



Original Research

Soil seed bank and mapping *Chromolaena odorata* an invasive weed in agro-ecosystems of Serengeti district, Tanzania

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ABSTRACT

The spread of *Chromolaena odorata* in some parts of Serengeti district has stimulated interest in the prediction of their soil seed bank and mapping its distribution. Thirty clusters from each agro-ecosystem namely fallow land, grazing land, and cultivated land were sampled for soil seed bank assessment. Each cluster was randomly demarcated into five 20 m² plots. Soils were collected from 0-5 cm, 5-10 cm, and 10-15 cm depths using a 10 cm diameter and 5 cm length cylinder. Coordinates were taken using a hand held GPS (Map76 cx) along transects. Each soil sample was soaked for a minimum of 30 minutes in a solution of sodium hexametaphosphate (50 g/L) and sodium bicarbonate (25 g/L) and poured over a set of three different sieve sizes to remove debris. The results were converted to number of weed seeds per square meter, and statistically analysed using R software version 3.5.1. Quantum GIS (1.8.0) was used to map the distribution of the weed. The soil seed bank in all agro-ecosystems decreased significantly ($P < 0.05$) from 0-5 cm to 10-15 cm soil depths. Mean weed seed densities varied depending on land use but significantly highest in fallow land followed by cultivated land ($P < 0.05$). In cultivated land the top soil had more than twice Siam weed seed densities (1254 seeds/m²) than in the bottom soil layers (597 seeds/m²). The Siam weed was found to have ability to thrive in a wide variety of soils, hence increase its invasion success. Distribution maps of *C. odorata* in Serengeti district and surrounding areas provide insight on the aggressiveness of the weed according to its spread and infestation levels. Future research work should be carried out to study fallow age in relation to soil seed bank of *Chromolaena odorata* and physio-chemical properties of the soil and their influence on distribution of the weed.

Introduction

Chromolaena odorata (Asteraceae) King and Robinson (1970) is remaining a huge threat to natural and semi-natural ecosystems in most parts of the world (Zachariades et al. 2009) thereby compromising ecosystems integrity. This invasive alien shrub attracts significant attention because

of the threat it poses to agriculture and livelihoods. It has been noted on a list containing 100 of the world's worst invasive species by the IUCN (ISSG, 2002). It is an important invasive weed throughout the tropical regions of Africa, Asia and Oceania (Muniappan et al. 2005; Zachariades et al. 2013). This weed was accidentally introduced in Tanzania and observed for the first time in Serengeti district where it is known as "*amachabhongo*" meaning recent invaders. The first collection of *C. odorata* in Tanzania was in 2011 from Ngoreme division in Serengeti district. Following its introduction probably from Kenya, the weed is now quickly spread through the whole district and nearby districts. However, a field survey conducted by Sibuga et al. (2013) in some parts of Serengeti district determined that *Chromolaena odorata* was dominant mainly on uplands with gentle slopes that formally were used as grazing areas. Other severely infested areas were along road sides, cultivated land, fallow land and areas near homestead. Local communities identified major threats posed by *Chromolaena odorata* to include reduction of grazing areas, reduced availability of grasses for thatching and difficulties to uproot rhizomes of the weed during land preparation for crop production (Sibuga et al. 2013). Given that the weed seeds are predominantly disseminated by the action of wind, it has the potential to encroach the nearby Serengeti National Park, an area of significant biological diversity and global significance. The negative impacts of plant invasions in protected areas were addressed by Foxcroft et al. (2017), who considered the impacts on species and communities, on ecosystem properties, and on biogeochemistry and ecosystem dynamics, as the most important ones. Even though little research has been carried out in Africa's protected areas, the available work reveals that the selected biodiversity indicators and other ecosystem properties are being impacted upon by this weed (Foxcroft et al. 2013).

The distribution and density of weed species on a piece of land depend largely on the size of its soil seed bank (SSB). Most of the weed species in arable cropping systems are annuals while others are perennials, some knowledge of the weed seed bank may be a good starting point for an integrated weed management programme (Forcella, 1993; Buhler et al. 1997). This has stimulated interest in the prediction of their soil seed bank and distribution (Mack et al. 2000; Rejmánek et al. 2005; Pejchar and Mooney, 2009) worldwide. Although the arrival and continuous spread of *C. odorata* is thought to pose a serious threat to subsistence and commercial agriculture in Serengeti district very little has been done to elucidate its soil seed bank and its distribution patterns. Therefore, the aim of this study was to provide baseline information of *C. odorata* SSB and its distribution patterns in Serengeti district, Tanzania.

