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Review

Chromolaena odorata invasion in Nigeria: A case for coordinated biological control

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Abstract

Chromolaena odorata (L.) King and Robinson (Asteraceae: Eupatorieae) is an invasive perennial weedy scrambling shrub of neotropical origin, widely acknowledged as a major economic and ecological burden to many tropical and subtropical regions of the world including Nigeria. Here, we examine the invasion and management of *C. odorata* in Nigeria over the last seven decades using historical records and field surveys and ask: (i) Does the usefulness of *C. odorata* influence its invasion success? (ii) Is a coordinated control approach against *C. odorata* needed in the face of its usefulness or do we need to develop strategies for its adaptive management? We searched major institutional libraries in Nigeria and carried out extensive research of historical records using different data base platforms, including Google Scholar, Science Direct, ISI web of Science, SciFinders and Scopus. Apart from the biological invasive characteristics of *C. odorata* and the increased anthropogenic disturbances occurring over the time period, the records indicate that the ethno-pharmacological, funcigicidal, nematicidal importance of the plant and its use as a fallow species and as a soil fertility improvement plant in the slash and burn rotation system of agriculture is partly responsible for the invasion success of the weed. The current distribution and infestation levels of this invasive weed in Nigeria are mapped. The current methods of control and the failed attempt made by the Nigerian government to eradicate the weed between the late 1960s and 1970s are discussed. We argue that even in the face of the usefulness of *C. odorata*, it is reasonable to implement a nationwide coordinated control programme against it with biological control as a core component, because weed biological control does not eliminate the target species, instead it aims to establish an equilibrium which maintains the weed's population below the level where it causes significant harm to natural and semi-natural ecosystems.

Key words: invasive alien weed, spread and distribution, weed status, conflict of interest, biological control, Nigeria

Introduction

Invasive alien plant species impact negatively on agriculture, livelihoods and the conservation of biodiversity (Mack et al. 2000; Rejmánek et al. 2005; Pejchar and Mooney 2009) worldwide, causing significant economic losses (Pimentel 2002; Perrings et al. 2010). As is common with other invasive alien plant species, *Chromolaena odorata* King and Robinson, 1970 (=*Eupatorium odoratum*) (Asteraceae) is and remains a huge threat to natural and semi-natural ecosystems in most parts of its introduced ranges (see Zacharides et al. 2009) thereby compromising ecosystems integrity. This invasive alien shrub which smothers existing native plant communities also attracts significant attention because of the threat it poses to agriculture and human livelihoods. *Chromolaena odorata,* known in Nigeria as Awolowo, Akintola or Queen Elizabeth weed, is a perennial weedy shrub native to the Americas from southern Florida to northern Argentina including the Caribbean islands (McFadyen 1988).

Following its introduction from Sri Lanka into southern Nigeria in 1937 (Ivens 1974), it has reached alarming proportions in Nigeria (Lucas 1989; Uyi et al. 2013; Uyi and Igbinosa 2013), Cameroon, Ghana, and other parts of Africa (Zachariades et al. 2009; 2013), and is now one of the worst weeds in Nigeria and West Africa. The biotype of *C. odorata* found in West and Central Africa differs from the invasive form found in South Africa, in both morphology and aspects of its ecology (Zachariades et al. 2009; Paterson and Zachariades 2013) and is thought to originate from Trinidad, Tobago and adjacent areas in the West Indies. The southern African *C. odorata* biotype is not the subject of this paper. The biology and ecology of both biotypes of *C. odorata* has been well documented (see Holm et al. 1977; Gautier 1992; Witkowski and Wilson 2001; Rambuda and Johnson, 2004) and reviewed in Zachariades et al. (2009).

Because of its presence over large areas and its invasive nature, the application of chemical and mechanical control methods is not sustainable in terms of cost and practicability, hence biological control of the weed was attempted in Nigeria in the 1970s (Cock and Holloway 1982), but this effort was not successful (Julien and Griffiths 1998). Following the unsuccessful control attempts, biologists, ecologists, conservationists, agriculturists and non-professionals in the country have continuously differed on the best way to respond to the *C. odorata* invasion, partly because the weed is thought to offer a variety of benefits. For example, many publications describe the importance of *C. odorata* as a fallow species in slash and burn fallow rotations practiced by farmers in the country (e.g. Akobundu and Ekeleme 1996; Tian et al. 1998; Akobundu et al. 1999; Tian et al. 2005) and there are also many publications on its medicinal uses in several parts of the country (e.g. Odugbemi et al. 2007; Ajao et al. 2011; Alisi et al. 2011). Furthermore, the importance of the weed in livestock nutrition, improvement of soil fertility and its potential use as a pesticide has been reported (see references in Table 1).

At present, there are no control or management efforts in place to check the spread of the weed in Nigeria. With the exception of the earlier publications by Ivens (1974) and Lucas (1989), we are not aware of any later attempt to review and/or assess the invasiveness and status of *C. odorata* in Nigeria. Due to the perceived usefulness of *C. odorata*, the initiation of a control or management programme would require a proper understanding of its invasion and management history. Here, we examine the invasion (spread and distribution) and management of *C. odorata* in Nigeria over the last seven decades using historical records and field surveys. We ask: (i) How rapidly did *C. odorata* spread and why? (ii) What is the current extent of spread and impact? (iii) What attempts were made to control *C. odorata* and were they successful? (iv) Do the positive attributes of *C. odorata* influence the continuous spread of the weed? (v) Is a coordinated control approach against *C. odorata* needed in the face of its usefulness or do we need to develop strategies for its adaptive management? To answer these questions, we undertook a thorough literature search using the internet and major institutional libraries in Nigeria.

Methods

We systematically surveyed between November 2011 and December 2013 reports in University of Benin and Nigerian Institute for Oil Palm (NIFOR) libraries in Benin City, Nigeria, published by Federal Ministry of Agriculture and Rural Development and in national and international scientific journals from 1960s until the present day. Information gathering also involved the use of different data base platforms, including Google Scholar, Science Direct, ISI web of Science SciFinders and Scopus. The eligibility criteria were deliberately broad in order to ensure that we included all relevant materials. All reports and papers that mention *C. odorata* and its control in any capacity (for example spread, status, control measures) were included in the selection process. Over one hundred records were identified. A thorough search of these records was carried out to examine the narrative surrounding *C. odorata* in each record. These records were used to answer the questions raised earlier.

