A review of current knowledge of the weedy species *Themeda quadrivalvis* (grader grass)

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Abstract

This review of grader grass (*Themeda quadrivalvis*) attempts to collate current knowledge and identify knowledge gaps that may require further research. Grader grass is a tropical annual grass native to India that is now spread throughout many of the tropical regions of the world. In Australia, it has spread rapidly since its introduction in the 1930s and is now naturalised in the tropical areas of Queensland, the Northern Territory and Western Australia and extends south along the east coast to northern New South Wales. It is a vigorous grass with limited palatability, that is capable of invading native and improved pastures, cropping land and protected areas such as state and national parks. Grader grass can form dense monocultures that reduce biodiversity, decrease animal productivity and increase the fire hazard in the seasonally dry tropics. Control options are based on herbicides, grazing management and slashing, while overgrazing appears to favour grader grass. The effect of fire on grader grass is inconclusive and needs to be defined. Little is known about the biology and impacts of grader grass in agricultural and protected ecosystems in Australia. In particular, information is needed on soil seed bank longevity, seed production, germination and growth, which would allow the development of management strategies to control this weedy grass.

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Introduction

Grader grass (*Themeda quadrivalvis*), also known as habana oat grass, was introduced to Australia in the 1930s, and spread rapidly along the east coast of Queensland, as well as into drier inland areas, across into the Northern Territory and Western Australia, and south into New South Wales. It is now a major weed, especially in northern and coastal central Queensland, where infestations continue to expand (Smith 2002). This vigorous and unpalatable grass is capable of invading both native and improved pastures and reducing productivity, as well as being a weed along roadsides and in some crops (Bishop 1981).

However, little is known about the biology and impacts of grader grass on agro-ecosystems in Australia (Groves 1991). This review attempts to collate current knowledge on the species, including its ecology, current and potential distribution, impacts and control methods, and to identify knowledge gaps that may require further research.

Origin and spread

Current distribution

Grader grass is native to India, but now also occurs in Thailand, Indonesia, Papua New Guinea, China, the Middle East and tropical America (Lazarides 1980; Price *et al*. 1988; FAO 2006). It has also been recorded in California, Florida, Kansas and Louisiana, USA (Towne and Barnard 2000; USDA 2006). The first record of the species in Australia occurred in September 1935 at Habana, near Mackay in north Queensland (21°02′S, 149°05′E) (Bishop 1981; Batianoff and Franks 1998). The seed seems to have been introduced in contaminated straw packing (Bishop 1981).

It spread rapidly through Queensland, and by 1963 had spread north of Cairns (17°S) and as far south as Brisbane (27°S) (Blake 1969; Bishop 1981). In 1967–68, the grass was introduced to the Northern Territory as a contaminant in pasture seed, and is now widespread in the Darwin and Katherine regions (Groves 1991; Pitt 1998). It spread to New South Wales soon after, with the earliest specimen in the New South Wales Herbarium collected at Kundabung on the north coast in 1972. The species has now reached as far south as Nowra (33°S) on the NSW south coast, and as far west as Broome (18°S) in Western Australia (Figure 1). It is widespread through virtually all coastal and many northern inland regions of Queensland and to a lesser extent in the Northern Territory and Western Australia and its range appears to be expanding.

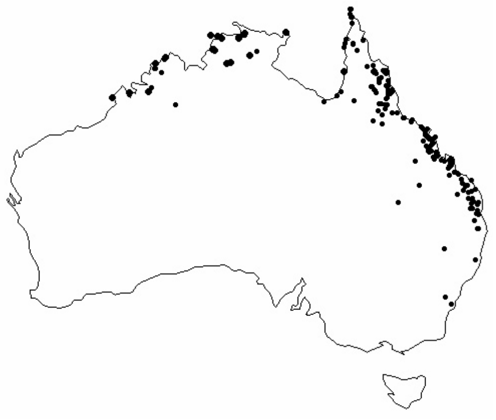

Figure 1. Current distribution of grader grass (*Themeda quadrivalvis*) in Australia, as determined from database records of the species. (Source: Queensland, New South Wales, and Northern Territory Herbariums, and Australian Virtual Herbarium: http://www.chah.gov.au/avh).

