



HAL
open science

The dilemma of Guinea grass (*Megathyrsus maximus*): a valued pasture grass and a highly invasive species

Aaron C. Rhodes, Robert M. Plowes, John A. Goolsby, John F. Gaskin, Boaz Musyoka, Paul-André Calatayud, Massimo Cristofaro, Eric D. Grahmann, Dino J. Martins, Lawrence E. Gilbert

► To cite this version:

Aaron C. Rhodes, Robert M. Plowes, John A. Goolsby, John F. Gaskin, Boaz Musyoka, et al.. The dilemma of Guinea grass (*Megathyrsus maximus*): a valued pasture grass and a highly invasive species. *Biological Invasions*, 2021, 23, pp.3653-3669. 10.1007/s10530-021-02607-3 . hal-04293817

HAL Id: hal-04293817

<https://hal.science/hal-04293817>

Submitted on 20 Nov 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



The dilemma of Guinea grass (*Megathyrsus maximus*): a valued pasture grass and a highly invasive species

Aaron C. Rhodes · Robert M. Plowes · John A. Goolsby · John F. Gaskin ·
Boaz Musyoka · Paul-André Calatayud · Massimo Cristofaro · Eric D. Grahmann ·
Dino J. Martins · Lawrence E. Gilbert

Received: 13 July 2020 / Accepted: 23 July 2021

© The Author(s), under exclusive licence to Springer Nature Switzerland AG 2021

Abstract On a global scale, invasive grasses threaten biodiversity and ecosystem function. Nevertheless, the importation of forage grasses is a significant economic force driven by globalization. Pastureland and rangeland are of critical economic and ecological importance, but novel grass species may lead to invasion. Recognizing that economically important species can also be ecologically damaging creates a contentious debate for land managers, policymakers, and ecologists alike. Many Afrotropical perennial grass species have been intentionally introduced pantropically given their high forage production and resistance to stress. However, these traits may also confer competitive ability, increasing the possibility of unintended escape and invasion. Further, these traits

have posed challenges for traditional control methods using chemicals, prescribed fire, and mowing. The use of classic biological control may alleviate the ecological impact in invaded areas. In this literature synthesis we examine Guinea grass (*Megathyrsus maximus*); whose economic value in many countries is undeniable, yet its impact on native ecosystems is a mounting concern. First, we introduce Guinea grass taxonomy, general biology and ecology, and the geographic and genetic origins. Second, we review the economic value and the ecological impacts. Third, we review the control of Guinea grass in undesired areas using chemical and mechanical means. Finally, we review current efforts to use biological control.

A. C. Rhodes (✉) · R. M. Plowes · L. E. Gilbert
Brackenridge Field Laboratory, University of Texas at
Austin, Room 109, 2907 Lake Austin Blvd, Austin,
TX 78703, USA
e-mail: aaronrhodes@utexas.edu

J. A. Goolsby
United States Department of Agriculture, Agricultural
Research Service, Edinburg, TX 78541, USA

J. F. Gaskin
United States Department of Agriculture, Agricultural
Research Service, Sidney, MT, USA

B. Musyoka · P.-A. Calatayud
International Centre of Insect Physiology and Ecology
(ICIPE), P.O. Box 30772-00100, Nairobi, Kenya

P.-A. Calatayud
CNRS, IRD, UMR Évolution, Comportement et Écologie,
Génomes, Université Paris-Saclay, 91198 Gif-sur-Yvette,
France

M. Cristofaro
BBCA ONLUS, Rome, Italy

M. Cristofaro
ENEA, SSPT BIOAG, Rome, Italy

E. D. Grahmann
El Coyote Ranch, Riviera, TX, USA

D. J. Martins
Mpala Research Centre, Nanyuki, Kenya

Keywords *Megathyrus maximus* · Biological control · Rangeland · Livestock · Guinea grass · *Panicum maximum*

Introduction

The introduction of nonnative grasses is at the intersection of two powerful drivers of biodiversity loss: the spread of invasive species and land conversion for pastureland development. Invasive plants, directly and indirectly, threaten biodiversity (Hejda et al. 2009; Tilman 1999), ecosystem function and biogeochemistry, (Williams and Baruch 2000), and further compound their impact by altering established disturbance regimes such as fire (Brooks et al. 2004; D'Antonio and Vitousek 1992). Consequently, the human-mediated invasion of plants has been highlighted as a critical driver of human degradation of Earth (Vitousek 1997) and a leading cause of biodiversity loss (Keane and Crawley 2002). The pantropical conversion of hundreds of millions of hectares of naturally occurring ecosystems to pasturelands compounds the impact of nonnative grass species (Jank et al. 2014). However, these negative ecological impacts must be reconciled with the socioeconomic forces promoting exotic grass introduction and land conversion (Fig. 1) (McGeoch et al. 2010).

The development of rangelands and pastureland for livestock production drives the movement and cultivation of Afrotropical perennial grasses (Ghosh et al. 2016; Jank et al. 2014; Mitchell and Bakker 2014). Given the economic importance of forage grasses, there may be contention around recognizing some of these grasses as being invasive since this could lead to restrictions on their use (Brenner 2010; Friedel et al. 2011; Hanselka 1988; Smith 2010). Nonnative grasses often have characteristics of monodominance that reduce ecosystem function and resilience (Williams and Baruch 2000), and they are often considered both invasive for their detrimental impact on ecosystems and economically important due to their value as pasture grasses (Friedel et al. 2011; Marshall et al. 2012; Sutton et al. 2019). A paradigm for weighing the positive and negative value associated with translocating plant species remains a critical step (Mooney 2005). International policy is in a positive trend to mitigate invasive species effects, yet global

movements of species due to trade—introductions, both purposeful and accidental, also continue to rise (McGeoch et al. 2010).

Guinea grass (*Megathyrus maximus* (Jacq.) B.K. Simon and Jacobs) exemplifies this dichotomy as a valuable pasture grass recognized for high livestock yields through increased forage production, palatability, and tolerance of herbivory (Maciel et al. 2018; Sukhchain 2010), yet is also a highly successful invasive species globally (CABI 2020). Guinea grass's valuable traits for livestock also correspond with its high potential as an invasive species (e.g., high biomass accumulation and tolerance to herbivory and variable environmental conditions). Therefore, it is timely to review the agro-economic benefits of an introduced rangeland grass versus its detrimental impacts on native flora, fauna, and ecosystems, as well as agriculture (Fig. 1) (Marshall et al. 2012).

Several morphotypes of Guinea grass occur sympatrically in both native and nonnative ranges (Cook et al. 2005; Mercadier et al. 2009). Of these morphotypes, two forms can be found growing sympatrically in wild populations both in introduced areas (e.g. Texas, Florida) and in its native range (e.g. Kenya, South Africa). These varieties include a tall form that is generally 50% larger in morphological characteristics and occurs in moister conditions than a short form (Fig. 2). The size differences may be due to hybridization between genotypes (Usberti-Filho et al. 2002) or the multiplication of ploidy level, given that Guinea grass is known to have sexual diploids, and facultative to strict apomictic tetraploids and higher ploidy levels ($7 \times$ and $11 \times$) (Kaushal et al. 2015). These morphologic and genotypic differences play an important role in selecting morphotypes for agricultural use and may inform the management of morphologically distinct invasive forms.

Our objective is to present a review of scientific literature concerning Guinea grass and present its importance as a forage species and its negative impact on ecosystem function. First, we discuss the taxonomy, geographic and genetic origins, and general biology of Guinea grass. Second, we review the economic value for pasture development, economic detriment as an agricultural weed, and the ecological impacts on native plants and fire regimes. Third, we review the control of Guinea grass in undesired areas using chemical, mechanical, prescribed fire, and grazing. Finally, we consider the use of natural

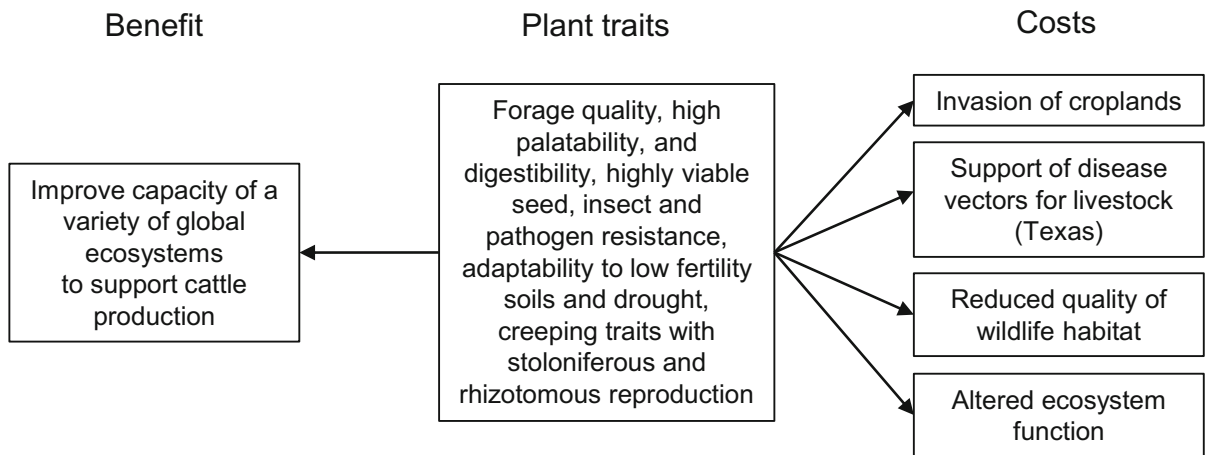


Fig. 1 Conceptual framework of the significant costs and benefits of forage species and the functional traits often selected for collection and cultivation

enemies to reduce the ecological impacts of Guinea grass. We describe ongoing work in the search for an appropriate arthropod species for biological control.

