warranted for several reasons: 1) the morphological and physiological variability present within and between the different agronomic types that constitute the African lovegrass complex; 2) the conflicting reports about its competitive features; and 3) its ability to survive and reproduce under diverse climatic (temperate, semi-arid and subtropical) and edaphic (red acid, brown earth and sandy soils) conditions, including soils that are acidic and/or high in heavy metals such as Al, Mn and Cu (Fleming *et al.* 1974). What is well established is that, in Australia, African lovegrass (except the cultivar Consol) can be a serious weed.

Several studies in invasion ecology have described general 'weedy characteristics' (Baker 1964; Bazzaz 1986; Rejmanek and Richardson 1996). Rejmanek and Richardson (1996) compared different species from the genus *Pinus* to develop a list of these characteristics. The characteristics possessed by the most successful invasive *Pinus* species centred on reproductive traits including small seed mass, short juvenile periods (referring to the interval between germination and when the plant can produce seed), short intervals between seeding events and high germination success. In describing the life history traits of not just 'weedy' plants, but early-colonising plants in general, Bazzaz (1986) identified the following 3 characteristics as a 'must' for plants colonising disturbed ecosystems: 1) the ability to survive a wide variety of environmental conditions; 2) the ability to tolerate shortages and excesses of nutrients; and 3) opportunistic reproduction.

African lovegrass displays many of these 'weedy characteristics' including: high seed production and germination success (Johnston and Cregan 1979; Maze *et al.* 1993); the ability to delay germination if conditions are not favourable (Johnston and Shoemark 1997); tolerance of dry conditions (Campbell 1983; Tischler and Voigt 1990; Balsamo *et al.* 2006); tolerance of low nutrient conditions; the ability to respond to nutrient addition; and tiny seeds that are spread easily by a range of common vectors (Campbell 1983; Parsons and Cuthbertson 1992).

Dominance by African lovegrass in native or sown pasture is promoted by disturbance and selective grazing of more palatable species. Conflicting evidence concerning its competitive ability and the fact that its persistence within Australia mirrors harsh conditions such as dry spells, low soil nutrients and high acidity suggest that it is probably not a competitive species at the early stages of establishment. Instead, it might have the ability to survive conditions that many species cannot. This characteristic is not surprising considering that it was selected and introduced because it was known to be capable of surviving harsh edaphic and climatic conditions. It has, thus, persisted in these environments, building up large populations and spreading into new areas. Once present, it forms dense monocultural swards that prevent other more desirable species from establishing. Populations can spread along roadsides, riverbanks and railways, where opportunities for long-distance dispersal are frequent.

The poorest pastoral trait of the African lovegrass complex has been described as its low palatability and nutritional value, particularly once its tissue matures and seed is set (Leigh and Davidson 1968; Klett *et al.* 1971). However, evidence from research overseas and within Australia indicates that its palatability and nutritional value can be increased with intensive management practices (Leigh and Davidson 1968; Squires and Myers 1970; Voight *et al.* 1970; Klett *et al.* 1971; Dahl and Cotter 1984; Masters and Britton 1990). While African lovegrass can respond positively to fertiliser addition once established, it is not known whether it has the capacity to spread into and then persist on more fertile soils. Some Australian studies have found that African lovegrass can survive on the more fertile acidic red soils, as well as brown earth soils, when sown in these areas (Leigh and Davidson 1968; Strickland 1973).

Evidence suggests, however, that African lovegrass might not be competitive when other grasses are present within these pasture communities. Since African lovegrass has the capacity to respond to changing conditions, if a pasture is degraded because of disturbance or the onset of drought and its seeds arrive at an opportune time, it might be capable of establishing. Although evidence is needed, African lovegrass could be capable of building up high populations on more productive soils, particularly when its prolific seed production and its low palatability to grazing livestock when mature are considered. Long lag periods between introduction and range expansion are not uncommon for invasive plant species. Range expansion has been known to occur decades after the initial introduction of an invasive plant and is often facilitated by an increasing buildup of propagule pressure coupled with changes in land-use and disturbance regimes (Radosevich *et al.* 2003; Wangen and Webster 2006).

Control strategies

Research is needed to develop specific guidelines for the control of African lovegrass populations. This includes the collation of accurate information on its current distribution within Australia. Information on its infestation range is essential to assess how serious a problem African lovegrass is and for the development of an effective control program in response. There is little published research available on the best practices for controlling African lovegrass. This is probably a reflection of its reputation as a useful forage grass under intensive management in many countries. As a result, few studies have treated African lovegrass as a weed and aimed to reduce its population.

Another reason for the paucity of published research treating African lovegrass as a weed within Australia, is the lack of incentives or funding for research on this species because it is not universally declared a weed. Universal declaration of this species as a weed might increase research opportunities and promote the development of rigorous control programs. This is evidenced by the fact that such programs are underway in regions where African lovegrass is a declared weed. For example, the Southern Tablelands and South Coast Noxious Plants Committee has developed an African lovegrass Regional Weed Management Plan 2003 to 2008. This comprehensive plan aims to develop best practices for the control of African lovegrass, depending on the size of infestations. It also aims to implement training and education and to coordinate efforts across agencies. The plan calls for eradication of African lovegrass in newly infested areas and small populations, but recognises that eradication in heavily infested areas would be difficult and possibly impractical. Instead, the aim is to develop management guidelines to reduce the population size, including stringent protocols to prevent further spread from these locations.

