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Management strategies for the noxious invasive parthenium weed (*Parthenium hysterophorus* L.) in Uganda

Martha Ibore Natukunda[1,2*], Kevin Natukunda[1,3], Gerald Kyeyune[1], Sharon Mbabazi Tusiime[1,4], Isaac Agbemafle[5] and Jenipher Bisikwa[1]

[1]School of Agricultural Sciences, Makerere University, Kampala, Uganda.
[2]Department of Agronomy, Iowa State University, United States.
[3]Department of Genetics, Development and Cell Biology, Iowa State University, United States.
[4]Department of Horticulture, Iowa State University, United States.
[5]School of Public Health, University of Health and Allied Sciences, Ho, Ghana.

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Parthenium weed is a noxious invasive species that has negative effects on agriculture and also causes allergic reactions in humans. The goal of this study was to evaluate several management strategies for parthenium weed and assess the suitability of each control measure for farmers, and other stakeholders in Uganda. Field experiments were conducted in a completely randomized design, and the quadrat sampling method used to assess the effect of mulching, foliar application of table salt solution, hand pulling, slashing, hand hoeing, foliar herbicide application, and integrated weed management on parthenium plant populations. All tested weed management strategies except foliar herbicide application significantly ($P \leq 0.05$) reduced parthenium plant populations, with parthenium weed counts for treated plots reducing on subsequent data collection days. The experimental data showed that parthenium plant populations increased for the untreated plot overtime. The authors recommend that a combination of multiple weed control measures (integrated weed management) are utilized for effective management of parthenium weed in Uganda to reduce limitations that result when one management strategy is used singly. This study informs farmers, the general public, and researchers how to effectively control parthenium weed, contributing to reduction of the numerous negative effects of parthenium weed on human livelihoods.

Key words: Agriculture, invasive, management, noxious, parthenium weed, Uganda.

INTRODUCTION

Weeds are undesirable plants that are growing out of place (Baucom and Holt, 2009; Monaco et al., 2002). Weeds reduce crop yields by competing for nutrients, water, carbon dioxide and sunlight (Monaco et al., 2002).

*Corresponding author. Email: mibore@iastate.edu Tel: +1 515-509-9524.

Some weeds also exhibit allelopathy, a biological phenomenon in which weeds produce toxins that can influence germination, growth, survival, development, and reproduction of crops (Cheng and Cheng, 2015). In the livestock industry, weeds reduce the quality of forages, making them unpalatable or poisonous to livestock, ultimately lowering the quality of animal products (Bridges, 1994; Patel, 2011). Weeds can be alternative hosts for pathogens and insect pests of crops, aiding survival from one season to the next (Monaco et al., 2002; Onwueme and Sinha, 1991). Weeds negatively impact human health through allergies, and poisoning (Bridges, 1994). These negative attributes make weeds undesirable to humans. One of the noxious invasive weed species of public health concern in Uganda is parthenium weed (*Parthenium hysterophorus* L.), commonly known as Congress weed, or Lugono in the eastern region of Uganda. Parthenium weed originated from South America, and is one of the world's most noxious plants invading, Africa, Australia, and Asia (Joshi et al., 2016; McConnachie et al., 2011; Navie et al., 1996; Patel, 2011; Khari and Kumar, 2018). In Africa, Parthenium weed has successfully inhabited many areas in the east and southern regions (Abdulkerim-Ute and Legesse, 2016; Nigatu and Sharma, 2013; McConnachie et al., 2011; Seta et al., 2013; Wabuyele et al., 2014; Worku, 2010; Zuberi et al., 2014). A study conducted in East Africa (Uganda, Kenya and Tanzania) identified multiple locations inhabited by parthenium weed, and highlighted the need to devise control measures to prevent further spread (Wabuyele et al., 2014). Parthenium weed is well adapted to a wide range of growth conditions and soil types, is very prolific, and under favorable conditions, flowering can occur 28-42 days after seedling emergence (Chamberlain and Gittens, 2003; Abdulkerim-Ute and Legesse, 2016; Adkins and Shabbir, 2014; Navie et al., 1996). A single parthenium plant can produce more than 15,000 seeds which are spread by farm machinery, animals, pasture seed lots, stock feed, wind, and running water (Adkins et al., 2010). The observed widespread distribution of parthenium weed in various parts of Africa suggests the need for management strategies to control further spread.