Materials and Methods

Description of the study Site

Serengeti district is located in northern part of Mara region, Tanzania. It is located at $1^{\circ} 35'22''$ S and $34^{\circ} 11'33''$ E. The climatic condition of the area is tropical, characterized with annual rainfall ranging from 700 mm to 1500 mm and the annual range of temperature is 24°C to 27°C . The main economic activities in Serengeti district is agriculture for consumptive crops, cash crops and livestock keeping.

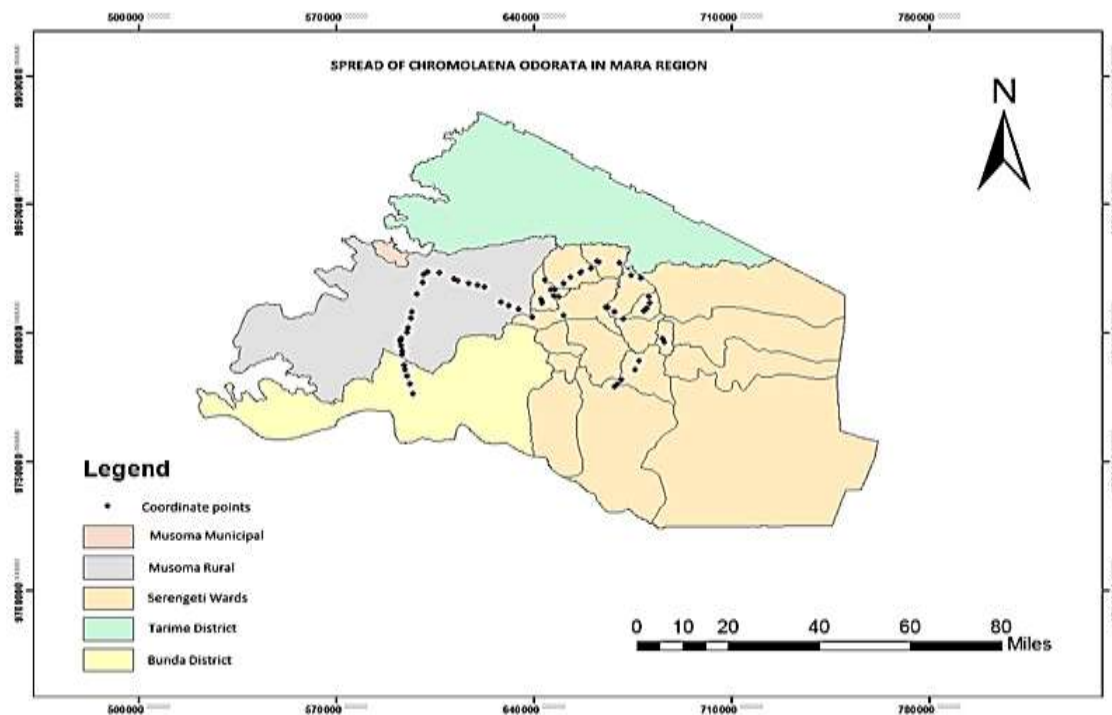


Figure 1. A map of Mara region showing coordinate points in Serengeti district which is the area of potential threat with *Chromolaena odorata*. Other points fall in Musoma rural and Bunda districts where the weed was also recorded.

Sampling Design and Data Collection

Meetings were held with key stakeholders in the District Government Authorities and non-governmental organisations to discuss and identify villages where the surveys would be undertaken. The meetings involved administrators, environmentalists, livestock, forestry, land and agricultural officers. In selected villages within each ward, field visits were made to determine the weed soil seed bank and its distribution. Ngoreme ward with the following villages; Buchanchari, Majimoto, Nyagasense, Kenyamonta, Mesaga and Magatini was intensively studied as it was mentioned to be the most affected ward in the district. Some transect surveys were also done

outside Serengeti district to observe potential spread of the weed. Thirty clusters from each land use namely fallow land, grazing land and cultivated land were sampled for SSB assessment. Each cluster was randomly demarcated into five 20 m² plots. Soils were randomly sampled from five points within each plot at 0-5 cm, 5-10 cm and 10-15 cm layers using a 10 cm diameter and 5 cm length soil cylinders. GPS coordinates were taken for mapping the distribution of the Siam weed.

Data Analysis

Each soil sample was soaked for a minimum of 30 minutes in a solution of sodium hexametaphosphate (50 g/L) and sodium bicarbonate (25 g/L) (Malone, 1967). This suspension was poured over a set of three sieves, the upper one being 2.0mm mesh opening, followed by 0.85mm and the lower one being 0.589 mm. The contents were washed through these sieves by a fine spray of water. Rationale of sieving was to remove stones, coarse materials and other debris. The debris collected in the lower sieve was transferred onto a Whatman number 1 filter paper and left to dry for 24 hours. Once dried, all seeds of *Chromolaena odorata* were separated by hand. The results were converted to number of weed seeds per square meter, and statistically analysed using R × 64 3.5.1 software where the means of soil seed bank in each soil depth among the three land uses were compared. Quantum GIS desktop (3.12.1) was used to produce weed distribution maps.

