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Effectiveness of management (coping) strategies for *Chromolaena odorata* by smallholder farmers in Serengeti District, Tanzania

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Abstract

The study aimed to assess the performance of farmer-led production practices adopted in maize farming systems to recommend the best adoption methods for coping with *Chromolaena odorata*, one of the world's deadliest invasive alien species (IAS). The study also aims to make this adaptive strategy available so that smallholder farmers can readily use it to make better decisions on the effective use of land infested with this IAS for crop production, particularly in the Serengeti area, where communities are already experiencing a strong establishment and spread of this and other IAS.Field experiment was conducted in Serengeti District to test if the local community's management practice for managing *Chromolaena odorata* as one of the major invasive species dominated the area is cost-effectively and can be adopted for the management of this invasive. The experiment was laid out. The setting up of the *Chromolaena odorata* management (weeding) plots in the trial sites of this study were done in six different weeding categories. These categories were based on informed management practices conducted by local communities in the Serengeti District as strategies for dealing with *Chromolaena odorata* infestation in their cultivated land. Weeding levels were used to test which management practice perform well in agricultural field with *Chromolaena odorata*. One way Analysis of Variance (ANOVA) was used to assess for the significant variation between treatments. The finding indicate that In treatment where *Chromolaena odorata* was managed well there was an increase of yield compared to the treatment with less management. Such adaptation is a crucial component of securing the invaded crop areas' future food production in the face of global environmental change. These results should inform relevant sectors, and stakeholders of this important initiative and encourage collaboration for implementation in affected areas.

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Introduction

Invasive weed species pose a real challenge to farming by increasing economic costs and declining yields (Hoffmann and Broadhurst, 2016; Nghiem *et al.*, 2013; Paini *et al.*, 2016). Invasive species present significant threats to global agriculture, and species such as *Chromolaena odorata* (from here onwards referred to as *C. odorata*) exhibiting significant adverse impacts to local livelihoods induce about 40% production costs (Shackleton *et al.*, 2019). In the developing world, small farms produce a large percentage of the food; however, they are worse off than the rest of the population regarding their food security in these countries. Furthermore, although most of the world's population will live in urban areas by 2030, farming populations will not be much smaller than today. Therefore, for the foreseeable future, dealing with poverty and hunger in many parts of the world means confronting the problems that small farmers and their families face in their daily struggle for survival. (Dixon *et al.*, 2001; FAO., 2001; OECD/FAO, 2015). Likewise, the number of invasive species is expected to increase and spread with further escalation of agricultural systems' impacts. As the invasion threats are continually rising, other global changes and challenges (e.g., climate change, degraded soils, lack of arable land) exacerbate current food productions causing grave concern for future food security and the consequent effect on the local population's economy and livelihood (Lobell *et al.*, 2008; Pimentel *et al.*, 2001; Shackleton *et al.*, 2019).

Over the coming next three decades, agricultural areas are expected to experience a growing season that will likely have higher temperatures than the present condition, exacerbating the current invasions and facilitating the new ones (Pyšek *et al.*, 2020) crop production being impacted in various ways. For example, invasion threat on maize crop, which comprises the top 75% of the total value of the agricultural output for most of the countries in the world (including Tanzania), is likely to be very high in the future, given most of its areas being infested with invasive pests and pathogen. Similarly, the Sub-Saharan Africa agricultural sector is at risk of the invasive weed, resulting in lower productivity (Pimentel *et al.*, 2001; Simberloff *et al.*, 2013). However, it is unknown how much effects these invasive weed species have on smallholder farmers' social and economic. Also, the information about the better adaptive strategies by farmers residing in invaded agricultural land, particularly in the Serengeti region, Tanzania, is scanty. Nevertheless, a well-managed agricultural land has tremendous potential to promote food security. While invasive weeds and pests remain among the key factor for the decline in global agricultural production, there is an urgent need to encourage more adaptive capacities for farmers to manage this invasion to build sustainable farming systems and improve food security. Clearing more forest land for cultivation to increase food production is not an option due to adverse impacts on biodiversity and ecosystem services provision (Moss, 2008). Hence, increasing agricultural yields in a framework of sustainable intensification is, therefore, an essential solution. Sustainable production can be made by improving agricultural practices through adaptive strategies and creating more favourable policy environments, for example, to integrate locally simple, cost-effective weed management approaches in crop production practices. It is crucial to adapt crop production to the increasingly challenging areas invaded by IAS using traditional crop production approaches used by local communities.