Guinea grass taxonomy

Megathyrus maximus has a long history of taxonomic revisions at both generic and species levels, compounded in part by multiple global introductions from several African sources and further distribution of both tall and short forms and multiple cultivars, including a hybrid form of two related species (*M. maximus* and *M. infestus*) (Bon et al. 2011; Parsons 1972). Guinea grass species have been variously assigned to genera; *Panicum*, *Urochloa*, and *Megathyrus* (Table 1). Giussani et al. (2001) proposed placement in *Urochloa* based on sequences of chloroplast gene *ndhF*, yet morphological characteristics suggest that proposed moves to *Bracharia* or *Urochloa* should be avoided (Brown 1977; Reinheimer et al. 2005). Retention in *Panicum* presents further problems since this would make *Panicum* paraphyletic (Simon and Jacobs 2003). To resolve these issues, *Megathyrus* was elevated from subgenus and presently includes *M. maximus* and *M. infestus*, two species characterized by a distinct transversally rugose upper lemma and P.C.K. C4 Kranz subtype of leaf anatomy (Simon and Jacobs 2003). However, some databases have not been updated and still retain alternate generic placements [e.g., PLANTS database, (USDA NRCS 2020)].

Combined molecular and morphological data Soreng et al. (2015) has reaffirmed *Megathyrus* as the valid genus, and we use that nomenclature here. Within the species complex, Guinea grass has numerous infraspecific taxa (Table 1).

Biology and ecology

Guinea grass is a tufted perennial C4 bunchgrass that reproduces by seed and vegetatively through both rhizomes and stolons in highly variable environments such as savannas (Rhodes et al. *in prep.*), grasslands (Ho et al. 2016), tropical forests (Mantoani and Torezan 2016), cultivated pasturelands (Maciel et al. 2018) and in agricultural settings, especially with sugarcane (Cabrera et al. 2015) and citrus (Chandramohan et al. 2002). Individual plants produce many panicles with seeds that mature and drop over several weeks. Seed dispersal is likely via seed-eating birds, or arthropods and seeds will adhere to wet surfaces allowing mechanical dispersal (CABI 2020). Anthropogenic dispersal is driven by movement on vehicles and mowers (Veldman and Putz 2010).

The short form has become a major invasive threat in parts of southern Texas and northeast Mexico. Morphologically, the tall and short forms from Kenya, South Africa, and Texas both key to *M. maximus* (Agnew 2006; Flora Zambeziaca 2019). The two forms may be differentiated by height and leaf size (Fig. 2). The lack of intermediate growth forms in



Fig. 2 Morphotypes of Guinea grass in North America. Guinea grass (*M. maximus*) grows in dense clumps with a high density of plants connected through very short rhizomes. Guinea grass culms are erect and cylindrical with either glabrous internodes or hairy internodes. The culms are sometimes branched, and this branching may develop into stoloniferous growth, where the leaf and root tissue will form vertically as the culm begins laying over. These stoloniferous nodes often reproduce one to three individuals per culm (Alves, Xavier 1986). Short and tall forms of Guinea grass are differentiated by their morphological characteristics of the leaves and stems. They can grow sympatrically, but large Guinea grass favors wetter shadier environments, while short form Guinea grass can grow in mesic and open areas. Short form Guinea grass generally grows 1–2 m tall, while tall form Guinea grass grows 2–3 m in height in well-watered conditions (Photo 1). Leaves are highly variable with light green to bluish-green leaves which are linear, narrowly lanceolate and vary in size for the short form from 12 to 40 cm long, and 12 to 25 mm wide and large Guinea grass leaves can reach up to 60 cm long and 35 mm wide. Panicles for both short and tall Guinea grass are ovoid racemose and terminal from 15 to 65 cm long. Reddish-brown spikelets are oblong, rounded on the back, either glabrous or pubescent 3.5 mm long when mature (Alves, Xavier 1986). The ligule is membranous with a ciliate margin and is from 1 to 3 mm long (Wagner et al. 1999). Guinea grass is highly plastic in both its vegetative characteristics (size, color, hairiness) (Ellis 1988) and reproductive strategy (seed vs. vegetative (Rhodes et al. *in prep.*)), which has led to many morphotypes being described in its native range (Njarui et al. 2015).

wild populations, even in close proximity such as at Mpala, Kenya, and Brownsville, Texas, indicates a level of reproductive isolation, perhaps from apomixis or from differing ploidy levels (Fig. 2). However, several intermediate size classes exist as products of breeding programs (Jank et al. 2001; Sukhchain 2010; Usberti-Filho et al. 2002).

Information on the biology of Guinea grass typically refers to the tall form, being a well-studied pasture grass in its introduced ranges, yet differentiation between the two forms in published literature is rare. Guinea grass can exhibit high intraspecific variation in morphological traits, yet some of this variation is attributable to the two forms (Fig. 2) and growth under a wide range of environmental gradients. Descriptions of Guinea grass characterize it as growing on light-textured (loams and sandy loams), well-drained soils in areas with high mean precipitation ranging from 750 to 1700 mm per annum and few frost days (Alves and Xavier 1986; Bogdan 1977; Holm et al. 1977). Chou and Young (1975) report that it has strong allelopathic effects, and this trait may facilitate invasion.

Major limiting abiotic factors of Guinea grass's potential range may be minimum temperatures and rainfall. The short form of Guinea grass has been known to grow at 500 mm of rainfall and may be more drought tolerant than the tall form. This could, in part, explain the expansive range of short form Guinea grass into the semiarid rangelands of south Texas, while the tall form is confined to the banks of the Rio Grande River in Texas. Similarly, at Mpala Research Station in Kenya, the short form is found in both the open and shaded portions of savanna sites, while the tall form is restricted to the Ewaso Ng'iro riparian zone. Although Guinea grass, generally, can tolerate dry conditions, droughts more prolonged than four months have been noted to cause high mortality rates (Holm et al. 1979). Guinea grass can survive mild frost and remain somewhat productive in cool-season climates (Islam and Thakuria 2002), although it is globally absent from cooler areas with increased frost days (Fig. 3). Guinea grass grows naturally in grasslands and savannas under woody plants or riparian areas. It can colonize open areas with sufficient soil moisture and sheltered areas with low ungulate herbivory under cover of woody plants, especially nitrogen-fixing trees (Rhodes et al. *in prep.*).

Table 1 Taxonomic summary of *M. maximus*

	Nomenclature	Describing Botanist	
Accepted name	<i>Megathyrsus maximus</i>	(Jacq.) B.K. Simon and Jacobs, 2003	
Synonyms	<i>Panicum bivonianum</i>	Brullo, Miniss, Scelsi & Spamp	
	<i>Panicum eburnum</i>	Trin	
	<i>Panicum heynii</i>	Roth	
	<i>Panicum hirsutissimum</i>	Steud	
	<i>Panicum jumentorum</i>	Pers	
	<i>Panicum laeve</i>	Lam	
	<i>Panicum maximum</i>	Jacq	
	<i>Panicum pamplermoussense</i>	Steud	
	<i>Panicum polygamum</i>	Sw	
	<i>Panicum praticola</i>	Salzm. ex Döll	
	<i>Panicum scaberrimum</i>	Lag	
	<i>Panicum sparsum</i>	Schumach	
	<i>Panicum teff</i>	Desv	
	<i>Panicum tephrosanthum</i>	Schinz	
	<i>Panicum trichocondylum</i>	Steud	
	<i>Panicum trichoglume</i>	Engl	
	<i>Urochloa maxima</i>	(Jacq.) R.D. Webster	
	Intraspecific taxa	var. <i>altissimum</i>	Kuntze
		var. <i>bulbosum</i>	(Kunth) Vasey
var. <i>coloratum</i>		C.T. White	
subsp. <i>commune</i>		(Nees) Peter	
var. <i>commune</i>		Nees	
var. <i>confine</i>		Chiov	
var. <i>congoensis</i>		Vanderyst	
var. <i>glaucum</i>		Nees	
var. <i>gongylodes</i>		(Jacq.) Döll	
var. <i>heterotrichum</i>		Peter	
var. <i>hirsutissimum</i>		(Steud.) Oliv	
var. <i>hirsutum</i>		Peter	
var. <i>laeve</i>		Nees	
var. <i>laevis</i>		Nees	
var. <i>maximum</i>		M. Sharma	
subsp. <i>pubescens</i>			
var. <i>pubiglume</i>	K. Schum		
var. <i>trichoglume</i>	Robyns		

Despite well-established descriptions of Guinea grass's environmental conditions, there is only anecdotal evidence of expanded physiological limits in nonnative regions. Along with release from biotic stressors, another possible explanation for such expansion is that extensive breeding programs and highly variable genotypes and phenotypes contribute to an expanded range of suitable habitat conditions for