Potential distribution in Australia

In its native range in India, grader grass grows best in areas receiving between 500 and 1250 mm of rainfall annually, although it grows in areas receiving as little as 375 mm (Dabadghao 1960; Bishop 1981; FAO 2006). It also appears to grow well today in much wetter areas, being a predominant species of grasslands on well drained lateritic soils in a region of India receiving an average annual rainfall of 3200 mm (Thaware *et al*. 1989; Thaware and Jadhav 1989). In this region, the grass persisted in a year with nearly 4500 mm, although it produced less hay (Thaware *et al.* 1989). This suggests that the species is adapted to a wide range of moisture regimens, which is evident in its current Australian distribution (Figure 1), where average annual rainfall ranges from about 450 mm in inland regions to more than 2000 mm on the north-eastern tropical coast (Bureau of Meteorology 2006).

To examine the potential for further spread of grader grass, the computer package CLIMEX Version 2.0 was used to predict the potential climatic range of grader grass in Australia. CLIMEX is a simulation model that can compare the relative potential for growth and persistence of populations in different locations based on their climatic preferences (Sutherst and Maywald 1985). It has often been used to predict the geographic distribution of both plant and animal pests (Mack *et al*. 2002).

The known distribution of grader grass in Australia (Figure 1) was used by the authors of this review to estimate parameter values that describe its response to temperature, moisture and light (Sutherst *et al*. 2004). The Tropical Savannah Template, provided in CLIMEX, was used as a starting point. Parameters were then repeatedly manipulated and the simulation rerun until the predicted distribution included all known locations where grader grass has been found. The parameter values driving the CLIMEX output (temperature and moisture index and degree-days per generation) were then validated against known distributions of grader grass in other continents. The temperature index describes the response of the plant to the daily temperature cycle (°C) with DV0 (16) and DV3 (38) being the temperature below and above which no growth occurs and DV1 (28) to DV2 (34) being the optimum temperature range for growth (Sutherst and Maywald 1985). Similarly, the moisture index (as a proportion of soil moisture storage capacity) describes the plant's response to soil moisture, which is calculated weekly within CLIMEX. SM0 (0.1) and SM3 (1.3) are the soil moisture levels below and above which plant death occurs, with SM1 (0.2) to SM2 (1.0) being the soil moisture range for growth (Sutherst and Maywald 1985). We calculated the degree-days (360) required for the completion of 1 generation after observing potted grader grass plants from emergence to seed maturity.

These parameters were then used in CLIMEX to predict other locations within Australia where grader grass might persist (Figure 2). The final output from CLIMEX, the eco-climatic index (EI), summarises the overall response to temperature, moisture and day length (Sutherst *et al.*

2004). It can help distinguish between areas where grader grass is likely to present a weed problem and those where the climate may be less suitable (Kriticos 1996). It should be noted that this indicates only whether a location is suitable climatically, and does not consider other factors, such as competition, dispersal ability, soil types and the impacts of humans (Sutherst *et al*. 2004).

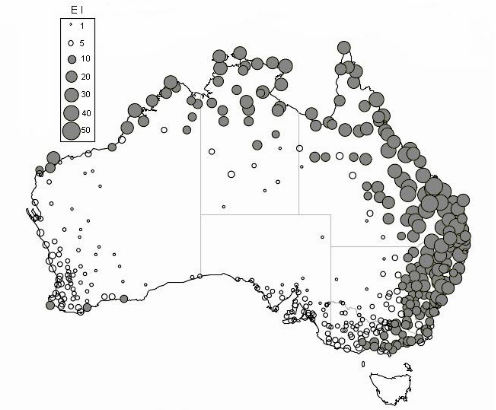

Figure 2. Potential distribution of grader grass (*Themeda quadrivalvis*) in Australia based on modelling with CLIMEX software. The size of each dot corresponds with the Ecoclimatic Index (EI) value for that location, representing the suitability of the climate for the persistence of grader grass. Areas with EI values of less than 10 (shown as unfilled circles) are considered only marginally suitable, while those over 30 represent a very favourable climate.