Invasive species present significant threats to global agriculture, with the magnitude and distribution of the threats varying between countries and regions (Paini *et al.*, 2016). Invasive species have caused a severe reduction in agricultural communities' food production, leading to loss of income and increased livelihoods vulnerability (Pratt *et al.*, 2017; Shackleton *et al.*, 2019).Smallholder farmers will need the relevant, cost-effective adaptive strategies that they can use to get the optimal crop yield from their invaded land to meet future challenges. Some of these strategies can be found within the traditional and indigenous agronomic practices (TIAP) commonly used by farmers in the spectrum of different crop production approaches as implemented in the invaded agricultural land.Indigenous communities rely extensively on knowledge and networks such as TIAP, which has significantly enhanced their livelihoods and economies, thus, promoting the survival and persistence of its individuals and their resources (Cámara-Leret *et al.*, 2019). Their knowledge and practices are crucial to breeding efforts to adapt agriculture to climate change (Guarino & Lobell, 2011). Recently, platforms such as the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) have acknowledged the need to include into science assessments and policy the underexplored role that culture plays in improving the beneficial contributions of nature to people (Díaz *et al.*, 2018; Isbell *et al.*, 2017). This recognition acts as a wake-up call for understanding and tapping opportunities inherent in communities to address the problems and challenges they face in the course of engaging themselves in day-to-day livelihoods activities such as agricultural production. Adapting TIAP in crop production to control invasive species (e.g., *C. odorata*) will help secure and make available smallholder farmers the underutilized and abandoned agricultural land areas that invasive weeds have infested. This is important since the ranges of many IAS (including weeds and plant pathogens are predicted to increase in the face of global changes. Therefore, many areas of the world will experience a decline in food production and increased vulnerability to food and livelihoods security in the coming decades (Pyšek *et al.*, 2020; Shackleton *et al.*, 2019).

Material and methods

Study area description

The Serengeti district is in the eastern part of the Mara region and is located at 1°30'S 2°40'S and 34°15'E 35°30'E (Fig. 1). The district has a surface area of 10,373 km², 659 km² of which have been used only for agriculture, livestock, and residence (URT, 2016). The district divided into three agro-ecological zones: high, medium, and low lands, highlands with attitudes ranging from 1,860m to 1960 m above sea level; middle lands with attitudes ranging from 1,401m to 1,860m above sea level and low lands with attitudes ranging from 1,200m to 1,401m above sea level. The region usually experiences a double rainy season, long rains from February to May, and a short rainy season from August to December (URT, 2016).