To examine the extent of spread of *C. odorata* in Nigeria, opportunistic surveys were conducted by the individual authors between 2003 and 2013 in different parts of the country; results were used to map the current distribution of the weed.

Results and discussion

History and current distribution of Chromolaena odorata *in Nigeria*

The first collection of *C. odorata* in Nigeria was in 1942 from a forestry plantation near Enugu, in south-eastern Nigeria and is thought to have resulted

Table 1. The status of *Chromolaena odorata* as a weed versus its usefulness in Nigeria.

References	Weed	Beneficial	Author's submissions
Adebayo (2013)	*		Threat to biodiversity and agriculture
Adebayo and Uyi (2010)	*		-
Adetoro et al. (1998)		*	Improvement of soil fertility
Adeyemi (1989)	*		Weed of plantation crops
Afolayan (1988)	*		Threat to agriculture
Agamagu et al. (2008)	*		Threat to agriculture
Agbim (1987)		*	Fallow species/improve soil fertility
Agunbiade and Fawale (2009)		*	Biomarker and bioremediation
Ajao et al. (2011)		*	Medicinal plant
Akinmoladun et al. (2007)		*	-
Akinyemiju and Alimi (1989)	*		Threat to agriculture
Akobundu and Agyakwa (1998)	*		
Akobundu and Ekeleme (1996)		*	Fallow species/improve soil fertility
Akobundu et al. (1999)		*	-
Alisi and Onyeze (2009)		*	Medicinal plant
Alisi et al. (2011)		*	-
Amiolemen et al. (2012)		*	Improvement soil fertility
Anoliefo et al. 2003		*	Phyto-remediation
Aro and Fajemilehin (2005)		*	Livestock nutrition
Aro et al. (2009)		*	Medicinal plant
Aweto and Iyanda (2003)		*	Fallow species
Borokini (2011)	*		Threat to biodiversity conservation
Egbe and Oladokun (1987)	*		Threat to agriculture
Ekeleme et al. (2004)		*	Fallow species/improve soil fertility
Ekhator et al. (2013)	*		Threat to agriculture
Ekpa (1996)		*	Medicinal plant
Etejere (1980)	*		Agricultural weed
Etejere (1982)	*		-
Etejere (1983)	*		-
Etuk (1973)	*		-
Eze and Gill (1992)	*		-
Fadiyimu et al. (2005)		*	Livestock nutrition
Fasuyi et al. (2006)		*	-
Gill et al. (1996)	*		Weed of plantation crops
Hoevers and M'boob (1996)	*		Threat to biodiversity and agriculture
Igboh et al. (2009)		*	Medicinal plant/livestock nutrition
Ige et al. (2008)	*		Agricultural weed
Iheagwam (1983)	*		-
Ikuenobe (1992)	*		Weed of plantation and arable crops
Ikuenobe and Anoliefo (2003)		*	Fallow species/improve soil fertility
Ikuenobe and Ayeni (1998)	*		Weed of plantation and arable crops
Ilondu (2011)		*	Fungicide
Ilori et al. (2011)		*	Manure
Ivens (1972)	*		Threat to agriculture
Ivens (1973)	*		-
Ivens (1974)	*		-
Ivens (1975)	*		-
Iwu (1993)		*	Medicinal plant
Jibril and yahaya (2010)		*	Improvement of soil fertility
Komolafe (1980)	*		Threat to agriculture
Komolafe (1976)	*		-
Lucas (1989)	*		-
Nwokolo (1987)		*	Livestock nutition
Obatolu and Agboola (1993)		*	Improvement of soil fertility
Odeyemi (1981)		*	Biogas
Odeyemi et al. (2011)		*	Nematicide
Odugbemi (2006)		*	Medicinal plant
Odugbemi et al. (2007)		*	-

Table 1 (continued).

References	Weed	Beneficial	Author's submissions
Odukwe (1965)	*		Weed of agriculture and forestry
Ogbe et al. 1994	*		Weed: allelopathic effect
Ogundola and Liasu (2007)	*		-
Oigiangbe et al. (2007)	*		Host of important pests of crops
Okeke and Omaliku (1992)		*	Soil fertility
Okigba et al. (2010)		*	Fungicide
Olaniyi et al. (2009)		*	Improvement of soil fertility
Olaoye (1986)	*		Threat to agriculture and forestry
Olaoye (1977)	*		-
Olaoye (1976)		*	Improvement of soil fertility
Olaoye and Egunjobi (1974)	*		Threat to agriculture and forestry
Onwugbuta-Enyi (2001)	*		Allelopathic effects on crops
Otoikhian and Oyefa (2010)		*	Medicinal plant
Owolabi et al. (2010)		*	Medicinal plant/essential oil
Riddock et al. (1991)	*		Weed: prevent tree seedling growing
Sheldrick (1968a)	*		Weed of plantation crops
Smith and Alli (2005)		*	Threat to agriculture
Taiwo et al. (2000)		*	Medicinal plant
Tian et al. (2005)		*	Fallow plant
Tian et al. (1998)		*	Fallow plant
Utulu (1996)	*		Weed of plantation crops
Uyi and Igbinosa (2013)	*		Threat to biodiversity and agriculture
Uyi et al. (2013)	*		-
Uyi (2011)	*		Threat to biodiversity and agriculture
Uyi et al. (2011)	*		Threat to biodiversity and livelihoods
Uyi and Aisagbonhi (2009)	*		Threat to agriculture
Uyi et al. (2008)	*		-
Yeni et al. (2010)		*	Fungicide
Total	45	41	
Percent	52.32	47.68	

from the importation of contaminated seeds of the forest tree *Gmelina arborea* Roxb., 1814 (Verbenaceae) from Sri Lanka in 1937 (Ivens 1974).

Following its introduction, the weed quickly spread through eastern Nigeria in the 1940s and was first reported by Ivens (1974) to the west of the river Niger in 1955 and from Lagos and its environs in 1960 (Odukwe 1965) from where it might have spread into Benin Republic and other countries in West Africa. By 1960, *C. odorata* had occupied the south-eastern states of Nigeria, from where it spread into Cameroon (Hoevers and M'boob 1996). Its rapid spread through the entire southeast in the 1940s to reach the southwest of the country in the 1950s may have been as a result of regional trade, and human and vehicular movement especially by the colonial administration and local politicians at the time. The civil war in Nigeria between the late 1960s and early 1970s may have also facilitated the spread of *C. odorata* from the south-eastern region because of the movement of people, troops and military hardware during and after the war. Disturbed soil in forest clearing provides an ideal habitat for the plant and the construction of new roads in the country through the rainforest zones appears to have greatly influenced the distribution of the weed at the early stages of invasion.