Parthenium weed has negative effects on humans, both directly by impacting human health, and indirectly by affecting crop and livestock production (Adkins and Shabbir, 2014; Kaur et al., 2014). In humans, allergic reactions to parthenium weed can result in an acute form of contact dermatitis, bronchitis, asthma, and hay fever (Adkins and Shabbir, 2014; Kaur et al., 2014; Lakshmi and Srinivas, 2012; McConnachie et al., 2011). It is estimated that up to 73% of people are sensitive to parthenium weed with females being twice more sensitive than males (Khari and Kumar, 2018). In the livestock industry, parthenium weed reduces pasture carrying capacity by up to 90%, taints livestock products such as milk and meat reducing their value, and is toxic to livestock (Hundessa and Belachew, 2017). A significant amount (10-50%) of parthenium in pastures can kill cattle and buffalo (McConnachie et al., 2011; Tudor et al., 1982). In crop production, allelopathic effects of parthenium weed, mainly caused by the chemical allergen, parthenin can negatively impact agricultural crops (Belz et al., 2007; Wakjira et al., 2009). For instance, in Ethiopia, sorghum (*Sorghum bicolor*) grain yield was reduced by between 40-97% when parthenium weed was left uncontrolled throughout the season (Tamado et al., 2002).

In Uganda, parthenium weed has been reported in the central region (Kampala and Masaka districts), the eastern region (Jinja district), the western region (Mbarara and Kasese districts), and the northern region (Pader district) (Wabuyele et al., 2014). Although parthenium weed presents a major challenge to crop production, livestock rearing, and human health in Uganda, studies informing farmers, and other stakeholders (the public and researchers) on how to properly manage parthenium weed are limited. Therefore, farmers have inadequate knowledge on management strategies for this invasive weed. The goal of our study was to evaluate multiple control measures for parthenium weed and assess the suitability of each control measure for farmers in Uganda. Seven parthenium management strategies were tested including: mulching, foliar application of table salt solution, hand pulling, slashing, hand hoeing, foliar herbicide application, and integrated weed management (IWM) for their effect on parthenium weed populations in field experiments. Additionally, authors made recommendations for parthenium weed management based on their findings. The specific objective of this study was to generate knowledge on suitable measures for managing parthenium weed in Uganda for farmers, the general public, and researchers, reducing negative effects of parthenium weed on human livelihoods.

MATERIALS AND METHODS

Study area and experimental design

This study was conducted at Makerere University, Uganda (00°21'00''N 32°34'03''E) in a demarcated non-cropped site that was naturally infested with parthenium weed (approximately 80% parthenium weed) during the second rains of 2010 and first rains of 2011. A completely randomized design was utilized in this study, with seasons as replicates. To set up experiments, the demarcated area was divided into eight 3 m x 3 m (9 m^2) plots, with a spacing of 0.6 m between plots to prevent drift and inter-plot interference. At the start of the experiment, all plant species at the experimental site were recorded to determine the plants that co-existed with parthenium weed. This was followed by deep ploughing to remove all existing plants and allow different plant species to sprout on their own. Approximately three weeks later, when the parthenium weed was at the rosette growth stage (Kaur et al., 2014; Khari and Kumar, 2018) seven management practices (mulching, foliar application of table salt solution, hand pulling, slashing, hand hoeing, foliar herbicide application and IWM) were randomly assigned to individual plots while the eighth plot was left untreated throughout the experiment. Prior to application of treatments, data on parthenium weed populations was collected for each plot. Other plant species were also recorded for each plot.

Materials and equipment

Materials used for respective treatments in assigned plots were; dry hay grass, table salt, and Gramaxone. Equipment used during treatments include: a watering can, a hand-held slasher, a hand hoe, a knapsack sprayer, a measuring cylinder, and all personal protective equipment (headgear, gloves, protective suits, aprons, respirators, foot, and eyewear).

Treatments and application

In total, this study had eight treatments, an untreated or control plot and seven treated plots. The seven parthenium management strategies used for our study were reviewed by Mekonnen (2017), Khari and Kumar (2018), Kaur et al. (2014), Isaac et al. (2013) and Swanton and Weise (1991).

Control

No weed management treatment was applied to the control plot and all the naturally inhabiting plants were allowed to grow throughout the experiment.

Mulching

Mulch is a layer of material (living or nonliving) placed over the surface of the soil to suppress weeds and protect the soil from erosion. In our study, dry hay grass, a nonliving mulching material (Isaac et al., 2013) was spread on the assigned plot at a thickness of approximately 3 cm. Mulching was done twice during the experiment, first at the start of the experiment and halfway through the experiment.