Results and Discussion

Soil seed bank of *Chromolaena odorata*

The SSB in all land uses decreased from the top soil to the bottom soil. No seeds were found below 10 cm soil depth in all land uses (Table 1). Soil seed bank in 0-5 cm soil depth differed significantly $p < 0.05$ among the three land uses (figure 3). Also, SSB in 5-10 cm soil depth differed significantly $p < 0.05$ in fallow and cultivated lands (Figure 4). Soil seed bank in 0-5 cm and 5-10 cm soil depths was found to differ significantly among all three land uses (Table 3). The number of seeds of *C. odorata* in the top soil (0-5cm) layer was significantly ($p < 0.05$) higher than those in the lower layers in all three land uses (Figure 2).

Table 1. Mean values of SSB of *Chromolaena odorata* in different land uses

Fallow land (seeds/m ²)			Cultivated land (seeds/m ²)			Grazing land (seeds/m ²)		
0-5cm	5-10cm	10-15cm	0-5cm	5-10cm	5-15cm	0-5cm	5-10cm	5-15cm
3883	697	0	1254	597	0	896	0	0

This was expected, since weed seeds shed from plants are initially deposited on the soil surface before being moved down by earthworms or rodents or seepage by rain water. In areas under

fallow, most of the weed seeds remained on top 5cm soil (Table 1). This is possible because most of fallow lands are undisturbed and the litter layer is intact; therefore, sinking of the seeds to deeper layers is minimal.

Table 2. Differences in SSB of *Chromolaena odorata* per soil depth in different land uses.

Land use type	Soil depth (cm)	Soil seed bank (Seeds/m ²)	t-Ratio	P-value
Fallow land	0-5	3883	16.25	0.000
	5-10	697		
Cultivated land	0-5	1254	15.16	0.000
	5-10	597		
Grazing land	0-5	896	22.23	0.000
	5-10	0		