The introduction of *C. odorata* into Nigeria instigated many local names tied to historical events at the time of its occurrence among the locals. For example, the inhabitants of mid-western Nigeria called it "Awolowo" apparently after Chief Obafemi Awolowo, the mercurial politician of the 1950-60s who conducted his electioneering campaigns with helicopter flights into the remotest villages in Nigeria, a period which coincided with the spread of *C. odorata* weed in the mid-western region. Other areas of the country have different names for it based on other happenstance that coincided with its appearance or mode of spread. For example, in Warri area of the Niger

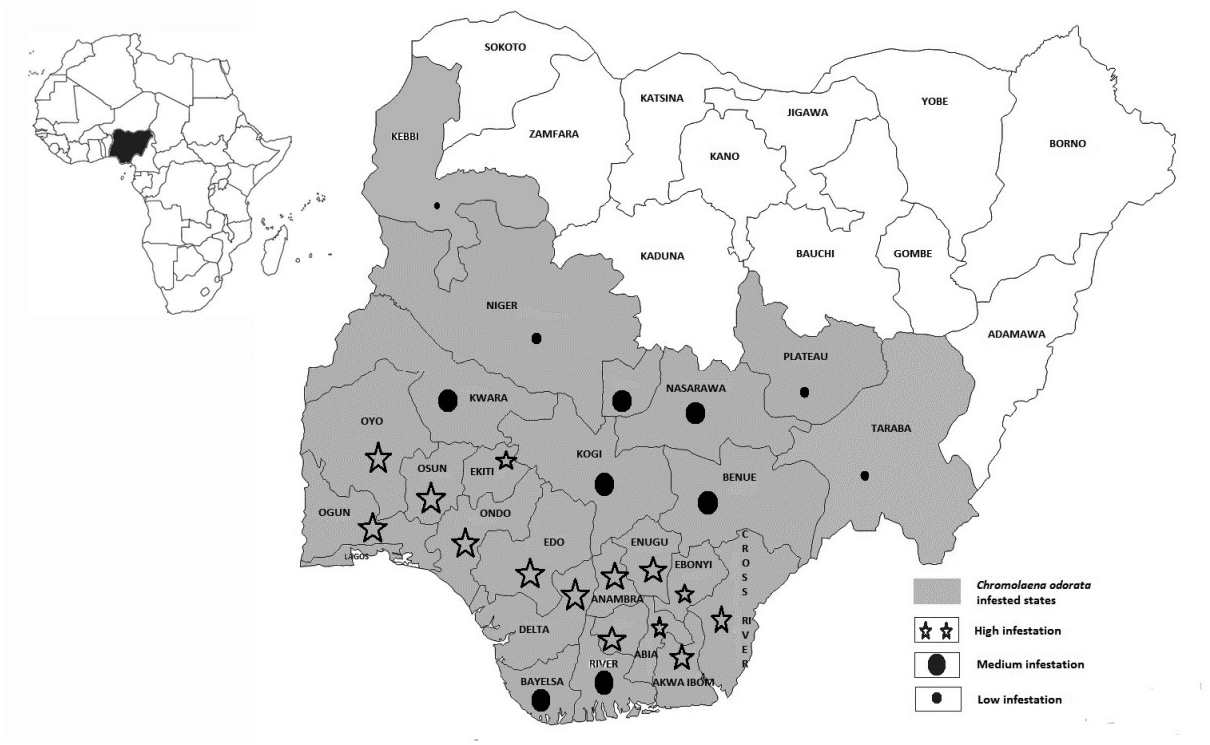

Figure 1. Distribution and infestation levels of *Chromolaena odorata* in Nigeria.

Delta, it is called "Ogbeko" or "Shell-copy" (the latter literally a corruption of Shell Petroleum Development Company (SPDC) whose oil prospecting activities in the Niger Delta Region coincided with the appearance of the weed). To the west, the weed is referred to by other names such as "Akintola" or "Awolowo". In eastern Nigeria, it is called several names among which are "Obialofulu" and "Queen Elizabeth" indicating that the spread of weed might have been widely noticeable during the period of the queen's visit to Nigeria in 1956. There is no known local name for it in the Hausa language which probably is due to its absence in the drier climes of northern Nigeria which is predominantly populated by the Hausas.

Overall, the invasive success of *C. odorata* is thought to depend upon the combination of its high reproductive capacity, high growth rate and net assimilation rate (Ramakrishnan and Vitousek 1999), its capacity to suppress native vegetation through light competition (Kushwaha et al. 1981; Honu and Dang 2000), its allelopathic properties (Gills et al. 1996; Onwugbuta-Enyi 2001) as well as its ability to grow on many soil types and in many climatic zones (Timbilla and Braimah 1996; Goodall and Erasmus 1996; Robertson et al. 2008).

The results of the surveys conducted between 2003 and 2013 in the different regions of Nigeria indicate that *C. odorata* is now present in all parts of Nigeria, except in the northeast and far north (Figure 1) where the prevailing climatic conditions are probably not suitable for its growth and establishment. Infestations of *C. odorata* were rated in three categories viz; (i) high, (ii) medium and (iii) low (Figure 1). In category one infestation, *C. odorata* was present and abundant in all places suitable for its growth, completely smothering co-occurring vegetation, while in categories two and three infestations, the weed was less invasive. Infestations of the weed were observed in cocoa, rubber, oil palm and coconut plantations, arable crop farms (including cassava), nursery gardens, secondary forests, forest margins, wastelands, abandoned plots, road sides and other land use types.