Foliar application of table salt solution

A 15% table salt solution was prepared and sprayed on all plants in the assigned plot using a watering can. This treatment was done thrice at two weeks intervals during the experiment. The use of a salt solution for parthenium weed management is also described by Mekonnen (2017) and Kaur et al. (2014).

Hand pulling

All weeds, including parthenium weed on this plot were plucked by hand and discarded in a designated area for decomposition. For our study, hand pulling was done thrice on the assigned plot at two weeks intervals during the experiment. During hand pulling, gloves were worn to prevent direct skin contact and avoid allergic reactions from parthenium weed. Mekonnen (2017), Kaur et al. (2014), and Khari and Kumar (2018) described the used of handpulling or manual uprooting to control parthenium weed.

Slashing

A hand-held slashing or mowing equipment (slasher) was used to manually cut down weeds on the assigned plot. Slashing was done thrice at two weeks intervals during the experiment. Mekonnen (2017), and Onwueme and Sinha (1991) described slashing as an effective weed management strategy.

Hand hoeing

All plants on the assigned plot were dug up with a hand hoe. Hand hoeing was done thrice at two weeks intervals during the experiment. The use of hand hoeing or ploughing to control parthenium weed is reviewed by Mekonnen (2017) and Kaur et al. (2014).

Foliar herbicide application

In our study, Gramaxone was sprayed using a properly calibrated knapsack sprayer on the assigned plot at a concentration of 100 ml per 15 L of water. During herbicide application, personal protective equipment was worn. Foliar herbicide application was done thrice at two weeks intervals during the experiment. Herbicide application to control parthenium weed is reviewed by Mekonnen (2017), Kaur et al. (2014), and Khari and Kumar (2018).

Integrated weed management (IWM)

Integrated weed management is the application of numerous alternative weed control measures which include cultural, genetic, mechanical, biological, and chemical methods of weed control (Swanton and Weise 1991). In our study, multiple selected treatments, that were also tested singly, were used for the IWM plot, with each treatment being applied two weeks after the previous treatment. Hand pulling was done first followed by slashing, then hand hoeing, and then foliar application of Gramaxone as previously described. Throughout the experiment, field hygiene was ensured by carefully disposing off all weeds in a designated area for decomposition.

Data collection and sampling design

At the start of the experiment, different plant species at the experimental site were recorded to determine the plants that co-existed with parthenium weed in spite of allelopathy. Identification of weeds was done with reference to photographs from previous literature (Ivens, 1971). Parthenium weed was identified by looking at photographs of the identification kit developed by the Integrated Pest Management Laboratory-Collaborative Research Support Project (IPM-CRSP) provided by the parthenium project coordination office at Virginia State University, Virginia USA. To determine the effects of the selected management strategies on growth and development of parthenium weed, data on parthenium plant populations on respective plots was collected using the quadrat sampling method. Sampling was done by randomly throwing a 0.25 m^2 quadrat to each plot and counting parthenium plants inside the quadrat. On each day of data collection, four throws of the quadrat were done for each plot, the number of plants in each throw counted and used to estimate the parthenium plant population for each plot. To determine the parthenium plant population on each plot based on the four throws of the quadrat, the four values were summed up and multiplied by the total area of the quadrat (9 m^2). The resulting number was divided by the unit area of the quadrat (sum x 9 m^2/0.25 m^2). Data was collected two weeks after each time of treatment applications. At each time of data collection, all weed species on each plot were recorded to identify weeds that inhabited the same area as parthenium weed. Photographs of plots were also taken at the start and end of the experiment.

Data analysis

Using SAS 9.4 statistical package (SAS Institute, 2012), one-way Analysis of Variance (ANOVA) was used to determine the main effect of each weed management treatment on parthenium plant populations. The Tukey's multiple comparison test was used to determine differences among treatments.

RESULTS AND DISCUSSION

Plant species in the study area

At the start of the experiment, the experimental site was inhabited by both annual and perennial plant species including: parthenium weed at different growth stages (constituted approximately 80% of the plant population), star grass (*Cynadon dactylon*), Wandering Jew (*Commelina benghalensis*), sodom apple (*Solanum incanum*), couch grass (*Digitaria scalarum*), black-jack (*Bidens pilosa*), milk weed (*Euphorbia hirta)*, pig weed (*Amaranthus hybridus)*, goat weed (*Ageratum conyzoides*), guinea grass (*Panicum maximum*), oxalis (*Oxalis latifolia*), nutsedge (*Cyperus rotundus*), *Acacia* species and wild *Malvaceae* species. Among these, parthenium weed, sodom apple, black-jack, milk weed, pig weed, goat weed, and guinea grass are annual while the rest are perennial.