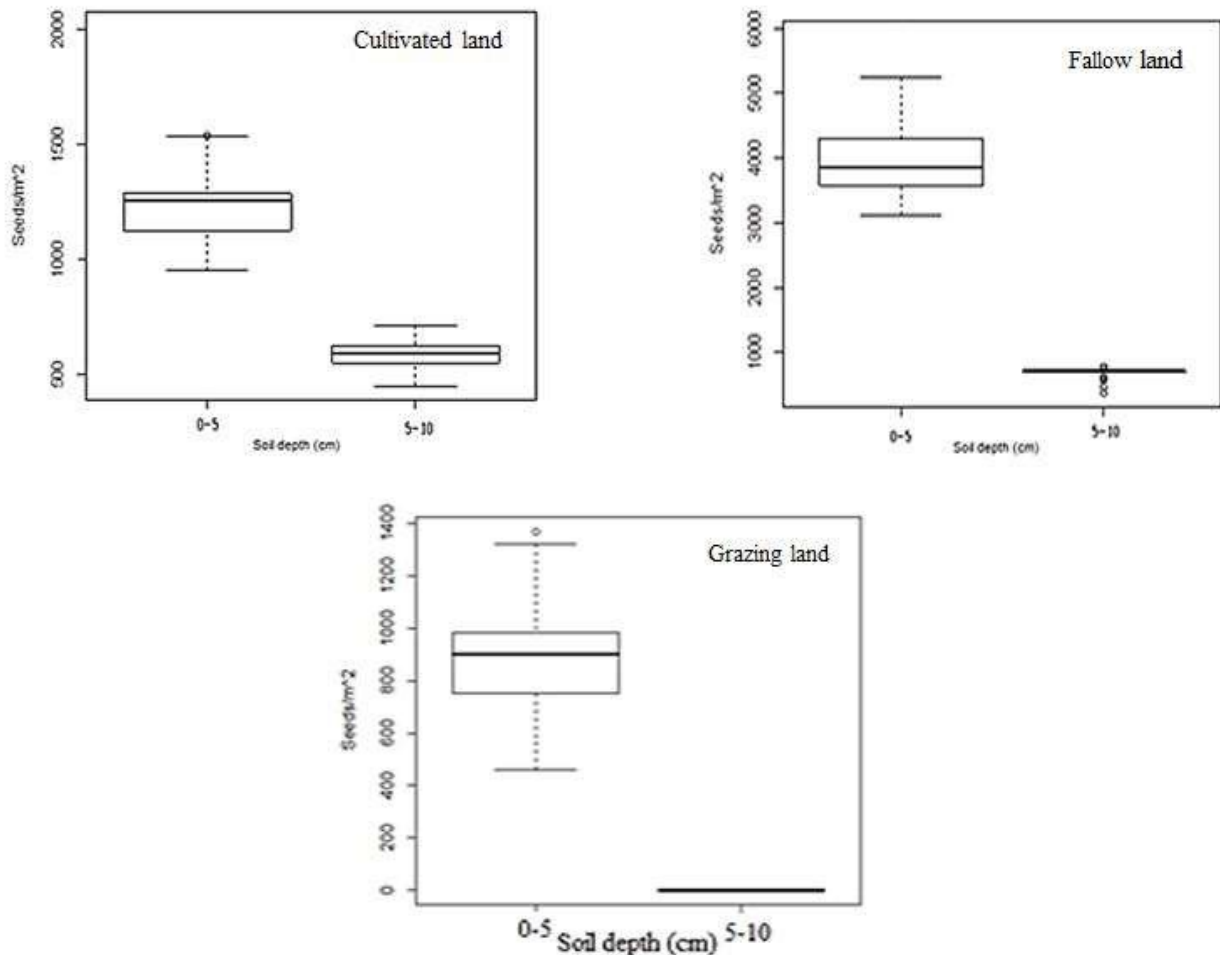


Figure 2. Box plots showing mean differences between soil seed bank in 0-5 cm and 5-10 cm depths among land uses.

Mean weed seed densities in all soil depths varied depending on land use but generally significantly ($p < 0.05$) higher in fallow land followed by continuously cropped areas (Table 2). This

may be due to frequent tillage and weeding that might have moved some of the seeds to the lower layers of the soil. But, Jones and Burch (1977) found higher numbers of seeds near the soil surface in relatively undisturbed habitats which is similar with results of this study. This might be due to that; fallows remain uncultivated for several years though their fallow age differs. Other studies from several African countries, reported the invasiveness of Siam weed that it is particularly severe in young fallow lands (with fallow periods shorter than 5 years) and light may be the major factor regulating its population size (Witkowski and Wilson, 2001). Also, studies by Slaats, 1995 suggested that in shifting cultivation, the weed replaces the natural secondary succession and becomes the dominant fallow species. Catarino et al. 2019 suggested that, the shortening of fallow periods can favour the encroachment of *C. odorata*. However, according to Waterhouse and Zeimer 2002, most of the *C. odorata* seeds produced by the plant enter the soil and build up a seed bank which may survive up to 6 years. In this case the applied control methods are generally unsuccessful to halt the spread of the weed due its short-term persistent seed bank (Witkowski and Wilson, 2001). On the other hand, grazing land had few SSB compared to other land uses. In grazing land, no seeds were found below 5cm soil depth (Table 1). This might be due to that; some seeds are normally broken down by cattle hooves as the cattle's search for fodder materials. Also, seeds of *C. odorata* are able to stick on cattle's bodies and hooves hence decreasing its SSB. Zachariades et al. 2009 reported that, Siam weed is a ruderal plant species that thrives in sunny and disturbed habitats, such as grazing lands, roadsides and cropped land, and can easily invade open spaces.

Table 3 . Comparison of SSB in 0-5 cm and 5-10 cm soil depths among land uses.

Soil depth (cm)	Land use type	Soil seed bank (seeds/m ²)	t-Ratio	P-value
0-5	Fallow land	3883	13.22	0.000
	Cultivated land	1254		
	Fallow land	3883	15.01	0.000
	Grazing land	896		
	Cultivated land	1254	6.21	0.000
	Grazing land	896		
5-10	Fallow land	697	3.63	0.001
	Cultivated land	597		