Guinea grass (CABI 2020). For example, short form Guinea grass is documented to grow in areas with lower annual precipitation (500 mm) with frequent dry periods in both introduced ranges in South Texas and its native range in Kenya. Short form Guinea grass has been observed on saline clay soils in West Texas (E. Grahmann obs.), suggesting expanding tolerance to soil resource limitation. Guinea grass in Mexico is

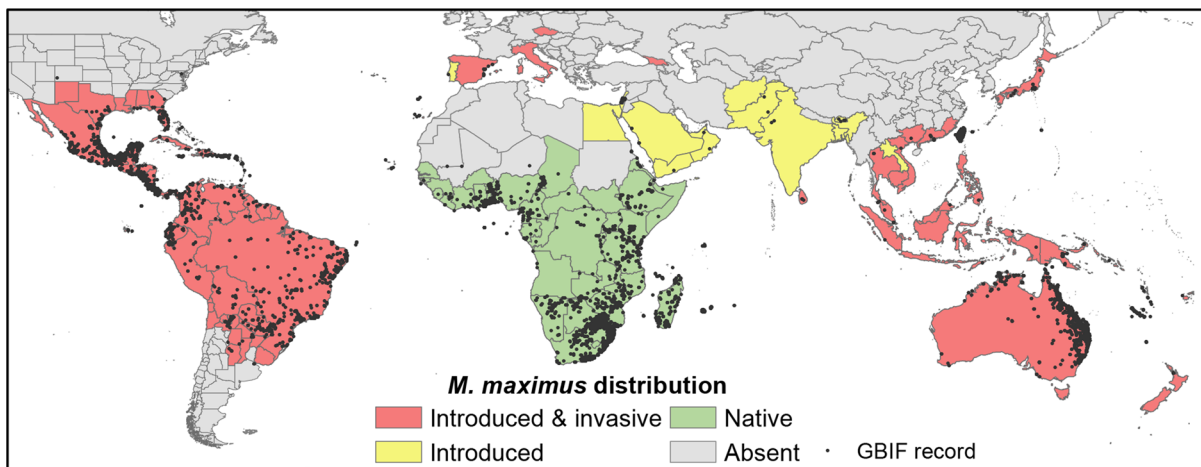


Fig. 3 Distribution and status of *M. maximus*. Introduced and invasive status based on CABI (online, April 2020), shown by country or state political boundaries. Location records sourced from GBIF (online, April 2020)

encroaching into higher elevation areas 1800 to 2400 m a.s.l. in Mexico's Altiplano region (A. Quero pers. obs.), yet there are no records of it growing above 1900 m elevation in its home range in east Africa (East African Herbarium, Kenya 2020). A clear understanding of the biogeography of Guinea grass in the context of invasion biology is currently lacking yet needed as it continues to invade unintended areas.

Geographic distribution

Guinea grass is native to Africa's wetter tropical, and subtropical regions yet have been widely introduced into other regions both accidentally and as a forage species beginning as early as the seventeenth century (Fig. 3) (CABI 2020; GBIF 2020; Parsons 1972). Guinea grass was generally imported for range improvement or by accident in chaff (Parsons 1972), and has since been cultivated extensively and utilized in tropical and subtropical regions globally (CABI 2020; Jank et al. 2014). Guinea grass growing in diverse conditions in its home range can lead to persistent ecotypes across a range of climatic conditions (Njarui et al. 2015), but it can also have sympatric morphotypes in its introduced and native ranges (Soti et al. 2020). Guinea grass now has a pantropical distribution (Fig. 3), where its success is due to its highly plastic vegetative characteristics and popularity as a forage species. However, in many regions, it has escaped from target pastures and

invaded recently disturbed sites, spreading along roadsides and into native grasslands, savannas, and forests (Espinosa-Garcia and Villasenor 2017; Ho et al. 2016; Mantoani and Torezan 2016; Rojas-Sandoval, Meléndez-Ackerman 2012; Veldman and Putz 2010).

Guinea grass introduction and cultivation varies on a country-to-country basis, where its economic benefits and ecological damage must be considered independently. Guinea grass is a vital forage throughout India following introduction as early as 1793 (Parsons 1972) and where research into increasing forage quality has been conducted (Sukhchain and Sidhu 1992). Guinea grass was introduced into Japan in the 1960s and was considered an excellent forage species for Japan's southern islands (Komatsu and Nakajima 1988). It has been a principal forage grass used in Queensland, Australia but is also considered an invasive weed (Holm et al. 1979). Guinea grass may have spread to the Antilles as early as 1684, where it was extensively cultivated and then reached mainland Latin America by 1797 through Columbia (Parsons 1972). Its fast biomass accumulation and tolerance to herbivory throughout the Americas led to comments of it being a miracle grass (Parsons 1972). The planting of pastures in Central America through the nineteenth century was attributed to expanding the livestock industry in Costa Rica, Guatemala, and Mexico (Parsons 1972). Guinea grass has been used as cattle forage in Brazil but tended to escape pastureland into tropical forest understories and disturbed sites,

especially roadsides (Mantoani and Torezan 2016). It was reported as an invasive weed in Mexico as early as 1910 (Hitchcock and Chase 1910) and is now considered a candidate for mitigation (Espinosa-Garcia and Villasenor 2017). In the United States of America, Guinea grass was collected in Lake City, Florida, in 1889 by Bitting, in South Texas along the Rio Grande in 1894 by Heller and in Hawai'i in 1903 (GBIF 2020). Despite these early collections, Guinea grass was only recently reported as an invasive in 1984 on the eastern coast in the Indian River–Fort Pierce area, Florida (Chandramohan et al. 2002). To date, Guinea grass has invaded large areas of South Texas, especially in the Rio Grande Valley (Lonard and Judd 2006). In our field observations, we only found the tall form in limited riparian areas along the Rio Grande River at Brownsville, while the short form is undergoing rapid expansion along roads and into rangelands and riparian zones through South Texas.

History of cultivation and breeding

Given its success as a forage species, Guinea grass has undergone extensive cultivation with major breeding programs, especially in India, Brazil, Japan, and Mexico (Ghosh et al. 2016; Savidan et al. 1989). Hybridization and selection have produced traits highly desirable for forage production. Traits that are commonly selected for include: forage quality, high palatability and digestibility, highly viable seeds, insect resistance, adaptability to low fertility savanna soils, drought tolerance, rapid seedling growth, and creeping traits with stoloniferous rooting (Jank et al. 2001; Savidan et al. 1989). Diploid sexual Guinea grass forms have been used for artificial doubling to produce autotetraploids and allowed to cross with apomictic individuals to fix desirable traits (Miles and Hare 2007; Resende et al. 2004). Higher forage production is linked to vegetative spread through stoloniferous growth traits transferred through backcrossing sexual and apomictic individuals (Savidan et al. 1989). These traits of high productivity, biotic/abiotic resistance, high reproductive output, and plasticity in reproductive mode likely improve the invasion success of Guinea grass.

Guinea grass has been used as a model plant for studying apomixis and polyploidy due to the ploidy-dependent expression of apomixis, which allows the

components of apomixis to be separated (Kaushal et al. 2018). Apomixis is considered essential for trait fixation by avoiding the genetic variability introduced through recombination (Calzada et al. 1996; Kaushal et al. 2018). Most cultivars of Guinea grass are tetraploid and reproduce in a facultative apomictic manner (Kaushal et al. 2015; Warmke 1954). However, Guinea grass displays a gradient of sexuality from full sexuality, facultative apomicts to obligate apomicts for diploid and tetraploid individuals (Nakajima and Mochizuki 1983). Diploid Guinea grass has either $2n = 16$ or $2n = 18$ chromosomes with two accessory chromosomes, and tetraploid are generally $2n = 32$ chromosomes (Kaushal et al. 2018; Nakajima and Mochizuki 1983). Sexuality in Guinea grass has been an important characteristic for developing hybrids (Nakajima and Mochizuki 1983) and has led to the fixation of traits associated with higher productivity (Savidan et al. 1989). Differences in genotypes and ploidy level could influence the economic value of Guinea grass or its invasiveness.

Breeding programs in Latin America introduced new genetic material from East Africa for improvement and were conducted in Brazil by Empresa Brasileira de Pesquisa Agropecuária, (EMBRAPA), in Colombia by Centro Internacional de Agricultura Tropical (CIAT), in Mexico by the Colegio de Postgraduados, and in Cuba by the Indio Hatuey Research Center during the 1980's (Savidan et al. 1989). In Brazil, at EMBRAPA Gado de Cort, an extensive breeding program for Guinea grass began in 1982 using autotetraploids crossed with apomictic individuals to fix desirable palatability traits (Resende et al. 2004). For example, in Brazil, programs at EMBRAPA evaluated 72 hybrids obtained from crosses between sexual and apomictic individuals to develop higher productivity in Guinea grass for forage production (Jank et al. 2001). An extensive breeding program for improving plant vigor and seed production was established by the National Grassland Research Institute of Japan in 1974 (Nakajima 1978). These types of programs continue to improve pathogen resistance and yield (Maciel et al. 2018). Tall Guinea grass remains a pasture grass under extensive development for pastureland and rangeland improvement despite growing concern about negative impacts away from pastures. While these programs increase the economic value of Guinea grass, these programs also increase the invasive potential.