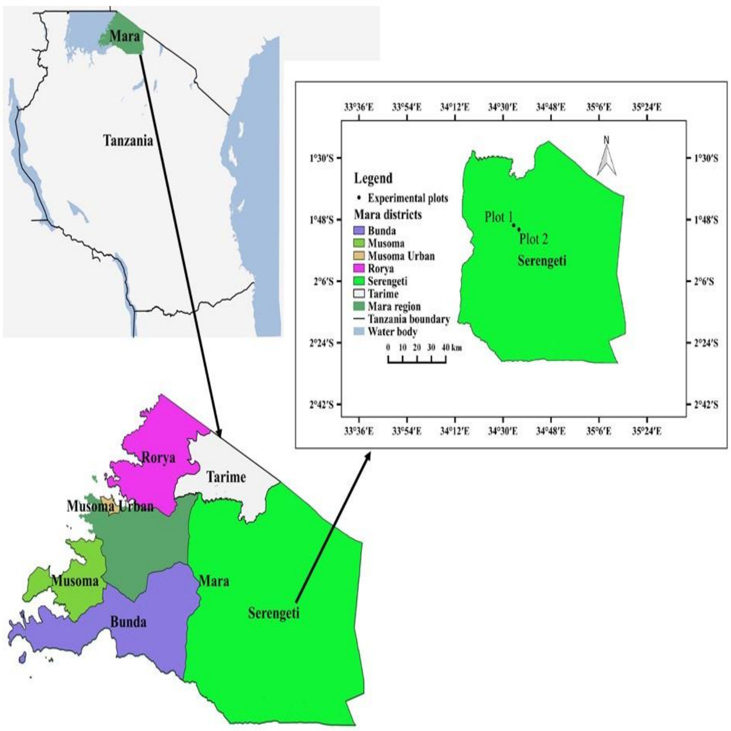

Fig. 1. A Map of Western Serengeti showing the (Serengeti District) study site.

Approaches used and major findings of this study

While attempts to use evidence-based approaches to control areas infested by invasive have to date been developed and tried in the field by the authorities responsible for invasive species management. Still, they have not led to a widely-agreed future course of action. Evidence from the field shows how different local communities in the Serengeti region have assembled knowledge and practices about different approaches to invasive weed (such as *C. odorata*) management and indicate how such information would significantly enhance local and regional effectiveness of the management actions while improving agricultural production in invaded agricultural land.

It documents what is known, unknown, and recommended to manage invasive species, *C. odorata*, synthesize and communicate the information from this so that decision-making and other stakeholders are informed. In close collaboration with the agricultural and livestock Department of Serengeti District, research, and local communities in the region, the study implemented the following objectives:

1. Identify those TIAP that are commonly and widely used by local farmers to produce maize in agricultural land invaded by *C. odorata* in the region;
2. Adopt those TIAP approaches to establish experimental sites for maize production in agricultural land invaded by *C. odorata* in the region;
3. Assess the production patterns in farmer-led practices in the farm (area) infested with *C.odorata*
4. Quantify the costs of production in different TIAP trial plots in the area invaded by *C. odorata*
5. Evaluate the yield and economic benefits of this TIAP for useful further recommendations to broader adaptation by communities in agricultural land invaded by *C. odorata* in the region and;
6. Make the evidence established from this study widely available.

Sampling design

A preliminary survey was conducted in different areas with the high infestation of *C. odorata* at which maize crops cultivated within the area of Western Serengeti. The selection of sites was chosen based on a high infestation of *C. odorata*, cultivation history of the land, and gaps in managing *C. odorata* during maize crop production. Two separate sites were selected in areas with a high infestation of *C. odorata*, cleared and ploughed, usually done in most community farms to allow experimental layout.

The experiment was laid out in a randomized complete block design with four replications. Weed infestation treatments were practised under randomized complete block design repeated four times. Naturally occurring other weed populations except *C. odorata* were carefully uprooted with hand pulling without soil disturbance.

The setting up of the *C. odorata* management in the trial sites of this study were in the following order; T1) Saw maize seed in plots with no *C.odorata* control; T2) Saw maize in plots with *C. odorata* controlled/weeded throughout the growing period; T3) Saw maize in plots with *C. odorata* controlled/ weeded once; T4) Saw maize in plots with *C. odorata* controlled/weeded twice; T5) Saw maize in plots with *C. odorata* managed three times; T6) Saw maize in plots with *C. odorata* controlled/weeded four times. These treatment categories (T1 to T6) were based on informed management practices conducted by local communities in the Serengeti District as strategies for dealing with *C. odorata* infestation in their crop production land.