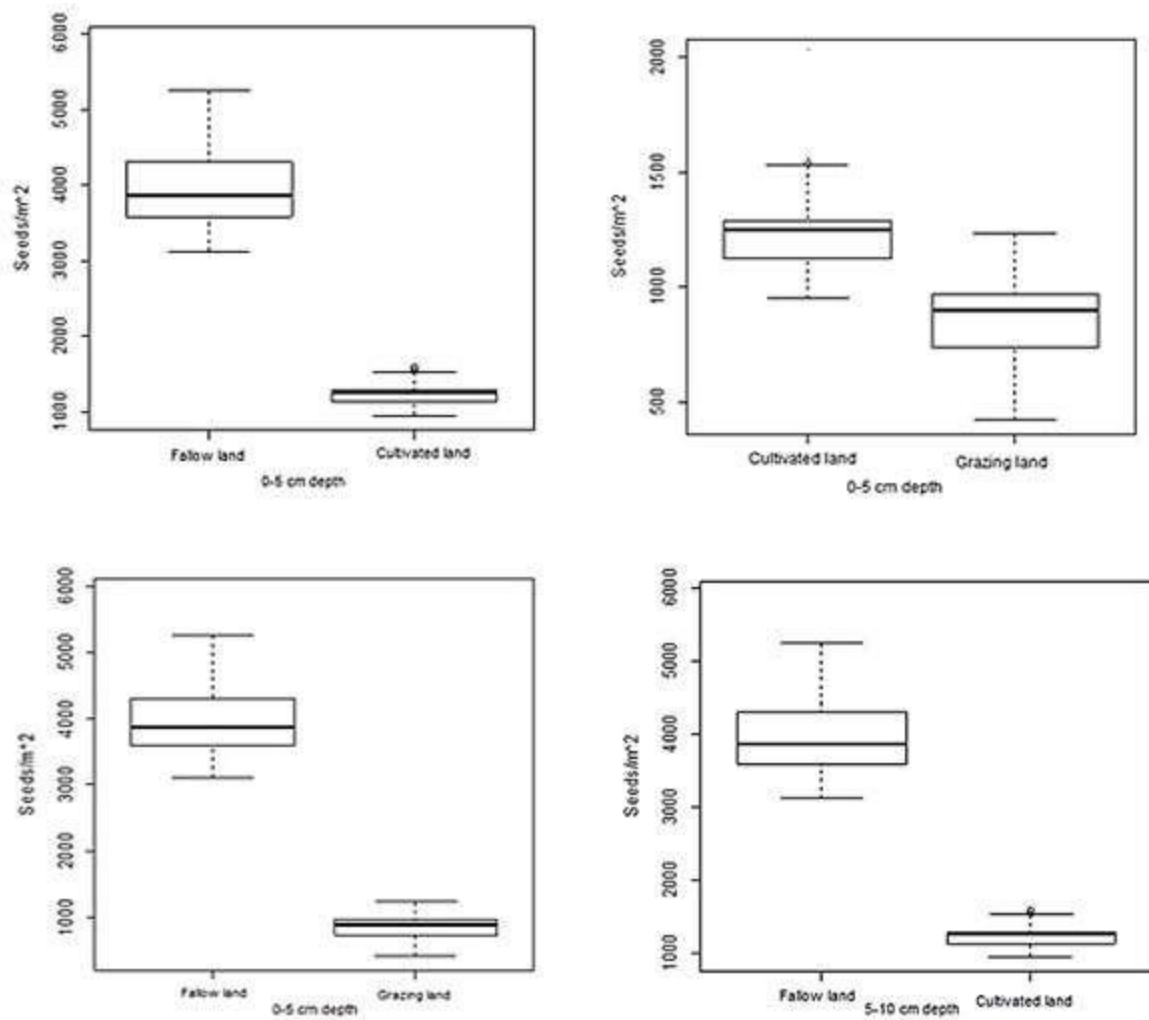


Figure 3. Box plots showing mean differences between soil seed bank in 0-5 cm and 5-10 cm depths among land uses.

Distribution of Chromolaena odorata in Serengeti district

Almost all villages in Serengeti district were invaded with *C. odorata*. High infestation levels of the Siam weed were observed in Buchanchari, Majimoto, Nyagasense, Kenyamonta, Mesaga and Magatini villages. Massawe, 2016 found that distribution of the Siam weed in Serengeti district where higher in Marasomocha, Nyamakobiti, Mesaga, Remng'orori and Gusuhi villages. He recorded low infestations in Nyamihiru, Busane, Magange and parts of Remng'orori village (Figure 5). Results of this study and those of Massawe, 2016 indicates that distribution of *C. odorata* is increasing fast to areas which were previously not infested and the magnitude appears to increase rapidly with time. It was said that, construction of new roads in the region has greatly influenced the distribution of the weed at the early stages of invasion. Its rapid spread through the entire district

(Serengeti) in eight (9) years period since its invasion in 2011 may have been as a result of trade, human and vehicular movement. Spread by wind is considered potential due to its seed structure and shape (Plate1) which is a characteristic of weed dispersed seeds. Zachariades et al. 2011 suggested that, Siam weed spreads mostly through its numerous seeds potentially in the millions in larger bushes being easily transported short distances by wind due to the tufts of hair that catch any breeze, also readily become lodged in clothing, animal fur or machinery.