The forage value of Guinea grass

While it is difficult to quantify the direct economic value of Guinea grass, this grass is often cited as being among the most important forage grasses in subtropical and tropical regions (Baldassini et al. 2018; Choudhary et al. 2018; Euclides et al. 2018, 1999; Maciel et al. 2018; Sukhchain 2010). Guinea grass is implicated as a species integral to the early expansion of pastureland development across the tropics (Motta 1953). For example, the conversion of tropical forests to pasturelands has created hundreds of millions of hectares of land sown with old-world C4 grasses (Williams and Baruch 2000), including Guinea grass (Jank et al. 2014). In Brazil, there are 190 Mha of pastureland with approximately 10% under Guinea grass cultivation, while cattle contribute nearly 7% of Gross Domestic Product (Jank et al. 2014). Further, Guinea grass seed exportation is a significant contributor to Brazil's seed export economy of 600 million USD annually, with over 16% of total grass seed exports being Guinea grass (Jank et al. 2014). A complete economic analysis of nonnative perennial grasses has yet to be completed but is warranted.

Rangelands and pasturelands are of critical economic importance to many developed and developing countries (Choudhary et al. 2018; Ghosh et al. 2016; Jank et al. 2014). Therefore, research into the cultivation and improvement of valuable pastoral species plays a vital role in food security and economic stability (Ghosh et al. 2016), both in commercial and informal settings. Tall form Guinea grass is considered a preferred choice as a forage grass and is therefore of high economic value across its pantropic distribution (Choudhary et al. 2018). It grows well in many conditions and yields abundant palatable and nutritious forage (Maciel et al. 2018). However, nutritive value declines rapidly through the growing season (Alderson and Sharp 1994). The economic value of short form Guinea grass is less evident in South Texas. A more focused assessment of the economic contribution of nonnative grass species may help weigh the benefits and consequences of using nonnative grasses with invasive traits.

Guinea grass in agricultural settings

Traits associated with high yields and fast growth in Guinea grass make it challenging to control, and escape from intended areas makes it a weed in other environments (Dias et al. 2013; Ho et al. 2016; Zenni and Ziller 2011). If Guinea grass escapes from intended pasturelands, it may invade other agricultural endeavors such as tree plantations and cash crops. For example, Guinea grass is considered a costly weed for many crops in Africa, America, Australia, and Asia (Baker and Terry 1991; Chandramohan et al. 2002; Dias et al. 2013; Holm et al. 1977). Guinea grass is a significant weed in sugarcane production globally, reducing yields by as much as 40% (Kuva et al. 2003). It may also reduce the establishment of native grass species such as *Miscanthus sinensis* grasslands in Taiwan (Ho et al. 2016) and suppress grass species important for northern bobwhite (*Colinus virginianus*) in Texas (Ramirez-Yanez et al. 2007). Guinea grass has also been implicated in the loss of ecotourism due to its conversion of native grasslands (Ho et al. 2016). Generally, Guinea grass is scored as a high-risk invasive species globally (Randall 2017).

Guinea grass also exhibits some positive impacts in agricultural settings. Guinea grass has been shown to suppress nematodes detrimental to various cash crops, including; tobacco, coffee, taro, and ginger (Bridge 1996; Sipes and Arakaki 1997; Sistachs et al. 1991; Stirling and Nikulin 1998). Guinea grass is also used in intercropping systems to be used as fodder (Borghi et al. 2013; George and Pillai 2000). Whether these positive effects outweigh the negative impacts on agriculture is not well studied and likely depends on specific circumstances. Juxtaposed against the positive economic impact of introduced grass species is the often significant detrimental effects of escaped grasses in agricultural and ecological settings (Espinosa-Garcia and Villasenor 2017).

In South Texas, short form Guinea grass has some value as a pasture grass, but many negative aspects impact crops, rangelands, and natural areas. In rangelands, it is implicated in the decline of ground-dwelling granivorous birds such as quail, a significant economic loss of ranches that rely on hunting for income (Fulbright et al. 2013). In Texas, short form Guinea grass provides an ideal, cool, shaded habitat for the survival of cattle fever ticks (*Rhipicephalus microplus*) on cattle, nilgai (*Boselaphus*

tragocamelus), and deer (*Odocoileus* spp.) since in these conditions, ground-dwelling tick predators such as beetles and ants are suppressed. Guinea grass thereby facilitates cattle fever tick populations by creating a 'pathogenic landscape' in Texas (Esteve-Gassent et al. 2014).

Invasive potential

The invasiveness of an introduced species and the invasibility of the introduced range interact to determine the success of invasion (Davis et al. 2000; Richardson and Pyšek 2006). Guinea grass's life history and functional traits are characteristic of many successful invasive species. Guinea grass traits allow it to spread rapidly, maintain high reproductive potential, and produce long-lived robust adults that are highly competitive (Ho et al. 2016; Zanine et al. 2018). This species can become monodominant, altering the plant community when it shades and outcompetes other plant species (Hejda et al. 2009). Higher photosynthetic rates, the rapid growth of seedlings, and accumulation of biomass in the absence of grazing and arthropod folivores and detritivores have been proposed as mechanisms that are more competitive than native grass plant species (Ho et al. 2016). Higher growth and carbon assimilation rates can alter the ecophysiological properties of invaded environments (Williams and Baruch 2000) and provide mechanisms that underlie the invasion of novel systems (Levine et al. 2003).

Currently, the dispersal range, rate, and mechanisms of Guinea grass seed are not well studied. Long-range dispersal of potentially invasive forms is often human-mediated along transportation corridors (Van Devender and Dimmitt 2006) when seeds, stolons, or rhizomes are inadvertently transported on vehicles, mowers, within hay, or cattle (Veldman and Putz 2010). Stolons and rhizomes represent a critical vegetative reproductive strategy and may be integral to its spread in areas where seedling germination is limited by abiotic conditions (Rhodes et al. *in prep.*). Once established, short-range dispersal may occur through local seed dispersal by birds or animals (Mantoani and Torezan 2016) or by stoloniferous growth from established (Rhodes et al. *in prep.*). Understanding the mechanisms of dispersal for

Guinea grass could improve our understanding of the biogeography of future invasions.

Impacts on natural ecosystems

Guinea grass degrades natural ecosystems by outcompeting native plant species (Ho et al. 2016), altering fire regimes (Ellsworth et al. 2013), promoting alternative stable states (Mantoani and Torezan 2016), and disrupting associated fauna that provides ecosystem services (Litt et al. 2014). In disturbed areas, Guinea grass can form dense tussocks that outcompete native flora (Baruch 1996) and impact native plant and animal community structure, species richness, or abundance (Litt et al. 2014). Highly plastic functional traits may allow Guinea grass to invade various plant community types and adjust to seasonal conditions (Ammond and Litton 2012; Ammond et al. 2013). Invasion into lowland grasslands in Taiwan replaces native grasses (e.g., *Miscanthus sinensis*) of a similar niche (Ho et al. 2016), suppresses tropical forest regeneration in Brazil (Mantoani and Torezan 2016), and fills the interspaces in semiarid savannas in Texas (Ramirez-Yanez et al. 2007). In some cases, Guinea grass may have a higher susceptibility to drought than native plants in the nonnative range, yet the trade-off for higher productivity may contribute to the exclusion of native plants in the same ecological niche (Baruch 1996; Ellsworth et al. 2013; Ho et al. 2016).

Disturbance of soils and vegetation may facilitate the spread of invasive species through changes in resource availability (Lonsdale 1999), and invasive grasses themselves can alter disturbance regimes, such as fire, creating positive feedbacks (D'Antonio and Vitousek 1992; Marshall et al. 2012). Guinea grass spreads quickly after a fire and mechanical treatments such as periodic mowing (Chandramohan et al. 2002). It can withstand fire if the roots are not destroyed, and in dense patches where it produces excess biomass, intense fires may alter the plant community and reinforce Guinea grass dominance (Ellsworth et al. 2013; Ho et al. 2016). Since Guinea grass is fire-tolerant (Ellsworth et al. 2013), a local Guinea grass invasion can exacerbate changes in ecosystem function and create alternate stable states where fire becomes a predominant property (Ammond et al. 2013; Grace et al. 2000).

Like other invasive grass species, Guinea grass promotes increased frequency in fire regimes (Brooks et al. 2004; D'Antonio and Vitousek 1992; Ellsworth et al. 2013). Accumulation of fuel loads can lead to tipping points that alter ecosystem states and lead to the degradation of rangelands (Brooks et al. 2010). Altered fire regimes have strong top-down effects on ecosystem function and threaten to shift biomes (e.g., cool desert to annual grassland (St Clair et al. 2016), and tropical forest to perennial grassland (Pivello 2011)). Guinea grass can produce year-round fine fuel loads, and it recovers rapidly after a fire (Ellsworth et al. 2013). In tropical environments, the fine fuel loads from perennial African grasses have been reported to reach 76% to 87% of the grass fuel load (Kauffman et al. 1998). Guinea grass has highly variable fine fuel loads ranging from < 1 to 19.0 Mg ha^{-1} , which has important implications for managing Guinea grass and restoring invaded areas (Ellsworth et al. 2013; Francis and Parrotta 2006; Portela et al. 2009). Guinea grass regenerates rapidly from underground rhizomes after a fire and accumulates biomass quickly to replace native grasses via competition, especially after fire (Ho et al. 2016). Fire-cycle feedback then promotes subsequent increases in grass invasion and the prevention of native species regeneration (Portela et al. 2009).