These surveys showed that the entire south-eastern, south-western, Niger Delta and parts of north-central regions have been colonized by *C. odorata* (Figure 1) and that the weed has

successfully spread to over 23 states of the 36 states in Nigeria, and is present in a wide range of vegetation zones including rainforest and fresh water swamp forest in the south (annual rainfall > 1600 mm) and woodland and grassland savannah zones in the north central (where annual rainfall ranges between 900 and 1600 mm). Figure 2 shows the vegetation zones of Nigeria with total annual rainfall. The rainforest, woodland savannah and fresh water swamp forest zones are particularly vulnerable and severely affected, with *C. odorata* achieving invasive status. *Chromolaena odorata* is now present in the guinea (woodland, grassland and tall grass) savannah states of Nasarawa, Benue, Kebbi, Kwara, Kogi, Plateau, Niger, Taraba and the Federal Capital Territory in Abuja where it had not previously been reported. However, the density of *C. odorata* infestations varies in these locations, ranging from medium to low (Figure 1). The situation today is dissimilar to that reported in the 1980s by Lucas (1989), in that the weed has now spread to large parts of the north-central region and parts of the northwest in Kebbi State. McFadyen (1989) predicted that the minimum annual rainfall requirement for *C. odorata* was 1200 mm, but a considerable lower limit has been recorded in Chad, Ghana and South Africa (Goodall and Erasmus 1996; Timbilla 1998; Kriticos et al. 2005). Because of the vast land area of the woodland and grassland savannah zones in Nigeria, it is believed that *C. odorata* is yet to achieve its maximum spread potential in the country. The weed range will probably increase further with change in climate if rainfall increases in the savannah zone.

The problems of Chromolaena odorata *in Nigeria*

In Nigeria and most parts of West Africa, *C. odorata* impacts on farming, pastoral agriculture, and biodiversity and on human welfare. *Chromolaena odorata* can easily invade open spaces and heavily disturbed environments such as croplands and neglected pastures, forest margins and disturbed rainforests. It competes effectively with crops and other plant species and may become dominant, thus causing loss of ecosystem integrity. Die-back of plants after flowering presents a fire risk during the intense dry season, causing extensive and frequent bushfires in southern Nigeria (Uyi and Igbinosa 2013). These bushfires impact negatively on human livelihoods and destroy cultivated crops (e.g. cassava, yam, cocoyam, maize, okra) and have resulted in the loss of plantain and cocoa plantations in southern Nigeria. The fires may prevent the recruitment of native plant species, leading to changes in the structure and composition of native flora. For example, te Beest et al. (2012) showed how fire interacted with the conventional clearing of *C. odorata* in South Africa and induced an intense canopy fire that caused a shift from woodland to grassland. Also McFadyen (2004) reported considerable damage to surrounding native vegetation due to fire caused by dry stems of *C. odorata*.

Although the arrival and continuous spread of *C. odorata* is thought to pose a serious threat to subsistence and commercial agriculture in Nigeria (Sheldrick 1968; Lucas 1989; and several references in Table 1), very little has been done to elucidate its full impact on agricultural crops (subsistence or commercial). Future research work should be carried out to support or refute speculations regarding the negative impact of the weed so as to guide stakeholder's decisions when considering control measures against the weed. As with other invasive weed species elsewhere, *C. odorata* is thought to be a problem in young tree crop plantations (e.g. rubber, oil palm, cocoa and fruit trees), cassava, yam, banana, plantain and other important agricultural crops in southern and central parts of the country.

The problem of *C. odorata* in rubber, cocoa, coconut and oil palm plantations is pronounced in the early stages of crop establishment, where its invasion can lead to the shading and smothering of young crops. Sheldrick (1968) reported that severe infestation of oil palm plantations in the early stage of growth by *C. odorata* have been found to delay fruiting in oil palms for two years.

In arable crops, the yield of maize has been found to be reduced by *C. odorata* infestations by as much as 17% while that of cassava was reduced by as much as 60–70% (Lucas 1989). Cassava is the most widely grown staple crop in Nigeria (FAO 2000) providing the main staple for most Nigerians especially the resource poor farmers and rural populations. Some local farmers interviewed during our survey are of the opinion that the invasiveness of the weed in rural areas especially in cassava farms is thought to cause serious apprehension about food and livelihood security. *Chromolaena odorata* is thought to impacts on crop establishment through competition and/or its allelopathic effects (Gill et al. 1996; Onwugbuta-Enyi 2001). For example, Ogbe et al. (1994) reported a strong inhibiting effect of the leaf extracts of *C. odorata* on the growth of maize seedlings. The most important effect of the weed

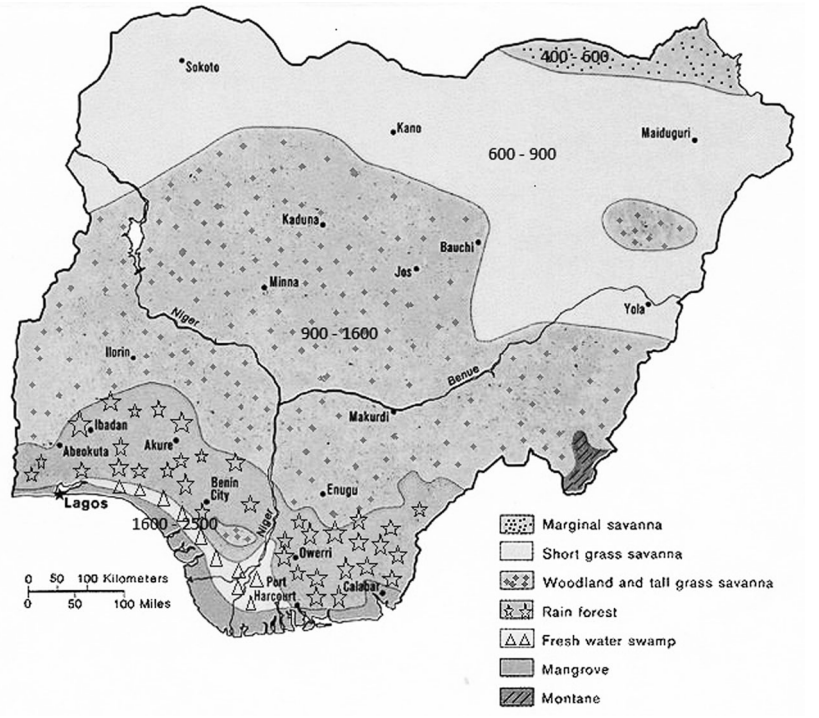

Figure 2. Vegetation types in Nigeria that are infested or have the potential to become infested by *Chromolaena odorata*. The total annual rainfall ranges in the different vegetation zones are shown on the map.

on crop production is probably its high cost of control, especially on small holdings. In Ghana for example, management of *C. odorata* in young infested plantation crops is known to contribute about a third of the cost of production (Timbilla et al. 2003). It has been observed that farmers in south-western Nigeria spend much of their time and money on the control of this weed (Adebayo 2013).