Land preparation was done by ox ploughing, two seeds of DK8031 hybrid maize variety sown per hole at an intra-spacing of 30cm. A compound fertilizer of 5g per plant was used at a uniform rate of 60 Kg N/ha in a growing time.

The application of pesticide was made once after the appearance of fall armyworm. *C. odorata* control was done by a hand hoe starting at the second week after the emergence of maize plant; 3, 6, 9, and 12 according to each treatment. The farming system did as per recommendations used by smallholder farmers in Serengeti District.

Data collection

Two weeks after emergence following sowing, ten plants per sub-plot were randomly sampled and tagged. The variables collected were plant height, plant weight, number of leaves per plant, stem diameter, root height and weight, cobs weight, number of cobs per plant, and grain yield on maize per cob. The plant height was measured in centimeters (cm) using a steel tape measure. Height readings were taken every three weeks till physiological maturity was determined in Days after Sowing (DAS). The plant stem diameter was measured per treatment plot. The number of leaves per plant was recorded concurrently every three weeks after sowing, using ten randomly sampled plants and the means recorded for analysis. The plant growth parameters were then computed and presented in tabular form: root height, weight, cob weight, and grain yield measured during harvest time.

Data analysis

The maize growth parameters and yield data were entered into M.S. Excel sheets, and their descriptive summaries and graphs were computed and generated. One way Analysis of Variance (ANOVA) was used to assess for the significant variation between treatments. These computations were performed with the software program Statistica (Stat Soft Inc., Tulsa, OK, USA, 2011), and significant means were separated based on Tukey's Honest Significance Difference (HSD) Test at $p \leq 0.05$

The comparative economic benefits and losses of *C.odorata* invasion in maize fields were estimated using simple economic analyses described by (Ndakidemi *et al.*, 2006). The profit or marginal net of return (MNR) was computed for each treatment as follows.

$$MRN = Y \, x \, P - TVC$$

Where Y is the grain yield of maize in (kg/ha), P is the selling price of maize at harvest (US$/kg), and TVC is the total variable cost of inputs related to treatments (i.e., land preparation, seeds, fertilizer, management, etc. in US$/ha).

The expenses of respective inputs and labour charges incurred during this calculation included; maize seeds, fertilizer and insecticide, land preparation, planting, weeding insecticide and fertilizer application, and harvesting. The selling price of maize grain yield at harvest was put at US$0.26/kg.

The marginal rate of return (MRR) for each treatment was computed using the formula:

$$MRR = MNR/TV$$

The interest rate on money spent buying farm input was set at 5%, and the costs and labour charges were fixed during this study based on the local payment rates, while the selling price of maize grain yield at harvest was fixed at US$0.26 kg.

Results and discussion

Maize crops and their production/yield were susceptible to the invasive species *C. odorata,* and this sensitivity increased with the extent of invasion. Maize yield in the infested area was lower than weeded plots (i.e., plots with no C. odorata) throughout the experimental areas based on farm-led production practices during the study period.

We also report a strong and significant association between maize yield and farm-led weed (*C. odorata*) management practices, with maize plots of no *C. odorata* weeding having the lowest yield in all studied fields (Fig. 2 and 3). There was a significant difference in grain yield ($F_{34,5}$ p <0.001) between plots with and without *C. odorata*, respectively, where plots with *C. odorata* infestation had radically lower yield than those without invasion.

These observed maize yield reductions are due to less intense weeding practices, thus calling for farmers-led, weeding practices that are recommended to be done throughout the maize plants grown in areas infested with *C. odorata*. One (T2) of six farmers-led weeding practices showed the highest record over the entire monitoring period, recording the highest maize cob weight and maize grain yield of 2795.5 kg^{-1} and 2403 kg ha^{-1}, respectively.