Nonnative grasses can have negative impacts on wildlife and their habitat (Fulbright et al. 2013; Grahmann et al. 2018; Ramirez-Yanez et al. 2007; Smith 2010) through altering vegetation structure (Grahmann et al. 2018), reducing the biodiversity of animals (Litt et al. 2014), and altering disturbance regimes (Brooks et al. 2004). Guinea grass's impact on plant communities includes alteration of successional patterns (Dias and Torezan 2020) and negatively impact reproduction, growth, survival, and establishment of tree and cactus species (Rojas-Sandoval et al. 2016). Guinea grass can remain in the understory long after reforestation and remediation in tropical forests (Dias and Torezan 2020). Guinea grass hinders native grasses and forbs, which indirectly reduces the biodiversity of native fauna (Kuvlesky Jr et al. 2002; Ramirez-Yanez et al. 2007). Guinea grass seed is palatable to northern bobwhite (Larson et al. 2012), yet vegetation structure created by monodominant African perennial grasses generally does not create suitable habitat for native birds (Grahmann et al. 2018; Moore 2010). Guinea grass reduces arthropod

biodiversity, which may have bottom-up effects on flora and fauna dependent on a diverse arthropod community (Moreno et al. 2014).

In a few cases, native plants do compete well with Guinea grass, such as in Brazilian tropical forests where the vine *Mikania* sp. reduces Guinea grass cover and biomass due to light competition (Mantoani and Torezan 2016). Similarly, in the Brazilian tropical forest understory, the shade-tolerant *Geophila repens* may prevent Guinea grass colonization through its foliar cover dominance and prevention of seedling establishment (Mantoani and Torezan 2016). In Costa Rica's Corcovado National Park, tall Guinea grass pastures were shaded out by secondary forests in less than 10 years after the park's establishment in late 1976 (LEG personal obs.). Ammond and Litton (2012) found that high functional diversity in native plants was necessary to reduce Guinea grass growth. They found a canopy tree, shrub, and ground covering forbs (*Myoporum sandwicense*, *Dodonaea viscosa*, *Plumbago zeylanica*) reduced Guinea grass's competitive ability, but each alone could not. This suggests that in restoration activities, a functionally diverse community of plants should be considered.

Guinea grass management and control

The control of invasive perennial grasses is complicated because some of the most important agricultural species are grasses and restoration of rangeland and grassland depends on the success of native grasses. Therefore, chemical and mechanical methods that typically target nonnative grass species would also damage desired species (Ray et al. 2018; Sutton et al. 2019). Control options depend on whether Guinea grass is invading grass crops, tree plantations, natural forested areas, or native rangelands. Available control techniques include combinations and interactions between chemical applications, cattle grazing, prescribed fire, mechanical removal, bioherbicides, and biological control using host-specific natural enemies from the plant's native range (Simmons et al. 2007). The use of grazing, fire, and bioherbicides have had some success in mitigating the impact of Guinea grass on native rangelands (Ramirez-Yanez et al. 2007) and in agricultural settings (Chandramohan et al. 2002). Improvements may also be gained through promoting

native soil microbial communities in addition to the sowing of native plants (Wubs et al. 2019).

Chemical and mechanical control

Management methods for Guinea grass depend heavily on the agricultural context and size of the area affected. Combinations of chemical and mechanical control are often used in agricultural settings. The use of glyphosate herbicide on Guinea grass in earlier growth stages requires low concentrations (Silva et al. 2018), so combined mechanical removal and chemical treatment may be appropriate in some settings. Despite continued attempts at chemical controls, Guinea grass has significant tolerance to herbicides, making chemical control expensive and not pragmatic across large areas (Chandramohan et al. 2002). A chemical application can negatively impact non-target species, making a chemical application over large areas undesirable for natural ecosystems (Cauble and Wagner 2005). Intensive mechanical removal of Guinea grass is effective in tropical forest restoration (Mantoni and Torezan 2016). Mechanical removal on 40 ha was successful after four removal events, allowing sufficient woody vegetation to outgrow and outcompete Guinea grass. This method may not be efficient for larger areas or reclaiming grasslands, although restoration responses will vary across plant functional groups and ecoregions (Davies and Sheley 2011). For larger areas, prescribed fire and targeted grazing (Rhodes et al. 2020) may improve management and control outcomes for perennial invasive grasses.

Prescribed fire and grazing

A combination of grazing and fire has successfully reduced the dominance of Guinea grass and its impact on native plants, which improves habitat for animal species (Ramirez-Yanez et al. 2007). However, in invaded grasslands where fire is common, Guinea grass can outcompete native grasses despite their evolutionary history with fire or classification as pioneer species after major disturbance (Ho et al. 2016). The use of grazing to lower fine fuel loads and reduce fire potential is a successful mitigation technique in areas where fire is uncommon (Evans et al. 2015). Targeted or prescribed grazing is a potential tool for mitigating Guinea grass impacts on native

plant communities, but such techniques require expertise and highly adaptable management (Frost and Launchbaugh 2003). General recommendations for the use of grazing to control invasive grasses are lacking due to the particularities of season, precipitation, and native plant communities (Frost and Launchbaugh 2003).

Biological control

Perhaps the most promising form of sustainable control (precluding prevention) may be classical biological control. In some cases, candidate biological control agents can be specific to a single genotype of a weed. Therefore, a biological control program could potentially target the short form of Guinea grass while minimizing impacts to tall form Guinea grass in areas where it is an important forage grass. For example, the leaf galling mite, *Floracarus perrepa*, consists of a suite of specialist genotypes, each developing on their genotype of the climbing fern, *Lygodium microphyllum* (Goolsby 2006). Similarly, leafhopper insects (Cicadellidae) that were released as biological agents for Gulf coast cordgrass (*Spartina alterniflora*) developed on only one grass genotype (Garcia-Rossi et al. 2003). In one of few other cases of grass biological control (Sutton et al. 2019), three agents were released to manage giant cane (*Arundo donax*) in Texas after careful host matching (Goolsby et al. 2017).

Biological control may also consider pathogen and bioherbicide options. Bioherbicides based on fungal compounds have had some success (Chandramohan et al. 2002). For example, specific bioherbicide activity of Radicinin derivatives, active compounds extracted from *Cochliobolus australiensis*, a plant pathogen fungus associated with buffelgrass, have been used (Masi et al. 2019). The use of bioherbicides has been successful in agricultural settings, but it is unknown whether restoration of native grassland or rangelands would respond well to bioherbicides or be cost-effective. Recently, smut affecting Guinea grass in North America has been described (Roskopf et al. 2019), which may provide an avenue for biological control. Leaf spot disease *Bipolaris maydis* in Brazil has been shown to lower Guinea grass yields, yet a new cultivar, “Zuri” was developed in 2014 to be blight resistant (Maciel et al. 2018). The specificity of fungal pathogens has not yet been tested in Guinea grass but is a worthwhile research avenue. While

pathogens and bioherbicides may have applications for controlling invasive grasses in agricultural settings (Chandramohan et al. 2002), their use in rangelands may also affect closely related native grasses (e.g., *Panicum* sp.). Import of pathogens would face complex regulatory pathways, so limiting a search for pathogens already found in the introduced range could be plausible.

Import of a highly specific arthropod from Guinea grass's native range may provide optimal biological control. Following the same approach used with *Phragmites australis* (Casagrande et al. 2018), such arthropods could be screened as candidates for biological control if they are found to be impactful and host-specific. One survey in Cameroon encountered a Geometrid moth and beetle species in the Alticidae, Chrysomelidae, and Riocerinidae families (Mercadier et al. 2009). Stem-boring larvae of the noctuids *Buakea kaeuae* and *Buakea obliquifascia* were associated explicitly with Guinea grass in Kenya (Moyal et al. 2011). However, mass-rearing attempts under laboratory conditions on Texas short Guinea grass were unsuccessful for unknown reasons (Vacek et al. 2021). Some genera of eriophyid mites, such as *Abacarus* and *Aculodes* are common pests on grass species (Laska et al. 2018; Sutton et al. 2019). An Eriophyid mite (*Abacarus* sp.) that infests leaves of Guinea grass has been recorded at Mpala, Kenya, while in Durban, South Africa a Diptilomiopid mite (*Diptacus* sp.) has been found (J. Goolsby and M. Cristofaro, pers. comm). The *Diptacus* sp. is under evaluation to determine its host specificity and potential damage to Guinea grass. Further exploration is planned in the genetic match location (Bon et al. 2011) for the Texas short form of Guinea grass near Durban, South Africa.

Guinea grass has invaded large areas of South Texas, especially in the Rio Grande Valley (Lonard and Judd 2006). The tall form is found only in limited portions of riparian areas along the Rio Grande River at Brownsville, while the short form is undergoing rapid expansion along roads and into rangelands (Soti et al. 2020). If these forms have different genotypic and geographic origins, these differences could provide an avenue for biological control of the short form but be less impactful on the more economically valuable tall form. The introduction of host-specific detritivores specific to Guinea grass may also be a possible avenue of research (Sands and Goolsby

2011). Removing thatch could reduce some of the shading effects of plant-plant competition and reduce the biomass accumulation associated with altered fire regimes.