In some forest species grown in Nigeria such as teak *Tectona grandis* Linnaeus, 1782 (Lamiaceae), *G. arborea* and *Terminalia superba* Engl. and Diels, 1900 (Combretaceae), the impact of *C. odorata* was minimal (Lucas 1989) and is sometimes not regarded as a problem in forestry plantations (Ivens 1974). However, the removal of *C. odorata* has been shown to allow rapid regeneration of indigenous forest in Ghana (Honu and Dang 2000). The weed is known to harbour some important pest of crops notably *Zonocerus variegatus* (Linnaeus, 1758) (Orthoptera: Pyrgomorphidae) (Boppré 1991; Oigiangbe et al. 2007) and *Aphis spiraecola* Patch, 1914 (Homoptera: Aphididae) (Uyi et al. 2008). The Pyrrolizidine alkaloids (PAs) obtained by *Z. variegatus* from the non-nutritional feeding on *C. odorata* protect the grasshoppers and their eggs from predators and parasitoids (Boppré 1991) leading to increased fitness and population density of this polyphagous pest of crops (including cassava).

In terms of the weed's impact on biodiversity in Nigeria, we did not find a single empirical published report. The majority of literature (including some of our own papers cited here) (Table 1) referring to *C. odorata* as a threat to biodiversity are mainly anecdotal. Therefore, future research should investigate this aspect as it will help elucidate its actual impact on indigenous and non-native species in the country. Elsewhere in West and South Africa, the weed has been reported to impact negatively on biodiversity conservation (Yeboah 1998; Leslie and Spotila 2001; Goodman 2003; Mgobozi et al. 2008). For example, Yeboah (1998) reported reduced diversity of small mammals in vegetation dominated by *C. odorata* in comparison to areas without the weed, while in South Africa, Leslie and Spotila (2001) showed how the growth of *C. odorata* along riverbanks interfered with the egg-laying of Nile crocodile *Crocodylus niloticus* Laurenti, 1768 (Crocodilia) and altered its sex ratio in the progeny through shading of nests. The allelopathic properties of the weed (Sahid and Sugau 1993)

aid it in gaining dominance in vegetation, and in competing with other aggressive invaders such as *Mimosa diplotricha* C. Wright ex Sauvalle, 1869 (Ekhator et al. 2013) and *Imperata cylindrica* (Linnaeus, 1759) Beauv. (Poaceae) (Ivens 1974) in Nigeria. In Nigeria, roadsides, abandoned building plots, railways and open places around human settlements are often overgrown by *C. odorata* bushes, thereby constituting a nuisance to traffic.

Reasons for the invasion success of Chromolaena odorata *in Nigeria*

Apart from biological factors, human and vehicular movements and construction of roads as well as the increased human disturbances associated with the recent economic growth and infrastructural development in the country, several other factors have been implicated in the continued spread of *C. odorata*. For example, while a worldwide effort is being made to manage the spread of this noxious weed (see reviews in Zachariades et al. 2009; 2011), some researchers (Table 1) in Nigeria do not see *C. odorata* as a threat to agriculture and biodiversity conservation because of its perceived usefulness. This perception alone could influence the continuous spread of the weed into new areas. To critically review the opinion of researchers in Nigeria about the status of *C. odorata*, we reviewed over eighty published information items on *C. odorata* in Nigeria, dated 1965 to 2013, available from a variety of sources (see methods section for details). Fifty-two percent of this published information on *C. odorata* in Nigeria by different researchers strongly regards *C. odorata* as a serious threat to agriculture and biodiversity conservation, while 47.6% reported *C. odorata* as either medicinal plant, nutritive plant for livestock diet, fallow plant in slash and burn rotation agricultural system or soil fertility improvement plant (Table 1).

Since the major conflict of interest surrounding *C. odorata* is its use as a soil-fertility improvement plant and as a fallow species in slash and burn rotation system of agriculture widely practised in the country, we compared publications on *C. odorata* as a weed versus its fallow and soil fertility improvement claims. Figure 3 shows the frequency of scientific publications on *Chromolaena odorata* in Nigeria between 1965 and 2013 showing researchers' opinions on its usefulness either as a fallow species or soil-fertility improvement plant versus its weed status. Between 1965 and 1974, 100% of researchers in Nigeria considered

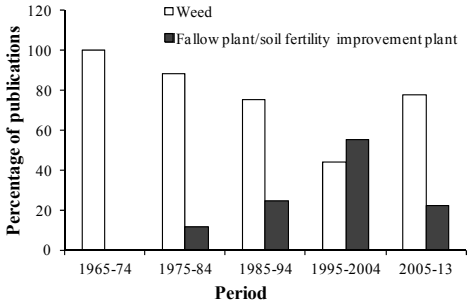

Figure 3. Frequency of scientific publications on *Chromolaena odorata* in Nigeria between 1965 and 2013 showing researchers opinion on the usefulness of the plant as a fallow species and soil fertility improvement plant versus its weed status.

C. odorata as a serious threat to biodiversity and agriculture, while from 1975 to 1984, 11.5% of publications considered it either as a soil fertility improvement plant or as a fallow species. From 1985 to 1994, 24.7% of researchers categorized *C. odorata* either as a fallow species or a soil fertility improvement plant; however, the majority (75.3%) of researchers at the time still regarded it as a weed. The numbers of publications in favour of *C. odorata* as a fallow species and soil fertility improvement plant increased between 1995 and 2004 to 55.5%. This increase in publications between 1985 and 2004, favouring *C. odorata* as a fallow species, might have contributed to its invasion success in Nigeria and other West African countries, and these "opinions" were largely responsible for the collapse and/or blockade of the FAO sponsored programme for the biological control of *C. odorata* in West Africa (Prasad et al. 1996; R. Muniappan personal communication November 2010).