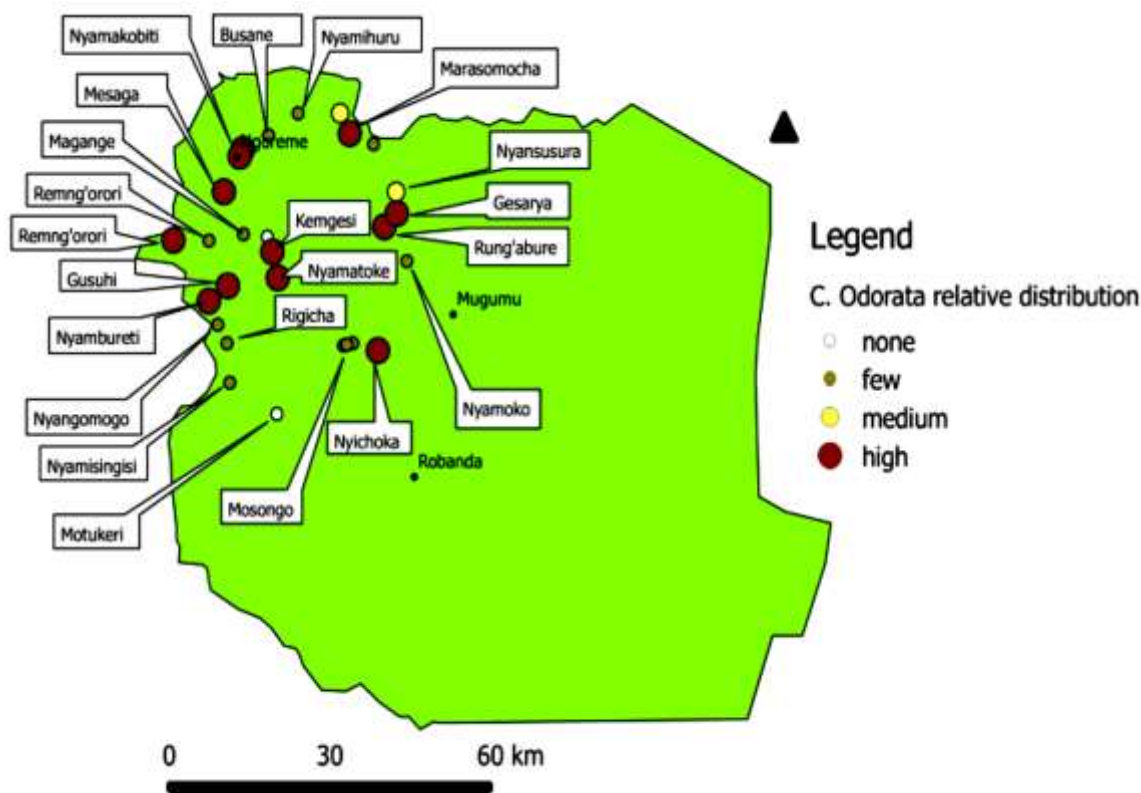


Figure 5. Relative distribution of *C. odorata* in surveyed villages of Serengeti district.

Source: Boniface H. J. Massawe survey in May, 2016.



Plate 1. Seed characteristics of *Chromolaena odorata*. Source: George Bulenga, 2019. A single mature plant of *Chromolaena odorata* can produce up to 440,000 seeds per year (Erasmus, 1985). Seeds are very light (25,000 dry seeds/g) and are windborne.

Influence of soil type on the distribution of Chromolaena odorata

This study found that, the weed has ability to thrive on a wide variety of soils. Figure 6 shows the soil map of Mara region indicating the soil types and the points where the weed was recorded. But the points are concentrated in Serengeti district where the intensive study was conducted followed by transect line from Serengeti district to Musoma rural and it ended in Bunda district (Figure 1). It was shown that, large part of Mara region is dominated by Fluvisol and Luvic Phaeozems soils which are mainly found in Serengeti district and mostly covering the whole Serengeti National Park¹ (Figure 6). Similar survey done by Massawe, 2016 reveals that, Serengeti district is mainly covered by Luvic Phaeozems and *C. odorata* can survive on different soil types (Figure 7). Several studies suggest that the invasive success of *C. odorata* is its ability to grow on many soil types (Timbilla and Braimah 1996; Goodall and Erasmus 1996; Robertson et al. 2008). Mandal and Joshi, 2014 found that, the weed has been found to thrive in all types of well-drained soil and on soils that are relatively low in fertility. Also, Liggitt, 1983 pointed out that the weed grows on soils ranging from sand dunes to heavy clays, and it is heavily dependent on the availability of light. Other scholars found that, the invasive success of *C. odorata* is thought to depend upon a combination of factors such as high reproductive capacity, high growth and net assimilation rates, the capacity to suppress native vegetation through competition for light and allelopathy, and its ability to grow in a

wide range of soil types and climatic conditions (Muniappan et al. 2005; Uyi and Igbinsosa, 2013). Even though no research has been carried out in Serengeti National Park¹, this study reveals that the Serengeti ecosystem is also under threat due to its ability to invade on each soil type and rapid spread of its seeds. The harmful effect of *C. odorata* in natural ecosystems is well documented (Foxcroft et al. 2013, 2017) and the invasion can have serious consequences for nature reserves, particularly on anthropogenic savannas (Macdonald and Frame, 1988). However, Massawe, 2016 in Serengeti district reveals that *C. odorata* can infest area with soils emanating from all three types of rocks (Igneous, Metamorphic, and Sedimentary) as parent materials. But no clear relationship could be established between the lithology and the Siam weed infestation in Serengeti district. Therefore, farther soil studies and the use of more detailed geological maps would probably give better insights.