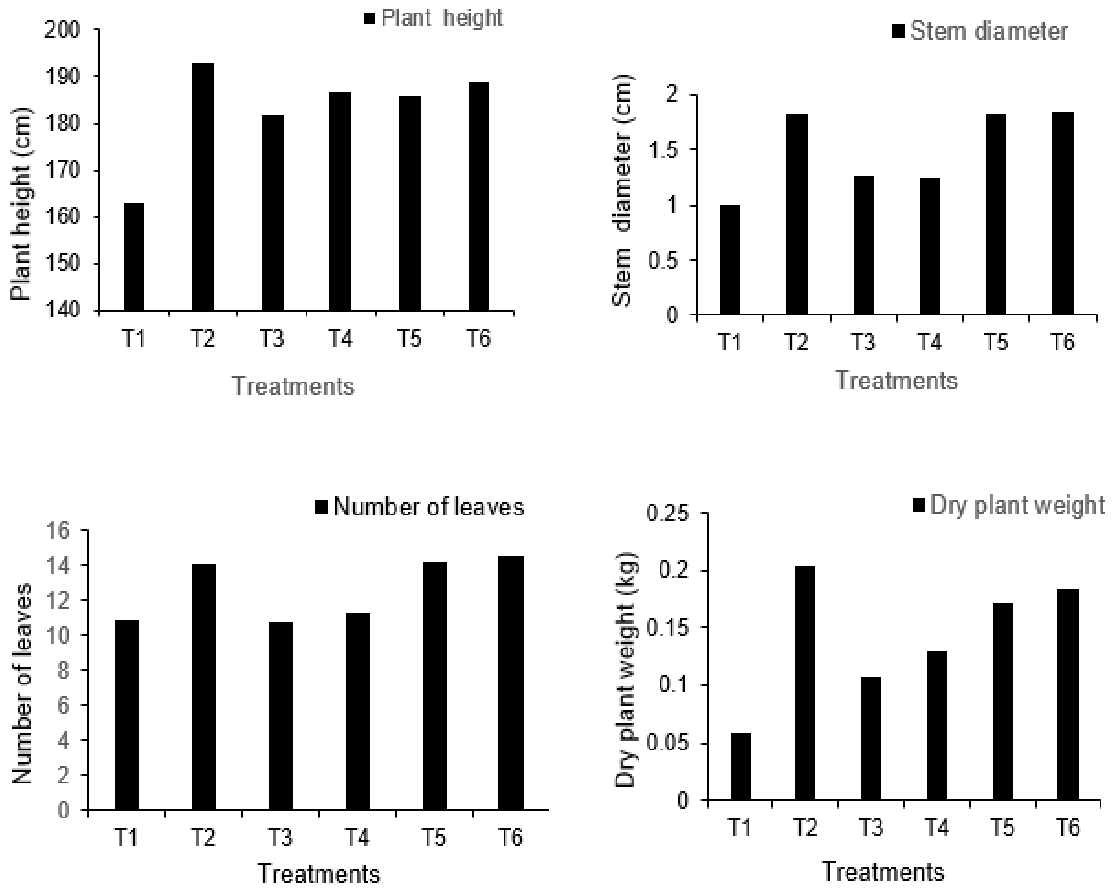

Fig. 2. Maize plant height (cm), stem diameter (cm), number of leaves, and dry plant height (kg) parameter recorded under different treatments during the field in the Serengeti region.
(Source: Own field data 202.