The weed is thought to reduce fallow lengths (see review in Koutika and Rainey 2010) partly because of its ability to: (i) establish easily and provide good plant cover rapidly after crops have been harvested; (ii) produce large quantities of biomass; (iii) suppress other weeds; (iv) mobilise plant nutrients from the lower soil layers; (v) decompose rapidly; and (vi) the ease of clearing before crop planting. Ikuenobe and Anoliefo (2003) reported that infestation of weeds was lower in plots cropped after *C. odorata* fallow than in a modified natural bush fallow. While evaluating the size and composition of weed communities under different planted fallow in a rotational hedgerow intercropping system in the forest/savannah transition zone in Nigeria, Ekeleme et al. (2004) considered *C. odorata* as a fallow plant rather

than a weed. The authors considered *C. odorata* as a natural fallow plant, which was better at reducing weed growth than the planted fallow *Leucaena leucocephala* (Lam, 1961) de Wit (Fabaceae). However, Tian et al. (2005) showed that *Pueraria phaseoloides* (Roxburgh, 1867) Benth. (Fabaceae) cover with one year fallow length could be a better alternative to natural *C. odorata* regrowth fallow for higher maize yield. *Chromolaena odorata* is considered a good fallow plant by several authors in Nigeria partly because of the speculative decrease in natural fallow lengths (Tian et al. 1999; Akobundu and Ekeleme 2002; Aweto and Iyanda 2003) and the unsustainability of slash and burn rotation system of agriculture. However, only few of these authors present data or figures trying to compare past and present fallow lengths to support the claim of fallow declines and those that do, lack sufficient evidence to support their claims. For example, Aweto and Iyanda (2003) give specific figures for fallows at present (2–3 years) and in the past (7–10 years), but they did not cite any sources for such data neither did they described the survey they undertook themselves. Similarly, Akobundu and Ekeleme (2002) present no data to back up their claim that puts current fallow length at less than 4 years and past fallow lengths at over 10 years. Ickowitz (2006) argued that without providing evidence of the past fallow lengths, or of the way in which current fallow lengths were determined, it is not possible to say that fallow lengths have not declined, but it is also not possible to say that they have. If in Nigeria, a crop (yams, cassava and maize) cycle of 1½ years and a fallow period of between 4–7 years were practised before the 1950s (Vine 1954, cited in Ickowitz 2006), and reports (although without sufficient evidence) suggest current fallow lengths of 4 years (e.g. Akobundu and Ekeleme 2002), fallow lengths do not seem to have decreased drastically as claimed by these authors.

Other studies (Olaoye 1976; Obatolu and Agboola 1993; Tian et al. 2005) have reported on the soil improvement abilities of *C. odorata*. Amiolemen et al. (2012) and Jubril and Yahaya (2010) assessed the nutrient status of soil under two year's *C. odorata* fallow in south-western and north-central Nigeria and found that the weed significantly influence the build-up of nutrients in the soil as it increase the essential elements in the soils. The authors then suggested the deliberate planting of the weed in crop lands and grasslands. We reasoned that their findings might not be valid because of the short duration of the research (2 years); and also because other factors (unknown) might have influenced their results. We propose that future studies should focus on measuring and comparing long term fallow (at least 10 years fallow) soil properties under *C. odorata* plants with soils under other indigenous fallow species. This will provide a thorough understanding of the influence of *C odorata* on soils under its canopy and the relationships that exist between them. It has also been suggested that the weed should be incorporated into the soil to serve as manure (Ilori et al. 2011). We think that the statement of McFadyen (1992) that, "there is no evidence that *C. odorata* directly enriches the soil" remains valid because no long-term studies with well-designed methods have been shown to dispute her hypothesis.

As common with other alien plants, its ethno-pharmacological importance has been elucidated in Nigeria and elsewhere (Phan et al. 2001; Akinmoladun et al. 2007; Alisi and Onyeze 2009; Owolabi et al. 2010; Alisi et al. 2011). The weed is reported to have antispasmodic, antiprotozoal, antitrypanosomal, antibacterial, analgesic, anti-fungal, antihypertensive, anti-inflammatory, astringent, diuretic and hepatotropic properties. A product made from *C. odorata* named eupolin has already been licensed for use in Vietnam for treating soft tissue burns and wounds (Raina et al. 2008). The importance of *C. odorata* in livestock nutrition in Nigeria is reviewed in Aro et al. (2009). Its use in the formulation of layers' diets, its influence on performance, nutrient availability, mineral utilization, blood and biochemical indices of monogastrics and poultry as well as its acceptance by West African dwarf goats (Fasuyi et al. 2005; Aro et al. 2009) are quickly changing the perception of the plant as a noxious weed to one of immense nutritional potentials. On the contrary, Sajise et al. (1974) reported that the high nitrate levels in young foliage can cause livestock death, while McFadyen (2004) reported that the PAs in the flowers have killed goats which ate the flowers. In Nigeria, its use as livestock medicinal plant has been reported (Otoikhian and Oyefia 2010).

There are some evidence that *C. odorata* has insecticidal, fungicidal and nematicidal properties. For example, Okigbo et al. (2010) evaluated the effect of *C. odorata* on post-harvest spoilage fungi of yams in storage in Nigeria and the authors found out that the weed is able to suppress rot-causing fungi of yam and they recommended it as a good natural plant fungicide against yam tubers rot fungi in storage. Similarly, Yeni et al.

(2010) proved the potentiality of the plant extracts for the control of post-harvest and transit fungal rot of tomato fruit. Its importance in the control of pawpaw rot fungi has also been documented by Ilondu (2011). Odeyemi et al. (2011) studied the effect of organic fertilizer and *C. odorata* residue on the pathogenicity of the nematode *Meloidogyne incognita* (Kofoid and White, 1919) (Nematoda, Heteroderidae) on maize and suggested that *C. odorata* in combination with organic fertilizers can be a viable option for the control of the nematode on maize. The use of *C. odorata* biomarker in assessing heavy metal contaminations in traffic and solid waste polluted areas and its possible use as a phyto-remediating agent in crude oil polluted soils have been suggested (Anoliefo et al. 2003; Agunbiade and Fawale 2009). From our examination of historical archives, it is demonstrable that the usefulness of *C. odorata* created a window of opportunity for its continuous spread into new areas in Nigeria, because from the late 1980s to the present day, opinions have always differed among stakeholders (biologists, agriculturists, conservationists and non-professionals) on the best way to respond to the weed.