Description and biology

Description

Grader grass is an erect, tufted grass that grows to more than 2 m in height and turns a distinctive orange-red or golden colour when mature. It has robust, cane-like stems with long complex seed heads made up of spikelet clusters in short racemes, each subtended by a spathe (Blake 1969; Wheeler 1992; Parsons and Cuthbertson 2001). The grass is similar in appearance to the native, perennial kangaroo grass (*Themeda triandra*). Kangaroo grass is generally smaller (usually growing to less than 1 m in height), and has a brown rather than golden appearance when mature (Pitt 1998; Parsons and Cuthbertson 2001). The two species are most reliably distinguished by the size of the spikelets and the nature of the hairs on their seed heads (Figure 3). Grader grass has smaller spikelets (4–7 mm long) and has conspicuous, tubercle-based hairs (distinct, bulbous-based bristles) on the seed head, while kangaroo grass spikelets are 8–14 mm long and are either hairless or have fine hairs with only a slightly bulbous appearance (Blake 1969; Bishop 1981; Wheeler 1992; Wheaton 1994; Pitt 1998; Parsons and Cuthbertson 2001).

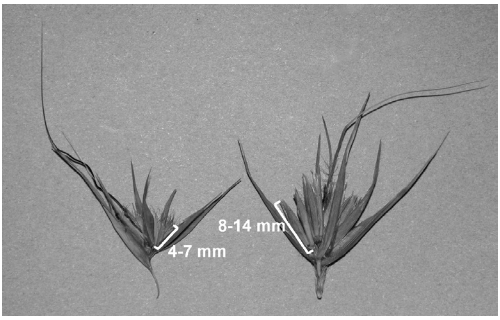

Figure 3. Differences in spikelet size between grader grass (*Themeda quadrivalvis*) (left) and kangaroo grass (*Themeda triandra*) (right).

Grader grass usually behaves as an annual (Sillar 1969; Bishop 1981), although Harden (1993) and Smith (2002) suggested it may also survive as a perennial but did not describe the situation where this would occur. The grass is able to grow rapidly, sometimes reaching more than 2 m in height within 6–8 weeks, and yielding over 3000 kg/ha after 3-months growth (Bishop 1981). Flowers can appear within 5–6 weeks of germination, with ripe seed being present at 10 weeks (Bishop 1981). Flowers generally appear between February and June in Australia (Wheaton 1994) but may occur outside of this period depending on climatic conditions such as timing and duration of seasonal rainfall.

Grader grass is a prolific seeder (Smith 2002), and seeds can apparently germinate throughout the year in northern Australia as long as light and moisture are present (Chapman 1969; Parsons and Cuthbertson 2001). In the Northern Territory, most seeds germinate between October and December following the onset of the wet season (Parsons and Cuthbertson 2001). This would probably also be the case in other areas with distinctive dry/wet seasons.

Germination

The seed of grader grass germinates rapidly. McIvor and Howden (2000) compared its germination with that of 18 common grass species of the seasonally dry tropics of northern Australia. They found that grader grass germinated before the other grasses, which could give it a significant competitive advantage during establishment. The authors of this review also found that 32% of sound grader grass seed was germinable 2 months after collection. It had low dormancy levels compared with many species after exposure on the soil surface (McIvor and Howden 2000), suggesting it relies on frequent seed input rather than persistent soil seed banks for long-term survival.

Keir and Vogler (unpublished data) found that only a low proportion (approximately 30%) of diaspores (hand-extracted from harvested whole inflorescences) contained caryopses. Of these diaspores, 29% were germinable 4 months after collection (April 2004), when germinated for 2 weeks at 20/30°C with a 12-hour alternation and light during the high temperature period. This result was comparable with the study by McIvor and Howden (2000). A further 24% of diaspores remained dormant, while 47% were unviable, when tested using standard Tetrazolium testing procedures (Moore 1985). A germinable seed bank of over 20 000 seeds per square metre can exist under dense infestations, but there appears to be a rapid decline in the viability of seed in the soil to almost zero within 15 months (Sillar 1969). Experiments also indicate that seeds will not germinate in the dark or under dense shade (Bishop 1981).