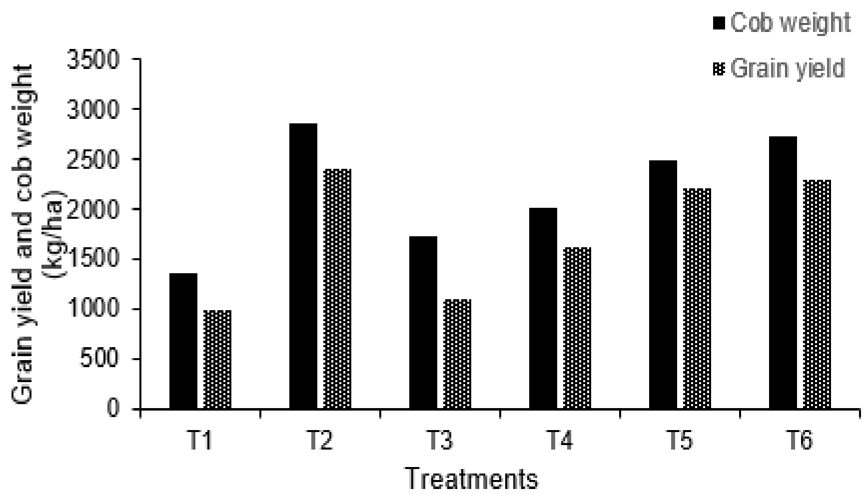

Fig. 3. Maize grain yield and cob weight (kg/ha) recorded under different treatments during the field in the Serengeti region (Source: Own field data 2020).

Significant differences (*p<0.005*) were observed in a marginal net return (MNR) and marginal rate of return (MRR) among the six different farmers-led maize production practices. The MRR was highest in maize growing without *C. odorata* throughout compared with plots that were infested with *C. odorata* at different levels. Proper timing and effective control of *C. odorata* on maize farms increased profits. The marginal rate of return was significantly greater for the treatment with appropriate and suitable management.

From the economic analysis, the increase in cob weight and yield with complete weeding of *C. odorata* translated into a significantly ($p< 0.05$) higher MRR and dollar profit for maize farmers in Serengeti region, northern Tanzania. With thorough weeding of *C. odorata*, there was an addition of 1411 $kg.ha^{-1}$ grain yield, equivalent to a 70% increase in dollar profit with the absence of invasive weeds *C. odorata* at Serengeti area. In this study, management of *C. odorata* in maize farms significantly increased maize growth performance, yields ($kg.ha^{-1}$), and cob grain yield kg relative to management times in each treatment. The effective control of *C. odorata* as observed in this study is attributed to the TIAP that were initiated by smallholder farmers in the Serengeti area as adaptation strategies to manage *C. odorata* in maize farms, and their innovation strategy seems to give better returns. At the same time, deal with this problem of invasion. The treatment where weeding of *C. odorata* was done three to four times to allow high growth of the assessed parameters and therefore increased yield ($kg.ha^{-1}$).

The decrease in the number of cobs per plant- with an increase in weed competition duration was due to competition of weeds with maize for different environmental factors for a longer time. (Nawab *et al.*, 1999) Also reported a reduction in the number of cobs per plant in a heavily weedy crop. Maximum grain weight per cob in weed-free treatments were attributed to the best utilization of available soil and climatic resources by maize plant in the absence of weeds. A reduction in grain weight per cob may be due to weed infestation. This corroborates well with the findings of researchers (Tanveer *et al.*, 2018). Reduced weeding times, in turn, results in a higher occurrence of weeds in the farm fields.

Conclusion

This is the first study that highlights how severe infestation by *C. odorata* can dramatically affect yields of annual crops in Serengeti District, contributing to other studies of IAS' impact on agriculture done elsewhere in Tanzania and the world at large. It suggests that effective farmers-led management practices of this weed are possible and might act as an effective, sustainable strategy for controlling (coping) with invasive *C. odorata* in infested areas and at the same time sustain agriculture production and food security, contributing to the realization of the Sustainable Development Goals. The study showed that the priority to help individual smallholder farmers grow maize in western Serengeti to cope with *C.odorata*, should be to utilize their local farmer-led weed management strategies currently being practiced in infested farmlands. National policies and decision-making bodies and international donors should therefore integrate locally-relevant effective, and evidence-based information into targeted investments in weed management strategies for *C.odorata,* enabling farmers to reduce infestation and improve the yield from their crops

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Declaration of interest statement

Authors declare to have no competing interests while submitting the manuscript for publication.

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