Control of invasive grasses presents significant challenges, given that many management options are infeasible at the scale typically required for significant ecological restoration (Brooks et al. 2010). Biological control may be the most cost-effective and longest-lasting type of control, barring the prevention of spread. In areas where tall form Guinea grass is highly desired as a forage species, the use of arthropods that focus on detritus, or reproduction (e.g., seeds), may allow stakeholders to grow Guinea grass but limit its fire impacts or its spread outside of intended areas. Biological control that reduces the biomass accumulation and propagule pressure of invasive grasses is a worthy strategy for the general management of invasive grasses.

Conclusion

Our review of the current literature shows a dichotomy of Guinea grass agricultural value against invasive costs and impacts. Contemporary literature describes its economic importance to the livestock industry (Jank et al. 2014) and as a highly detrimental invasive species (Ho et al. 2016; Ramirez-Yanez et al. 2007; Zenni and Ziller 2011). This dichotomy creates real challenges for managing perennial C4 grasses that are widely cultivated and distributed globally for rangeland improvement (Cox et al. 1988; Marshall et al. 2012). While invasive grasses often have characteristics of monodominance that reduce ecosystem function and resilience, they are often much slower to be considered invasive due to their economic importance (Friedel et al. 2011; Marshall et al. 2012). However, a provocative question is, “what can be done when a plant species is both economically important and ecologically damaging?” Some stakeholders would be wary of having economically important plant species labeled as noxious or invasive.

Nevertheless, an approach is required that allows continued sustainable use while mitigating invasive impacts. Biological control of the less economically important short form Guinea grass is plausible in Texas but presents the challenge of finding arthropods that have greater impacts on specific morphotypes of a

single species. Therefore, policymakers and land managers alike have critical challenges ahead due to the dichotomy of managing an economically important forage species that can be a highly damaging species to native ecosystems and some other agricultural land uses. A focus on control of Guinea grass where it is not wanted (e.g., South Texas) would be the most compelling outcome without harming agricultural and rangeland use areas.

Acknowledgements We thank Ivy Ng'iru of Mpala Research Centre, Kenya and Jason Lawson, and Shawn Evenson at the Brackenridge Field Laboratory (BFL) for field and laboratory support. Jimmy Rutledge and Bart DuPont of El Coyote ranch provided stimulating discussions and insights. During review of the manuscript, we received useful feedback from the reviewers which have improved several aspects of this paper. Finally, we greatly appreciate the financial support provided by The Lee and Ramona Bass Foundation.

Funding This research is supported by the Lee and Ramona Bass Foundation.

Availability of data and material Data will be uploaded into a free and open online data repository.

Code availability Not applicable.

Declarations

Conflicts of interest We have no conflicting or competing interests.

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

References

Agnew ADQ (2006) A field key to upland Kenya grasses. *J East Afr Nat Hist* 95:1–83

Alderson J, Sharp WC (1994) Grass varieties in the United States. Agriculture handbook (United States. Dept. of Agriculture)(USA)

Alves A, Xavier FE (1986) Major perennial weeds in Brazil: *Panicum maximum* Jacq., *Paspalum maritimum* Trin., *Brachiaria purpurascens* Hens., *Senecio brasiliensis* Less. in: Ecology and Control of perennial weeds in Latin America. FAO, pp 204–212

Ammond SA, Litton CM (2012) Competition between Native Hawaiian plants and the invasive Grass *Megathyrus maximus*: implications of functional diversity for ecological restoration. *Restor Ecol* 20:638–646

Ammond SA, Litton CM, Ellsworth LM et al (2013) Restoration of native plant communities in a Hawaiian dry lowland ecosystem dominated by the invasive grass *Megathyrus maximus*. *Appl Veg Sci* 16:29–39

Baker FWG, Terry PJ (1991) Tropical grassy weeds, 2nd edn. CAB International, Wallingford, UK

Baldassini P, Despósito C, Piñeiro G et al (2018) Silvopastoral systems of the Chaco forests: effects of trees on grass growth. *J Arid Environ* 156:87–95

Baruch Z (1996) Ecophysiological aspects of the invasion by African grasses and their impact on biodiversity and function of neotropical savannas Biodiversity and savanna ecosystem processes. Springer, Berlin, pp 79–93

Bogdan AV (1977) Tropical pasture and fodder plants. Tropical pasture and fodder plants. pp.xiii + 475 pp. ref.29 pp. London, UK

Bon M-C, Goolsby J, Mercadier G, et al. (2011) What do chloroplast sequences tell us about the identity of the commonly named Guineagrass, an invasive Poaceae in the southern United States? Proceedings of the XIII International Symposium on Biological Control of Weeds session 7 pg 322

Borghi E, Crusciol CAC, Mateus GP et al (2013) Intercropping time of corn and palisadegrass or guineagrass affecting grain yield and forage production. *Crop Sci* 53:629–636

Brenner JC (2010) What drives the conversion of native rangeland to Buffelgrass (*Pennisetum ciliare*) Pasture in Mexico's Sonoran Desert?: The social dimensions of a biological invasion. *Hum Ecol* 38:495–505

Bridge J (1996) Nematode management in sustainable and subsistence agriculture. *Annu Rev Phytopathol* 34:201–225

Brooks KJ, Setterfield SA, Douglas MM (2010) Exotic grass invasions: applying a conceptual framework to the dynamics of degradation and restoration in Australia's Tropical Savannas. *Restor Ecol* 18:188–197

Brooks ML, D'Antonio CM, Richardson DM et al (2004) Effects of invasive alien plants on fire regimes. *Bioscience* 54:677–688

Brown WV (1977) The Kranz syndrome and its subtypes in grass systematics. *Memoirs of the Torrey Botanical Club*:1–97

CABI (2020) *Megathyrus maximus* (Guinea grass). In. <https://www.cabi.org/isc/datasheet/38666>. Accessed: 20 Apr 2020

Cabrera DC, Sobrero MT, Chaila S et al (2015) Germination and Emergence of *Megathyrus maximus* var. *maximus*. *Planta Daninha* 33:663–670

Calzada J-PV, Crane CF, Stelly DM (1996) Apomixis—the asexual revolution. *Science* 274:1322–1323

Cauble K, Wagner RS (2005) Sublethal effects of the herbicide glyphosate on amphibian metamorphosis and development. *Bull Environ Contam Toxicol* 75:429–435

Chandramohan S, Charudattan R, Sonoda RM et al (2002) Field evaluation of a fungal pathogen mixture for the control of seven weedy grasses. *Weed Sci* 50:204–213

Choudhary M, Prabhu G, Palsaniya DR (2018) Response of guinea grass (*Megathyrus maximus*) genotypes to intercropping with forage legumes under varying nitrogen management options. *Grass Forage Sci* 73:888–896