Fire tolerance

The seed morphology is similar to that of kangaroo grass, suggesting that it may also be tolerant of fire (Sillar 1969). The seeds have a hygroscopic awn (*i.e.*, the awn twists when moistened), which can implant the seed into the friable soil surface (Chapman 1969). This can protect the seed from heat and enable it to survive fires.

While Skerman and Riveros (1990) and Wheeler (1992) suggest that burning can increase germination of grader grass and encourage its spread, fire as a stimulus for germination has not been proven. Since defoliation by burning or mowing increased subsequent grader grass germination by similar amounts (Sillar 1969), it may simply be the removal of plant cover that allows the seed to germinate better. However, plant-derived smoke extracts have been shown to stimulate germination of kangaroo grass (Baxter *et al*. 1994).

Dispersal

Grader grass seeds are not adapted for dispersal by wind or water, and have poor long-distance dispersal mechanisms (Bishop 1981; Parsons and Cuthbertson 2001). Most seeds are transported over long distances by humans and animals, such as on fur or clothing, in soil moved by graders, mud stuck to animals or machinery, plant material on slashers or as a contaminant in pasture seed or hay (Parsons and Cuthbertson 2001; Smith 2002).

Grader grass can readily colonise areas that have been overgrazed or disturbed (Bishop 1981). In the Mackay area where it was first recorded, it inhabits open eucalypt forest and disturbed areas such as roadsides or areas cleared of vegetation (Batianoff and Franks 1998). A study of pastures in central Queensland during the late 1970s showed that grader grass was found mostly in native pastures or Townsville stylo (*Stylosanthes humilis*) pastures (Anderson *et al*. 1983). Townsville stylo pastures were particularly susceptible to invasion, as early wet season grazing was recommended to reduce grass competition and improve productivity, but this also provided favourable conditions for grader grass invasion (Sillar 1969). Townsville stylo has now mostly disappeared due to its susceptibility to anthracnose, but a similar situation may occur in the future in areas sown with more recent *Stylosanthes* introductions and other legume species that are managed in a similar way.

Grader grass can inhabit most topographic situations, and appears to favour soils with medium-textured surfaces, *i.e*., fine sandy loams to sandy clay loams (Anderson *et al*. 1983; Skerman and Riveros 1990; FAO 2006). It still grows, albeit less commonly, on soils with light-textured surfaces (sands to sandy loams) or heavy-textured soil (sandy clays to clays) (Anderson *et al*. 1983). It is reported to prefer well drained soils and to decline on waterlogged soils (Skerman and Riveros 1990).

Impacts on agriculture, livestock production and biodiversity

Grader grass is not harmful to stock, and chemical analyses show that it has peak protein values similar to some improved pasture grasses (Bishop 1981). However, it is edible only for a short period, and is seldom grazed after the flowering stage (Bishop 1981; Kleinschmidt and Johnson 1987; Groves 1991; Smith 2002). As a result, it can dominate grazed areas as more desirable species are selectively removed by stock and replaced by grader grass.

In India, grader grass is used to produce fodder for livestock (Thaware *et al*. 1989) in a fertilised, rain-grown system (Thaware and Jadhav 1989). Thaware and Jadhav (1989) showed that, on acidic, lateritic soils in the high rainfall South Konkan region of Maharashtra, dry matter yields were increased from 4.7 to 7.7 t/ha with a basal application of 10 kg/ha of phosphorus followed by 30 kg/ha of nitrogen applied in equal parts in July, August and September. This increased net returns per hectare to landholders by almost 70%.