Presently, 77.8% of the publications on the status of *C. odorata* published between 2005 and 2013 strongly regard it as a serious weed that deserves urgent control to protect indigenous flora and fauna as well as to reduce its damage potential in cultivated farmlands and pasture lands, thus advocating the use of biological control as a management option against the weed. It is important to note that before the introduction of *C. odorata* into Nigeria, farmers and locals adapted well without it and they will surely adapt if the weed population is reduced using the appropriate control and management measures.

Control attempts

Recent studies have revealed that the impact of invasive plants change over time (Dostál et al. 2013; Yelnik and D'Antonio 2013), but this may not necessarily benefit native species recovery (Yelenik and D'Antonio 2013). However, it is still relatively sound to manage plant invasions because of the threat they may pose to agriculture and livelihoods. Although biologists, ecologists, conservationists, agriculturists and non-professionals in the country differ on the best way to respond to *C. odorata* invasion, several control options such as mechanical, cultural, chemical and biological control are available for its management.

Mechanical and manual control

Chromolaena odorata seedlings are slow to start and can be effectively controlled by hoeing, uprooting, use of machetes and bush knives at the early stages of crop establishment. Re-growth from rootstock can be carefully weeded by hoeing, and uprooting with either machetes or bush knives. The uprooted rootstocks are gathered together and burnt when dried (NACWC 1994; NIFOR 2003). NACWC (1994) reported that under zero tillage or in plantation crops, regular slashing carried out 4–5 times at 4–6 weeks intervals during the growing season satisfactorily suppress the weed. Are and Folarin (1970) recommended slashing four times a year in cocoa plantations, while Komolafe (1976, 1980) recommended a combination of slashing, ring weeding and mulching in tree crops. Ojuederie et al. (1983) reported that slashing alone in oil palm plantation increased bunch yield. Manual weeding of *C. odorata* 3, 8 and 12 weeks after planting of cassava has been recommended by IITA (1990) and NACWC (1994). Manual removal of the weed at 2–3 and 5–7 weeks after planting maize has been found to be effective (NACWC 1994). The mechanical method of control of *C. odorata* is the most popular among subsistence farmers in Nigeria due to its effectiveness, and availability of labour within the farmers' family. However, the method is slow, laborious, takes over 50% of the farmers' time, and it is not practicable in large-scale farming. The effectiveness of this control measure also depends on weather conditions especially rainfall, as stumps of the plants can easily re-grow during the wet season and this has been implicated in crop loss and farm abandonment in Edo and other southern states in Nigeria.

Cultural control

In most plantation crops especially oil palm, mulching is done around the bases of the trees to check the weed (NIFOR 2003). It is recommended that mulching with oil palm bunch refuse should be done up to 1.0 or 1.5 metres around the base of the palm to keep the weed in check at the early stage of growth of the palm. Although this method effectively suppresses *C. odorata* (NIFOR 2003), high labour costs and unavailability of mulching materials limits its use. *Pueraria phaseoloides* (Roxburgh, 1867) Benth. (Leguminosae), *Calopogonium mucunoides* Desv., 1826 (Fabaceae) *Centrosema pubescens* Benth., 1837 (Leguminosae) and *Vigna unguiculata* (Linnaeus, 1843) (Legumi-

nosae) have been recommended as cover crops for *C. odorata* suppression in tree crop plantations in Nigeria (Shedrick 1968; Komolafe 1976; 1980). Suppression of the weed by cover crops becomes inadequate as the canopy of the tree crop closes and the cover crops dry out. Establishment of the cover crops during field planting of tree crops is also a problem. A further disadvantage of this control measure is that it requires an initial implementation of mechanical and/or chemical control before it can be practiced.

Chemical control

Several herbicides have been found to give some control of *C. odorata* in Nigeria, but re-infestation can occur easily and quickly, as with most perennial weeds, due to its deep rooting system which contributes to its survival under different cultivation methods (Ikuenobe and Ayeni 1998). Systemic phloem-mobile herbicides such as glyphosate or imazapyr, which can effectively translocate into the root system, offer the most promising option for its control (Ikuenobe and Ayeni 1998). Soil applied herbicides or early post emergence herbicides such as atrazine and diuron that translocate through the xylem vessels are also effective against *C. odorata* seeds on the soil surface or on recently emerged seedlings. A range of herbicides has been evaluated for control of the weed in oil palm plantations in Nigeria. *Chromolaena odorata* treated with glufosinate-ammonium suffers from foliage desiccation, but the plant soon recovers. However, treating the weed with glufosinate-isopropylamine and glyphosate-trimesium suppressed re-growth for up to twelve weeks after treatment. Triclopyr and hexazinone + diuron were also reported to be effective in the control of the weed and suppressed its re-growth up to twenty weeks after treatment (Ikuenobe and Ayeni 1998). Application of imazapyr alone controlled *C. odorata* re-growth for up to thirty weeks after treatment. Ikuenobe and Ayeni (1998) recommended glyphosate at 2.4 kg a.i ha^{-1} and low rates (0.5 kg a.i ha^{-1} or less) of imazapyr. Several other herbicides (soil-active or pre-emergence herbicide) such as atrazine, simazine, oxadiazone, imazethapyr and imazaquin, were reported to effectively control *C. odorata* from seed or at early emergence stage at recommended rates before field planting of crops (Sheldrick 1968; Utulu 1996; Ikuenobe and Ayeni 1998). Ogundola and Liasu (2007) recommended cassava effluent as pre and post emergent herbicide (at seedling stage) for controlling *C. odorata* infestation on small scale farmland. Chemical control is effective but expensive and also poses some environmental problems, and is not practicable under the prevailing resource poor farming circumstances in most parts of Nigeria.