- Chou CH, Young CC (1975) Phytotoxic substances in twelve subtropical grasses. *J Chem Ecol* 1:183–193. <https://doi.org/10.1007/BF00987867>
- Cook BG, Pengelly BC, Brown SD, et al. (2005) Tropical Forages: an interactive selection tool. Tropical Forages: an interactive selection tool <http://www.tropicalforages.info/> accessed April 2020
- Cox JR, Martin-r MH, Ibarra-f FA et al (1988) The influence of climate and soils on the distribution of four African grasses. *Rangeland Ecol Manag/j Range Manag Arch* 41:127–139
- D'Antonio CM, Vitousek PM (1992) Biological invasions by exotic grasses, the grass fire cycle, and global change. *Annu Rev Ecol Syst* 23:63–87
- Davies KW, Sheley RL (2011) Promoting native vegetation and diversity in exotic annual grass infestations. *Restor Ecol* 19:159–165
- Davis MA, Grime JP, Thompson K (2000) Fluctuating resources in plant communities: a general theory of invasibility. *J Ecol* 88:528–534
- Dias J, da Fonte MAMA, Baptista R et al (2013) Invasive alien plants in Brazil: a nonrestrictive revision of academic works. *Nat Conserv* 11:31–35
- Dias J, Torezan JMD (2020) Factors Affecting the abundance of ruderal species and *Megathyrus maximus*, an Invasive C4 Grass in Atlantic Forest Restoration Sites. *FLORESTA* 50:1931–1938
- Ellis RP (1988) Leaf anatomy and systematics of Panicum (Poaceae: Panicoideae) in southern Africa. *Monogr Syst Bot Missouri Botanical Gard* 25:129–156
- Ellsworth LM, Litton CM, Taylor AD et al (2013) Spatial and temporal variability of guinea grass (*Megathyrus maximus*) fuel loads and moisture on Oahu, Hawaii. *Int J Wildl Fire* 22:1083–1092
- Espinosa-Garcia FJ, Villasenor JL (2017) Biodiversity, distribution, ecology and management of non-native weeds in Mexico: a review. *Revista Mexicana De Biodiversidad* 88:76–96
- Esteve-Gassent MD, Pérez de León AA, Romero-Salas D et al (2014) Pathogenic landscape of transboundary zoonotic diseases in the Mexico–US border along the Rio Grande. *Front Public Health* 2:177
- Euclides VPB, Carpejani GC, Montagner DB et al (2018) Maintaining post-grazing sward height of *Panicum maximum* (cv. Mombaca) at 50cm led to higher animal performance compared with post-grazing height of 30cm. *Grass Forage Sci* 73:174–182
- Euclides VPB, Thiago L, Macedo MCM et al (1999) Voluntary intake of three cultivars of *Panicum maximum* under grazing. *Revista Brasileira De Zootecnia-Braz J Anim Sci* 28:1177–1185
- Evans EW, Ellsworth LM, Litton CM (2015) Impact of grazing on fine fuels and potential wildfire behaviour in a nonnative tropical grassland. *Pac Conserv Biol* 21:126–132
- Francis JK, Parrotta JA (2006) Vegetation response to grazing and planting of *Leucaena leucocephala* in a *Urochloa maximum*-dominated grassland in Puerto Rico. *Carib J Sci* 42(1):67–74
- Friedel MH, Grice AC, Marshall NA et al (2011) Reducing contention amongst organisations dealing with commercially valuable but invasive plants: The case of buffel grass. *Environ Sci Policy* 14:1205–1218
- Frost RA, Launchbaugh KL (2003) Prescription grazing for rangeland weed management. *Rangelands Arch* 25:43–47
- Fulbright TE, Hickman KR, Hewitt DG (2013) Exotic grass invasion and wildlife abundance and diversity, South-Central United States. *Wildl Soc Bull* 37:503–509
- Gardener CJ, Mclvor JG, Jansen A (1993) Survival of seeds of tropical grassland species subjected to bovine digestion. *J Appl Ecol* 1:75–85
- GBIF (2020) GBIF.org GBIF Occurrence Download In. <https://doi.org/10.15468/dl.pftu3d>. Accessed: 22 Apr 2020
- George S, Pillai GR (2000) Effect of vermicompost on yield and economics of Guinea grass (*Panicum maximum*) grown as an intercrop in coconut (*Cocos nucifera*) gardens. *Indian J Agron* 45:693–697
- Ghosh PK, Palsaniya DR, Srinivasan R (2016) Forage research in India: Issues and strategies. *Agric Res J* 53:1–12
- Giussani LM, Cota-Sánchez JH, Zuloaga FO et al (2001) A molecular phylogeny of the grass subfamily Panicoideae (Poaceae) shows multiple origins of C4 photosynthesis. *Am J Bot* 88:1993–2012
- Goolsby JA, DeBarro PJ, Makinson JR, Pemberton RW, Hartley DM, Frohlich D (2006) Matching the origin of an invasive weed for selection of a herbivore haplotype for a biological control programme. *Mol Ecol* 15:287–297
- Goolsby JA, Vacek AT, Salinas C, Racelis A, Moran PJ, Kirk AA (2017) Host range of the European leaf sheath mining midge, *Lasioptera donacis* Coutin (Diptera: Cecidomyiidae), a biological control of giant reed, *Arundo donax* L. *Biocontrol Sci Technol* 27:781–795
- Grace JB, M.D. Smith, S.L. Grace, S.L. Collins, and T.J. Stohlgren. 2001. Interactions between fire and invasive plants in temperate grasslands of North America. Pages 40–65 in K.E.M. Galley and T.P. Wilson (eds.). Proceedings of the Invasive Species Workshop: the Role of Fire in the Control and Spread of Invasive Species. Fire Conference 2000: the First National Congress on Fire
- Grahmann ED, Fulbright TE, Hernandez F et al (2018) Demographic and density response of northern bobwhites to pyric herbivory of nonnative grasslands. *Rangeland Ecol Manag* 71:458–469
- Hanselka CW (1988) Buffelgrass: south Texas wonder grass. *Rangelands* 10(6):279–281
- Hejda M, Pysek P, Jarosik V (2009) Impact of invasive plants on the species richness, diversity and composition of invaded communities. *J Ecol* 97:393–403
- Hitchcock AS, Chase A (1910) The North American species of *Panicum*. Govt. Print. Off, USA
- Ho CY, Tsai MY, Huang YL et al (2016) Ecophysiological factors contributing to the invasion of *Panicum maximum* into native *Miscanthus sinensis* grassland in Taiwan. *Weed Res* 56:69–77
- Holm L, Pancho JV, Herberger JP et al (1979) A geographical atlas of world weeds. John Wiley and Sons, New York
- Holm LG, Plucknett DL, Pancho JV et al (1977) The world's worst weeds. University Press of Hawaii, Distribution and biology
- Islam M, Thakuria K (2002) Seasonal variation in green fodder production of important perennial grasses and legumes intercropping system. *J Agric Sci Soc North East India* 15:192–195

- Jank L, Barrios SC, Do Valle CB et al (2014) The value of improved pastures to Brazilian beef production. *Crop Pasture Sci* 65:1132–1137
- Jank L, Do Valle CB, De Carvalho J, et al. (2001) Evaluation of guineagrass (*Panicum maximum* Jacq) hybrids in Brazil. *Proceedings of the Xix International Grassland Congress: Grassland Ecosystems: An Outlook into the 21st Century* 498–499
- Kauffman JB, Cummings DL, Ward DE (1998) Fire in the Brazilian Amazon 2. Biomass, nutrient pools and losses in cattle pastures. *Oecologia* 113:415–427
- Kaushal P, Dwivedi KK, Radhakrishna A et al (2018) Ploidy dependent expression of apomixis and its components in guinea grass (*Panicum maximum* Jacq). *Euphytica* 214:152
- Kaushal P, Paul S, Saxena S et al (2015) Generating higher ploidies (7x and 11x) in guinea grass (*Panicum maximum* Jacq.) utilizing reproductive diversity and uncoupled apomixis components. *Curr Sci* 109:1392–1395
- Keane RM, Crawley MJ (2002) Exotic plant invasions and the enemy release hypothesis. *Trends Ecol Evol* 17:164–170
- Komatsu T, Nakajima K (1988) B-chromosomes in diploid Guinea grass (*Panicum maximum* Jacq.). *Jpn J Breed* 38:151–157
- Kuva MA, Gravena R, Pitelli RA et al (2003) Períodos de interferência das plantas daninhas na cultura da cana-de-açúcar: III-capim-braquiária (*Brachiaria decumbens*) e capim-colonião (*Panicum maximum*). *Planta Daninha* 21:37–44
- Kuvlesky Jr WP, Fulbright TE, Engel-Wilson R (2002) The impact of invasive exotic grasses on quail in the southwestern United States. *National Quail Symposium Proceedings* article 5: volume 22
- Larson JA, Fulbright TE, Brennan LA et al (2012) Selection of seeds of an exotic and three native grasses by Northern Bobwhites (*Colinus virginianus*). *Southwest Nat* 57:319–322
- Laska A, Majer A, Szydło W et al (2018) Cryptic diversity within grass-associated *Abacarus* species complex (Acariformes: Eriophyidae), with the description of a new species, *Abacarus plumiger* n. sp. *Exp Appl Acarol* 76:1–28
- Levine JM, Vila M, Antonio CMD et al (2003) Mechanisms underlying the impacts of exotic plant invasions. *Proc Roy Soc Lond Ser B Biol Sci* 270:775–781
- Litt AR, Cord EE, Fulbright TE et al (2014) Effects of Invasive Plants on Arthropods. *Conserv Biol* 28:1532–1549
- Lonard RI, Judd FW (2006) Notes on invasive plants in the Rio Grande Delta of Cameron County, Texas. *Tex J Sci* 58:271–277
- Lonsdale WM (1999) Global patterns of plant invasions and the concept of invasibility. *Ecology* 80:1522–1536
- Maciel GA, Braga GJ, Guimaraes R et al (2018) Seasonal liveweight gain of beef cattle on Guinea grass Pastures in the Brazilian Cerrados. *Agron J* 110:480–487
- Mantoani MC, Torezan JMD (2016) Regeneration response of Brazilian Atlantic Forest woody species to four years of *Megathyrsus maximus* removal. *For Ecol Manage* 359:141–146
- Marshall VM, Lewis MM, Ostendorf B (2012) Buffel grass (*Cenchrus ciliaris*) as an invader and threat to biodiversity in arid environments: a review. *J Arid Environ* 78:1–12
- Masi M, Freda F, Clement S et al (2019) Phytotoxic activity and structure–activity relationships of radicinin derivatives against the invasive weed buffelgrass (*Cenchrus ciliaris*). *Molecules* 24:2793
- McGeoch MA, Butchart SHM, Spear D et al (2010) Global indicators of biological invasion: species numbers, biodiversity impact and policy responses. *Divers Distrib* 16:95–108
- Mercadier G, Goolsby JA, Jones WA et al (2009) (2009) Results of a preliminary survey in Cameroon, Central Africa, for potential Natural Enemies of Guinea grass, *Panicum Maximum*. *Subtropical Plant Science* 61:31–36
- Miles JW, Hare MD (2007) Plant breeding and seed production of apomictic tropical forage grasses. *Seed Prod Northern Light Bioforsk FOKUS* 2(12):74–81
- Mitchell RM, Bakker JD (2014) Quantifying and comparing intraspecific functional trait variability: a case study with *Hypochoeris radicata*. *Funct Ecol* 28:258–269
- Mooney HA (2005) *Invasive alien species: a new synthesis*. Island Press Washington D.C, USA
- Moore SF (2010) Effects of guineagrass on northern bobwhite habitat use. *Masters Abstract International* 02 edn.
- Moreno LM, Meléndez-Ackerman E, Cheleuitte C et al (2014) Potential impacts of the invasive grass *Megathyrsus maximus* (Poaceae) on ground-dwelling arthropods in a Caribbean dry forest. *Caribbean Naturalist* 7:1–15
- Motta MS (1953) *Panicum maximum*. *Empire J Exp Agric* 21:33–41
- Moyal P, Le Rü B, Conlong D et al (2011) *Buakea* (Lepidoptera: Noctuidae), a new genus of African stem borers: morphological, ecological and molecular data. *Af Entomol* 19:23–35
- Nakajima K (1978) Comparison of major agronomic characters in Guinea grass and colored Guinea grass. *Jarq-Japan Agric Res Quart* 12:145–151
- Nakajima K, Mochizuki N (1983) Degrees of sexuality in sexual plants of Guinea grass by the simplified embryo sac analysis. *Japanese J Breed* 33:45–54
- Njarui DMG, Gatheru M, Mwangi DM et al (2015) Persistence and productivity of selected Guinea grass ecotypes in semiarid tropical Kenya. *Grassland Sci* 61:142–152
- Parsons JJ (1972) Spread of African pasture grasses to the American tropics. *Rangeland Ecol Manag/j Range Manag Arch* 25:12–17
- Pivello VR (2011) The use of fire in the Cerrado and Amazonian rainforests of Brazil: past and present. *Fire Ecol* 7:24–39
- Portela RCQ, Matos DMS, de Siqueira LP et al (2009) Variation in aboveground biomass and necromass of two invasive species in the Atlantic rainforest, Southeast Brazil. *Acta Botanica Brasilica* 23:571–577
- Ramirez-Yanez LE, Ortega-S JA, Brennan LA, et al. (2007) Use of prescribed fire and cattle grazing to control guineagrass. In: Masters RE and Galley KEM (eds) 23rd Tall Timbers Fire Ecology Conference: Fire in Grassland and Shrubland Ecosystems. pp. 240–245
- Randall RP (2017) *A global compendium of weeds*. Editor RP Randall, Perth Australia publisher
- Ray CA, Sherman JJ, Godinho AL et al (2018) Impacts and best management practices for Erect Veldtgrass (*Ehrharta erecta*). *Invasive Plant Sci Manag* 11:40–48