In Australia, grader grass is an undesirable species and can become a serious problem where areas are overgrazed or disturbed. It is capable of invading both native and improved pastures and, due to its low palatability, can greatly reduce animal productivity if it becomes dominant in a pasture (Sillar 1969; Wheaton 1994; Pitt 1998). It can also significantly reduce species diversity in native pastures (Smith 2002), forming virtual monocultures and excluding almost all other species by preventing seedling establishment (Earthworks 2003). By generating large fuel loads because it is ungrazed, it makes dry season fires more frequent and of higher intensity (Stocker and Mott 1981; Earthworks 2003). These altered fire regimens can have significant and often long-term/irreversible impacts on ecosystems (Grice 2003) such as increased tree death and excessive thinning of native woodlands.

Grader grass has also become a weed on sugarcane farms. Harvesting, burning and clearing headlands all give it an ecological advantage by providing bare ground for germination, although once the crop matures it is normally a problem only in neglected or poorly grown cane (Chapman 1969; Tilly 1977). Although no controlled trials have been conducted, it has been estimated that grader grass can reduce cane yields by up to 20 tons/acre (approximately 50.2 tonnes/ha), if uncontrolled, by competing for moisture, nutrition and light (Chapman 1969).

Lucerne and other legume seed crops may be invaded by grader grass, and it can become a problem in citrus orchards (Bishop 1981; Groves 1991; Parsons and Cuthbertson 2001). The species is also very common on roadsides, where it can look untidy, reduce visibility and represent a fire hazard (Bishop 1981).

Although it is generally not considered a serious economic threat to grazing or agriculture in areas on or near the Queensland coast (Bishop 1981), grader grass poses a significant threat to animal productivity in semi-arid monsoonal areas of northern Australia (Parsons and Cuthbertson 2001). Control may also be more difficult in these areas of lower rainfall, where the native pasture species often provide less cover, and there are fewer improved pasture species available for sowing (Bishop 1981).

Declaration status

Grader grass is currently declared in the Northern Territory as both a Class B and Class C noxious weed, meaning both growth and spread of the species are to be controlled and its introduction into the Territory prevented (Pitt 1998; Miller 2003). Although not declared in Queensland under State laws, several local councils have declared the species under subordinate Local law, including Cardwell Shire Council, Charters Towers City Council and Eacham Shire Council in north Queensland and Woocoo Shire Council in south-east Queensland.

Despite the views expressed by Bishop (1981), grader grass is regarded by other authors (Parsons and Cuthbertson 2001; Miller 2003) as a serious threat to both agriculture and the environment. It was nominated as one of 71 species to be assessed when determining the 20 most important Weeds of National Significance (WONS). Grader grass was ranked at number 34 based on criteria such as invasiveness, impacts, potential for spread and socio-economic and environmental values compared with higher-ranked grasses such as hymenachne (*Hymenachne amplexicaulis*) (8), Chilean needle grass (*Nassella neesiana*) (12) and serrated tussock (*Nassella trichotoma*) (15) and lower-ranked grasses such as mission grass (*Pennisetum polystachion*) (46), giant Parramatta grass (*Sporobolus fertilis*) (48) and African love grass (*Eragrostis curvula*) (50) (Thorp and Lynch 2000). Improved biological information, which is currently limited, may have altered the relative ranking of grader grass during the WONS process. A study examining the invasiveness of naturalised species in south-east Queensland also classed grader grass as a common and invasive species in that region (Batianoff and Butler 2002).

Control methods

Preventing the introduction of grader grass seeds into new sites is the first step in controlling spread. Since the seed is not easily dispersed by natural means, good hygiene practices, such as washing down vehicles and machinery and ensuring hay, pasture seed and stock are uncontaminated, will help prevent spread of seed (Chapman 1969; Pitt 1998; Smith 2002).

Pasture management

Good pasture management is also vital. Maintaining a vigorous pasture will help prevent invasion by providing competition and minimising light reaching the soil surface, thereby limiting germination (Bishop 1981; Mitchell and Hardwick 1995; Pitt 1998).