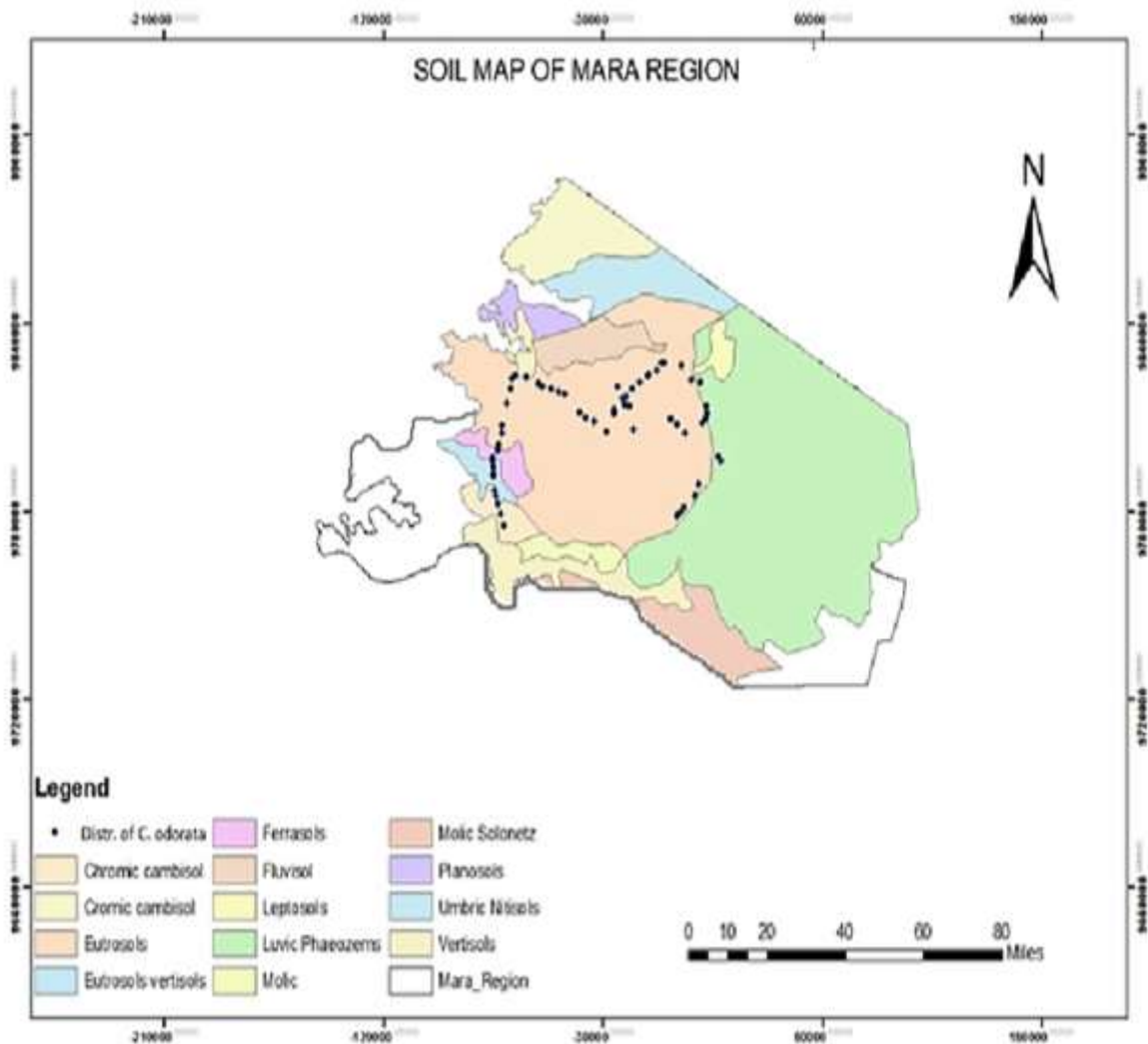


Figure 6. The soil map of Mara region showing the distribution of *Chromolaena odorata*. It shows that the weed thrives on a wide variety of soil types.