A number of different trials have been conducted in heavily infested regions of NSW and southern Queensland, but the findings are not published and therefore not easily accessible. For example, the Granite Borders Landcare group (a cross-catchment and cross-border umbrella group representing over 20 Landcare groups) has been involved in a number of different projects including herbicide trials, grazing management demonstrations, liming trials and the introduction of summer-active pasture species. The information being gathered from these programs is invaluable and should be shared across regions to ensure the development of comprehensive and effective control strategies for this species. If African lovegrass becomes a declared weed across Australia, opportunities for collaboration and coordinated effort should increase.

One of the few published studies within Australia that has investigated possible control measures for African lovegrass found that the herbicides tetrapion, glyphosate and 2,2-DPA were effective when applied selectively (Campbell *et al*. 1987). Tetrapion (at rates of 2.25 and 3.00 kg/ha a.i.) was the most effective at promoting kikuyu grass (*Pennisetum clandestinum*), the original dominant and desirable species for the local pasture. Suggested control strategies for African lovegrass from local government agencies tend to focus on preventing seed spread (Land Protection 2005). Recommendations for preventing seed spread include: for small populations, not mowing or slashing utility verges when plants are in seed, chipping tussocks out before flowering, and if plants are already in seed, cutting seed-heads and bagging them before chipping. For large populations, suggestions include buffer zones between infected paddocks and uninfected paddocks and confining livestock that have grazed in an infected pasture for more than 10 days so that seeds which are passed in dung can be controlled more readily following germination (ST and SCNPC 2003).

Since African lovegrass has built up large naturalised and undesirable populations across Australia, long-term management strategies are needed to reduce its dominance and build-up competition from other more desirable species (Panetta and Timmins 2004). Appropriately timed grazing might be the key to managing large populations of African lovegrass, as has been suggested for other undesirable and weedy grass species on pastoral lands (Kemp *et al*. 1996) and within conservation areas (Lunt *et al.* 2007). This strategy takes advantage of the positive characteristic that African lovegrass swards can be palatable and nutritious depending on the age of the tissue and the favourability of the conditions. This strategy could then utilise the research available from other countries that manage this species for its forage value. The difference would be that the management efforts would aim at reducing not maintaining its population by lessening the relative grazing pressure on other species as described below.

Grazing at the right intensity and at times of the year when African lovegrass is the most palatable might be the key for reducing its dominance. For example, based on 6 years of research, Dahl and Cotter (1984) developed a set of guidelines for the better management of the cultivar Ermelo (type Curvula) on clay loam soils in the high rainfall regions of south-eastern Oklahoma and north-eastern Texas. The general focus of their guidelines was to maintain the palatability of African lovegrass tussocks by either keeping the tissue from maturing or altering soil nutrient conditions. Suggested management strategies included: increasing stocking rates to graze off new growth within 2–5 days; timing grazing to target the period of maximum growth; applying fertilisers; and mowing or burning if higher stocking rates were not possible during peak growth periods.

Cell grazing, a method of partitioning paddocks into small areas and grazing sections heavily for short periods, might be an option for removing the selective pressure on more palatable species and reducing the dominance of African lovegrass (Earl and Jones 1996). Other grazing management options include heavy grazing immediately before flowering and strategically planned rest periods. This strategic grazing could act to increase the palatability of the African lovegrass tussocks by keeping the plant tissue young and reducing prolonged grazing pressure on other grasses (Kemp *et al*. 1996). Despite conflicting evidence on its competitive ability, another option for heavily infested and degraded pastures might be to cultivate and sow other perennial grasses to build up competitive communities that reduce the probability of African lovegrass re-establishing.

Conclusion

Experience in Australia indicates that Leigh and Davidson's (1968) assessment that 'with appropriate husbandry African lovegrass might be a valuable pasture; without this, it might be an embarrassment' seems half right. There is very little evidence that it has proved valuable as a pasture grass for stock anywhere in Australia, but there are numerous situations where it is a serious weed. Eradication is an unrealistic option at this stage and control of further spread seems the only possibility.

Control of African lovegrass would require a concerted, long-term effort, coordinated across properties, agencies, local shires, regions and states. The first step would be to develop an accurate map of its current infestation range. The next step would be the implementation of a rigorous control program aimed at reducing its population levels in infested areas, eradicating small discreet populations and preventing further spread. To achieve these aims, adaptive management strategies would be necessary because of the lack of information concerning the most effective control strategies (Buckley 2008). Adaptive management is where research is simultaneously conducted with management actions to create a feedback loop between science and practice. It would also be essential for training and education programs to be implemented on the identification and known growth characteristics of African lovegrasses. There is an urgent need for coordinated partnerships between the different agencies responsible for vegetation management along roads, railways and utility networks to prevent any further spread. The resources and momentum necessary to implement such a wide-scale program would be likely to come into fruition only if African lovegrass was universally declared a weed.

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