Experiments by Sillar (1969) found that both burning and defoliation (mowing) before the wet season encouraged germination of grader grass, while germination was prevented by resting pasture over two consecutive wet seasons. In addition, germination was greatly reduced, compared with initial densities, when rested areas were subsequently defoliated. Denuding the soil encouraged grader grass, while increased soil cover by pasture reduced grader grass density (Sillar 1969). Therefore, where grader grass is present, management practices that bare the soil, such as overgrazing, burning, soil disturbance, short slashing or using non-specific herbicides, should be minimised as they can increase infestations (Bishop 1981; Pitt 1998; Earthworks 2003). If fire is used, burning once every 3–4 years rather than annually may be preferable (Bishop 1981; Mitchell and Hardwick 1995).

Maintaining adequate cover to suppress grader grass may be more difficult in lower rainfall areas due to the sparser vegetation (Sillar 1969). Drought can encourage subsequent establishment, if cover is reduced (Mitchell and Hardwick 1995), so reducing grazing intensity at such times may be especially important. Sown pastures should be maintained with moderate stocking rates and adequate fertiliser applications (Bishop 1981). Spelling infested pastures at the beginning of the wet season may also help by giving perennial grasses a competitive advantage.

Once an area has become infested, weak points in the plant's life cycle can be targeted to achieve control. Since the grass is an annual, it must regenerate from seed each year. Control should therefore aim to prevent flowering and seeding by maintaining competitive pastures, which will limit germination and reduce establishment the following year (Pitt 1998; Parsons and Cuthbertson 2001). Slashing to prevent seed set is often a useful control method for annuals (Smith 2002). Experiments by Sillar (1969) found that cutting at full flowering reduced grader grass density more than cutting at the pre-flowering stage. Cutting or mowing at full-flowering and leaving cut material on the ground has since been recommended as an effective control (Kleinschmidt and Johnson 1987; Skerman and Riveros 1990). However, timing such a cut before seed is produced is difficult to achieve in practice (Sillar 1969), and slashed plants can produce new seed heads if conditions are favourable (Pitt 1998).

The soil seed bank appears to be relatively short-lived (Sillar 1969; McIvor and Howden 2000), so if germination and establishment can be prevented for one season, the problem can be greatly reduced (Anon 1967; Sillar 1969).

For isolated outbreaks or small infestations, hand-pulling or other manual control methods are recommended, preferably before seeding (Pitt 1998; Smith 2002). If seed heads are present, they should be burnt on site with enough heat to kill seeds, *e.g.* inside a drum (Miller and Harrison 1982; Pitt 1998; Parsons and Cuthbertson 2001).

Chemical control

A number of herbicides have been used to control grader grass once it has become established. Such control methods must be employed before seed set in order to prevent re-establishment the following year. Foliar spraying with glyphosate gives effective control; however, as it is non-selective, its use should be limited to where grader grass is the only remaining grass (Mitchell and Hardwick 1995; Earthworks 2003). Pasture seed should be sown after such spraying to compete with the next crop of grader grass seedlings (Mitchell and Hardwick 1995). Glyphosate can also be applied by spot-spraying or with a rope-wick applicator if grader grass is growing at least 25 cm above the pasture height (Pitt 1998; Parsons and Cuthbertson 2001).

Paraquat has also been used successfully on both seedlings and mature plants (Bishop 1981). In pastures, paraquat will damage both grader grass and other species, but perennial grasses will usually have enough root reserves to regenerate (Bishop 1981; Mitchell and Hardwick 1995). Plants should be sprayed while still young (<30 cm high) (Bishop 1981; Parsons and Cuthbertson 2001), while mature (seed at or before soft dough stage) grass requires a higher rate of paraquat and may need repeat sprayings (Tilly 1977; Bishop 1981). Bishop (1981) suggests that spraying with paraquat while seed is at, or before, soft dough stage will prevent production of fertile seed.

In sugarcane or other crops, application of pre-emergence herbicides may be beneficial. Diuron has been recommended (Tilly 1977; Parsons and Cuthbertson 2001), but its use is often restricted as soil should not be disturbed after application (Chapman 1969). Trifluralin is the most effective pre-emergence treatment in cane crops so long as it is incorporated into the soil surface (Chapman 1969; Tilly 1977; Bishop 1981; Parsons and Cuthbertson 2001), and in trials gave greater than 95% control three months after application (Chapman 1969).