- Reinheimer R, Pozner R, Vegetti AC (2005) Inflorescence, spikelet, and floral development in *Panicum maximum* and *Urochloa plantaginea* (Poaceae). *Am J Bot* 92:565–575
- Resende RMS, Jank L, Do Valle CB et al (2004) Biometrical analysis and selection of tetraploid progenies of *Panicum maximum* using mixed model methods. *Pesquisa Agropecuaria Brasileira* 39:335–341
- Rhodes AC, Plowes RM, Lawson J, et al. (*in prep.*) The reproductive ecology of invasive Guinea grass is mediated by disturbance history and savanna structure in South Texas.
- Richardson DM, Pyšek P (2006) Plant invasions: merging the concepts of species invasiveness and community invasibility. *Prog Phys Geogr* 30:409–431
- Rojas-Sandoval J, Meléndez-Ackerman E (2012) Effects of an invasive grass on the demography of the Caribbean cactus *Harrisia portoricensis*: Implications for cacti conservation. *Acta Oecologica* 41:30–38
- Rojas-Sandoval J, Meléndez-Ackerman EJ, Anglés-Alcázar D (2016) Assessing the impact of grass invasion on the population dynamics of a threatened Caribbean dry forest cactus. *Biol Cons* 196:156–164
- Roskopf EN, Abbasi M, Aime MC (2019) First Report of Guinea grass Smut Caused by *Conidiosporomyces ayresii* in North America. *Plant Dis* 103:760–760
- Sands D, Goolsby JA (2011) The case for biological control of exotic African grasses in Australia and USA using introduced detritivores. *Proceedings of the XIII International Symposium on Biological Control of Weeds* pp. 103
- Savidan YH, Jank L, Costa JCG et al (1989) Breeding *Panicum maximum* in Brazil 1. Genetic-resources, modes of reproduction and breeding procedures. *Euphytica* 41:107–112
- Silva AC, Goncalves CG, Scarano MC, et al. (2018) Effect of Glyphosate on guineagrass submitted to different soil water potential. *Planta Daninha* v36:e018180818
- Simmons MT, Windhager S, Power P et al (2007) Selective and non-selective control of invasive plants: the short-term effects of growing-season prescribed fire, herbicide, and mowing in two Texas prairies. *Restor Ecol* 15:662–669
- Simon BK, Jacobs SWL (2003) *Megathyrsus*, a new generic name for *Panicum* subgenus *Megathyrsus*. *Austrobaileya* 6:571–574
- Sipes BS, Arakaki AS (1997) Root-knot nematode management in dryland taro with tropical cover crops. *J Nematol* 29:721
- Sistachs M, Padilla C, Barrientos A et al (1991) Effect of seed dosage and time of seasonal culture intercropping on guinea grass (*Panicum maximum*) establishment. 2. Hibiscus cannabinus (Kenaf). *Revista Cubana De Ciencia Agricola (cuba)* 26(3):331–336
- Smith FS (2010) Texas today: a sea of the wrong grasses. *Ecol Restor* 28:112–117
- Soreng RJ, Peterson PM, Romaschenko K et al (2015) A worldwide phylogenetic classification of the Poaceae (Gramineae). *J Syst Evol* 53:117–137
- Soti P, Goolsby JA, Racelis A (2020) Agricultural and environmental weeds of south texas and their management. *Subtrop Agric Environ* 71:1–11
- St Clair SB, O'Connor R, Gill R et al (2016) Biotic resistance and disturbance: rodent consumers regulate post-fire plant invasions and increase plant community diversity. *Ecology* 97:1700–1711
- Stirling GR, Nikulin A (1998) Crop rotation, organic amendments and nematicides for control of root-knot nematodes (*Meloidogyne incognita*) on ginger. *Australas Plant Pathol* 27:234–243
- Sukhchain S (2010) Breeding Guinea grass—a review. *Range Manag Agroforest* 31:109–115
- Sukhchain SBS (1992) Interrelationships among total crude protein and digestible dry-matter production and their component traits in Guinea grass. *Euphytica* 64:59–63
- Sutton GF, Canavan K, Day MD et al (2019) Grasses as suitable targets for classical weed biological control. *Biocontrol* 64:1–18
- Tilman D (1999) The ecological consequences of changes in biodiversity: A search for general principles. *Ecology* 80:1455–1474
- Usberti-Filho JA, Usberti R, Paterniani RS (2002) Differential vegetative and reproductive performances among fifteen guinea grass hybrids. *Pesq Agrop Brasileira* 37:139–143
- USDA NRCS (2020) Plants Database. In. <https://plants.sc.egov.usda.gov/core/profile?symbol=URMA3>. Accessed: 20 apr 2020
- Vacek AT, Goolsby JA, Calatayud PA, Le Ru B, Musyoka B, Kariyat RR (2021) Importation and preliminary evaluation of the stem boring moth *Buakea kaeuae* as a potential biological control agent of invasive Guinea grass *Megathyrsus maximus*. *Southwestern Entomol* 46(1):257–260
- Van Devender TR, Dimmitt MA (2006) Final Report on “Conservation of Arizona Upland Sonoran Desert Habitat. Status and Threats of Buffelgrass (*Pennisetum ciliare*) in Arizona and Sonora. Project# 2004–0013–003”. Arizona-Sonora Desert Museum Tucson, AZ
- Veldman JW, Putz FE (2010) Long-distance dispersal of invasive grasses by logging vehicles in a tropical dry forest. *Biotropica* 42:697–703
- Vitousek PM (1997) Human domination of earth’s ecosystems. *Science* 277:494–499
- Wagner WL, Herbst DR, Sohmer SH (1999) Manual of the flowering plants of Hawai’i, Vols. 1 and 2. University of Hawai’i and Bishop Museum Press
- Warmke HE (1954) Apomixis in *Panicum maximum*. *Am J Bot* 41:5–11
- Williams DG, Baruch Z (2000) African grass invasion in the Americas: ecosystem consequences and the role of eco-physiology. *Biol Invas* 2:123–140
- Wubs ER, van Heusden T, Melchers PD et al (2019) Soil inoculation steers plant-soil feedback, suppressing ruderal plant species. *Front Ecol Evol* 7:451
- Zambeziaca F (2019) Royal Botanic Gardens, Kew. Online key. In. <http://apps.kew.org/efloras/fz/intro.html>. Accessed: 19 Nov 2019
- Zanine AD, Nascimento D, Da Silva WL et al (2018) Morphogenetic and structural characteristics of Guinea grass pastures under rotational stocking strategies. *Exp Agric* 54:243–256
- Zenni RD, Ziller SR (2011) An overview of invasive plants in Brazil. *Braz J Bot* 34:431–446

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.