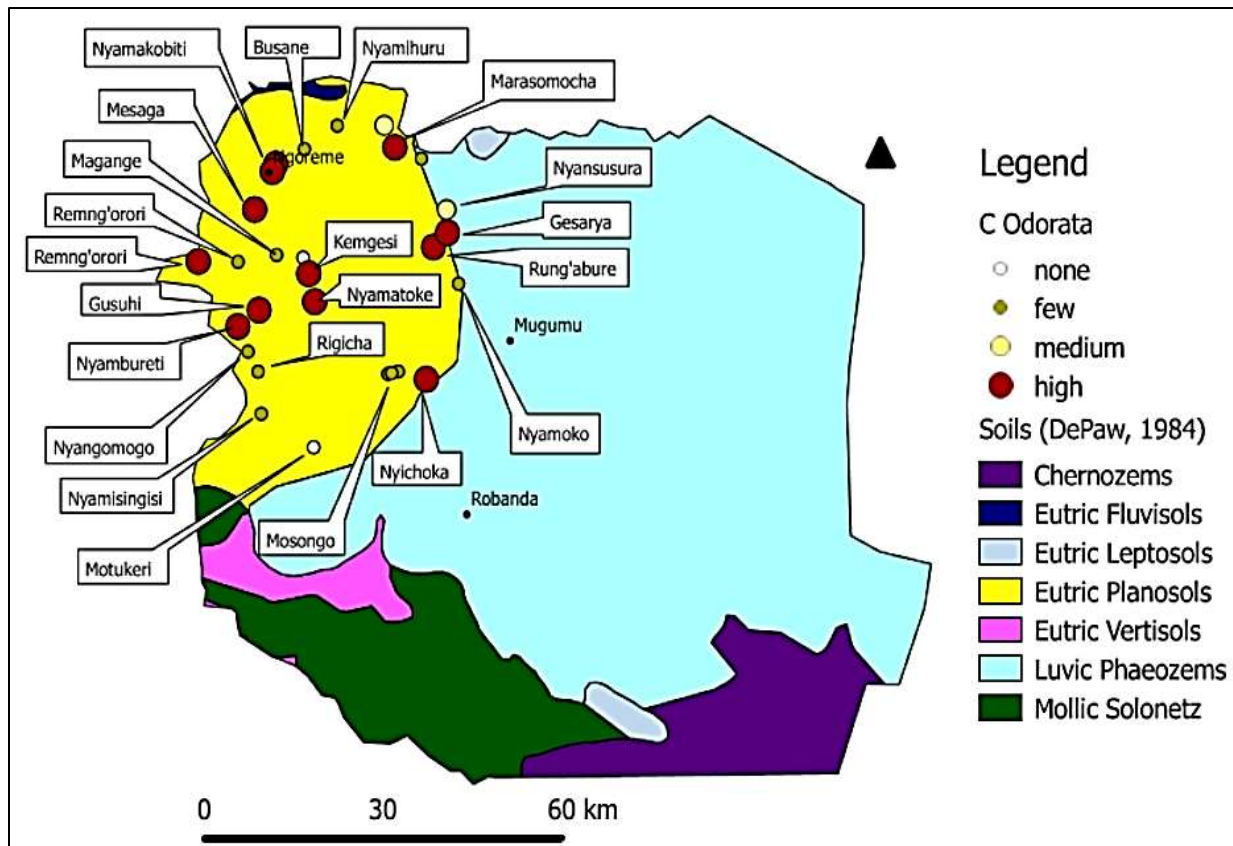


Figure 7. Relative distribution of *C. odorata* against 1:2,000,000 soil map of Serengeti district
Source: Boniface H. J. Massawe survey in May, 2016.

Conclusion

Soil seed bank and the distribution map of *C. odorata* in Serengeti district and Mara region as a whole provide insight on the aggressiveness of the weed according to its spread and infestation. In this way this Siam weed has spread large distances since initially being introduced into Serengeti district and it is now a serious weed in most parts of Mara region. The entire areas of Serengeti district and some parts of Musoma rural and Bunda districts have been colonized by *C. odorata* and that the weed is possibly to invade a wide range of areas in Tanzania. In this respect, immediate benefit of this research is to insemminate the knowledge base to ecologists and other stakeholders in order to have a common goal which will support efficient habitat ranking to restore invaded areas and protect non-invaded ecosystems. Monitoring the distribution of the weed in the country and follow up its expansion is more decisive. Finally, future research work should be carried out to study fallow age in relation to soil seed bank of *Chromolaena odorata* and physio-chemical properties of the soil regarding the distribution of the weed so as to guide stakeholder's decisions when considering control measures against the weed.

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Conflicts of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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