In contrast, once grader grass seedlings germinate in cane, many chemical controls cannot be recommended, as they are likely to damage the cane crop as well (Chapman 1969). Inter-row cultivation or post-emergence applications of amitrole, atrazine plus 2,2-DPA, or 2,2-DPA alone give the best control (Parsons and Cuthbertson 2001). Keeping headlands and waste areas free of grader grass can help prevent invasion of the crop and can provide other benefits such as removing harbourage areas for the cane rat (*Rattus sordidus*). In these areas, control has been achieved by cultivation or application of herbicides such as paraquat, 2,2-DPA plus TCA (trichloroacetic acid), or 2,2-DPA plus paraquat (Chapman 1969; Tilly 1977). Pre-emergence application of trifluralin or applying fluazifop butyl to seedlings is also recommended for grader grass control (Parsons and Cuthbertson 2001).

In lucerne and other legume seed crops, trifluralin, fluazifop butyl, haloxyfop and quizalofop have been used successfully overseas to control grader grass (Parsons and Cuthbertson 2001). In orchards or gardens, cultivation, heavy cover crops and heavy mulching around trees may be the best solutions (Bishop 1981). Herbicides currently registered for control of grader grass are listed in Table 1. Land managers should consult an agronomist and/or product labels for recommended application rates for their situation.

Directions for future research

In order to fully understand the potential impacts of grader grass and to develop more effective control strategies, more research is needed on certain aspects of its biology. Relatively little is known about the detailed biology of this species, with few detailed experimental studies performed, namely: Chapman (1969) on herbicides, Sillar (1969) on competition and McIvor and Howden (2000) on some aspects of germination. Although this research involved some experiments on seed longevity, viability and dormancy, more detailed studies are required to validate and expand on these original results, particularly in extensive

Table 1. Herbicides currently registered for grader grass control. (Source: Infopest Agvet, March 2004, Department of Primary Industries, Queensland).

Situation	Herbicide	Pest	Australian State[1]
Cotton Lucerne, Mung beans, Navy beans, Peanuts, Soybeans Sunflowers	Butroxydim	Grader grass	Qld, NSW Qld, NSW, Vic, NT Qld, NSW
Rights of way	Paraquat, Glyphosate	Annual grasses	Qld, NSW, Vic, SA, WA, Tas, NT
Agricultural land — non-crop	Glyphosate	Weeds — Grasses	Qld, NSW, Vic, SA, WA, Tas, NT
Farm land — non-crop	Glyphosate	Weeds — Grasses	Qld, NSW, Vic, SA, WA, Tas, NT
Non-agricultural land	Paraquat	Annual grasses	Qld, NSW, Vic, SA, WA, Tas, NT

[1] Qld = Queensland; NSW = New South Wales; Vic = Victoria; SA = South Australia; WA = Western Australia; Tas = Tasmania; NT = Northern Territory.

rangeland situations where control options are often limited to fire and grazing management. Information is needed on soil seed bank longevity and the seasonality and volume of seed production under different management and growing conditions.

More detailed information is also needed on the conditions required for germination and growth, such as optimal and limiting temperatures, moisture levels and light requirements. This would allow more accurate predictions of the potential geographic range of grader grass, as well as the times of year at which it is capable of germinating, which could have important management implications. Studies on the effect of fire (smoke and/or heat) on germination would also prove beneficial. Evidence suggests that burning encourages germination of grader grass seeds, so experiments are needed to determine whether germination is stimulated by fire or simply by the removal of plant cover. At present, it is recommended that burning be avoided to discourage grader grass establishment; however, anecdotal evidence suggests that burning has been successfully used to manage grader grass (Crowley and Garnett 2000). Outcomes may depend on the season of burning and this needs to be examined. For example, burning in the early wet season may kill grader grass seedlings that emerged with the first rains and allow perennials to regenerate. This first germination event may sufficiently deplete the grader grass seed bank that regeneration would be significantly lessened after the fire.

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