Biological control attempts against *Chromolaena odorata* in Nigeria

After careful consideration of the origin and biology of the weed (Ivens 1972), especially the fact that it arrived without its complement of natural enemies and that conventional control methods are not sustainable in terms of cost and practicability, the Nigerian government set up two committees between 1967 and 1979 to find ways of managing the weed (Iven 1974; Lucas 1989). 'Classical' biological control was identified as the most viable option for the sustainable management of the spread of the weed. The first biological control programme for *C. odorata* worldwide originated in Nigeria when in the late 1960s the Nigerian Institute for Oil Palm Research (NIFOR) funded the initial research on biological control of *C. odorata* by the Commonwealth Institute of Biological Control in Trinidad. This led to the identification of approximately 225 phytophagous insects and mites on *C. odorata,* mainly in Trinidad but also in other parts of its native range (Cruttwell 1972, 1974). Host range testing in Trinidad demonstrated that the leaf feeding moth *Pareuchaetes pseudoinsulata* Rego Barros, 1956 (Lepidoptera: Arctiidae) and the flower feeding weevil *Apion brunneonigrum* Beguin-Billecoq, 1910 (Coleoptera: Curculionidae) were sufficiently host specific to be recommended as biological control agents (Bennett and Cruttwell 1973) and this recommendation triggered the introduction and release of these two biological control agents in the southern part of Nigeria, probably in Ibadan (7°23'N and 3°55'E) and environs (Uyi 2011; Uyi et al. 2011) in the 1970s (Cock and Holloway, 1982). The details of *P. pseudoinsulata* and *A. brunneonigrum* releases and the locations of their actual release(s) in Nigeria at the time are not clear. Unfortunately, neither species established (Julien and Griffiths 1998), possibly due to ant predation (Cock and Holloway 1982) and/or because the biocontrol efforts were not sustained (Uyi et al. 2011). Regrettably, no further biological control efforts have been attempted since the 1970s. Uyi and Igbinosa (2013) identified some of the challenges against biological control of *C. odorata* in West Africa (including Nigeria) to include; lack of

government will to implement suitable policies, inadequate funds for research, a lack of capacity, and an apparent lack of interest in weed biocontrol by institutions and governments. Despite these challenges, there are prospects for the biological control of the weed in Nigeria because of the reasons detailed below.

Prospects for the biological control of Chromolaena odorata *in Nigeria*

The recent discovery of *P. pseudoinsulata* in Benin City (6°19'N and 5°37'E) in the Niger Delta Region of Nigeria (Uyi et al. 2011) has reawakened the hope of a successful establishment of the moth in Nigeria and thus improved prospects for the weed's biocontrol. The moth is believed to be present in Anambra, Delta and other southern states with similar climatic conditions to those prevailing in Benin City, Edo State, where the moth was discovered (Uyi et al. 2011). Uyi (2011) suggested two alternative scenarios to explain the presence of the *P. pseudoinsulata* in Nigeria viz; (i) the moth may have established after its initial release in Nigeria during the 1970s; or (ii) may have spread from the established sites in Ghana.

With the increase in awareness among some scientists about the problems of the weed, and the need for biocontrol of *C. odorata* and other invasive alien weeds in Nigeria, prospects exist for the formation of local working groups on the biological control of *C. odorata* and other noxious weeds in the country. This will no doubt help in the re-launching of a new biological control effort. If eventually launched, it would be important to sustain the programme to avoid failure as previously experienced in the early 1970s, and in the 1970s and 1990s in Nigeria and Ghana respectively. The proposed renewed biological control effort should focus on two candidate insect agents of high priority viz. *P. pseudoinsulata* and *Cecidochares connexa* Macquart (Diptera: Tephritidae). The reasons for, and advantages of, the choice of these two agents are discussed in Uyi (2011) and Uyi and Igbinosa (2013).

Coordinated control or adaptive management?

Apart from the failed national control attempt against *C. odorata* in the 1970s, the management of the weed has been the sole responsibility of individual land owners, concern institutions and farmers. Hence the management of this weed has been grossly uncoordinated. An uncoordinated approach is unlikely to curtail the continuous spread of any plant invader. The lack of a national programme against the weed coupled with its countless positive attributes has led to the question; is a coordinated approach still needed to control it or do we need to develop strategies for its adaptive management? Our findings from literature showed that several workers differ on how to respond to this weed. For example 52.3% of the papers published want control measures to be initiated against *C. odorata*, while the remaining 47.6% prefers the status quo (no control action). Uyi and Igbinosa (2013) advocated coordinated control against *C. odorata* and suggested the formation of a national working group on the management of the weed, while Borokini and Babalola (2012) suggested a form of adaptive management in which the beneficial attributes of the weed can be economically exploited to create job opportunities. It is however worthy of note that, even in the face of the usefulness of *C. odorata*, it will be reasonably sound to implement a biological control programme against it in Nigeria because biological control is not aimed at eliminating the target weed; its purpose is to establish an equilibrium which maintains the weed population below levels where they cause significant harm to agricultural, biodiversity conservation and livelihoods. Hence there would still be enough *C. odorata* to satisfy the potential users of this "resource".

Conclusion

Since the introduction of *C. odorata* into Nigeria in 1937, the weed has spread extensively especially in the last 5 decades. Apart from the invasive characteristics of *C. odorata*, the continuous spread of, and invasion by this weed in Nigeria has been due to: (i) the increased human disturbances associated with the recent economic growth and infrastructural development in the country; (ii) lack of an integrated control and management programme; (iii) lack of a sustained biological control programme; (iv) its perceived ethno-pharmacological, funcigicidal and nematicidal importance; and (v) its use as a fallow species and soil fertility improvement plant in slash and burn rotation system of agriculture. Given that *C. odorata* has attained a problematic status in agricultural lands and commercial plantations as well as being a perceived threat to biodiversity conservation and human livelihoods in the southern and central belts of Nigeria, it would be

justified to reduce its competitiveness in order to limit its menace in both natural and semi-natural ecosystems. We suggest the prioritizing of two biological control agents (*P. pseudoinsulata* and *C. connexa*) that can effectively inflict extensive but selective damage on this invasive alien weed.

In view of the prospects for the biological control of *C. odorata* that have been highlighted, the Nigerian government and institutions in the country are highly encouraged to initiate an integrated management programme against *C. odorata* in collaboration with the *Chromolaena* Working Group of the International Organization for the Biological Control of noxious animals and plants (IOBC) for technical support. If the spread and impact of *C. odorata* in Nigeria is to be curtailed and eventually reversed, several initiatives for control and management are required at both national and state levels. These include: (i) initiation and sustenance of an effective biological control programme; (ii) creation of sustained public awareness about the weed problem especially in areas that are sparsely infested or in un-infested areas which have the potentials to become infested; and (iii) the development of a coordinated and integrated control and management plan for *C. odorata* in Nigeria.

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