Statistical comparisons

There were significant differences ($P \leq 0.05$) in parthenium plant populations among treatments (Table 1). Parthenium plant populations were significantly fewer ($P \leq 0.05$) between the control and all treatments except herbicide (Table 2 and Figure 1). Therefore, all management strategies tested in our study with the exception of herbicide application effectively controlled parthenium weed. Mean parthenium plant populations ranged from 3762.0 to 56.2 per plot and populations were highest in the control plot, followed by the herbicide-treated, hand pulled, hand-hoed, IWM-treated, slashed, salt-treated, and mulched plots, respectively (Table 2 and Figure 1). The lowest parthenium plant populations observed for the mulched plot was not surprising because mulching smothers weeds, preventing emergence (Isaac et al., 2013). Parthenium plant populations were comparable between hand hoeing and IWM treatments, and also between slashing and salt treatments (Figure 1).

Parthenium weed management strategies

An examination of trends of parthenium plant populations for each treatment across the four data collection days showed that all the seven tested weed management measures reduced weed populations (Figure 2). With the exception of the control plot, all weed management treatments reduced parthenium plant populations over time. In the untreated control plot, parthenium plant populations increased progressively for the four data collection days as expected (Figure 2). Out of the seven weed management strategies tested in our study, two treatments (salt application and IWM) completely eliminated parthenium weed at the end of the experiments. Variation within treatments measured by the standard error of the mean (SE) was highest in the control plot indicating rapid increases in parthenium plant populations on subsequent data collection days. The SE was lowest in the mulched plot, an observation that can be explained by suppression of weed growth by the dry hay grass. Figure 3 shows sample photographs of the experimental site at the start of the experiment before deep ploughing (Figure 3A), after deep ploughing but before weed control treatments (Figure 3B), and at the start of the treatments, that is, when parthenium weed was at the rosette growth stage (Figure 3C). Respective plots at the end of the experiment are shown in Figure 3, panels D-K.

At the end of the experiment, the untreated control plot was inhabited by parthenium weed at different growth stages (rosette growth stage to mature plants) (Figure 3D). This was because mature parthenium plants produced seeds which germinated. Other weed species in the untreated plot were milk weed, pig weed, star grass, *Malvaceae* species and sweet potatoes (*Ipomea batatas*). Observations from the control plot are consistent with previous reports of the prolific and invasive nature of parthenium weed (Adkins and Shabbir, 2014; Kaur et al., 2014). Therefore, weed control measures should be applied when parthenium weed is still at the rosette stage to prevent seed production and additional colonization by new plants (Kaur et al., 2014). Mulching applied after clearing the plot effectively reduced parthenium plant populations throughout the experiment and only a few plants had emerged in areas with thinner mulch on the last sampling day (Figure 3E). Therefore, mulching is suitable for controlling parthenium weed, but more mulch should be added regularly to maintain the thickness and avoid emergence of weeds on thinner areas after decomposition. Mulching suppresses weed growth by acting as a physical barrier against weed emergence and cutting off direct sunlight (Isaac et al., 2013). Additional benefits of mulching are conservation of soil moisture, soil fertilization, protection from soil erosion, and improved soil quality (Isaac et al., 2013). Mulching with dry grass also utilizes locally available plant materials that can be readily accessed by farmers. Although our study was not conducted in a cropped area, mulching for parthenium weed management, mulching is not suitable for large-scale crop cultivation because it is laborious and time consuming. In addition to parthenium weed, milk weed was also able to grow in thinner areas

Table 1. One-way ANOVA of main effect for parthenium plant population per plot.

Treatment	Parthenium plant population per plot [z]
Parthenium weed control measures	0.0018[y]

[z] Plot sizes were 9 m^2.
[y] P-values of main effects were determined by Tukey's adjustment for multiple comparisons at P≤ 0.05.

Table 2. Mean parthenium plant population per plot, and pair-wise comparisons of each treatment to the control.

Treatment [y]	Mean parthenium plant population per plot [z]
Control	3762.0[a]
Herbicide	1467.0[ab]
Hand pulling	1008.0[b]
Hand hoeing	900.0[b]
IWM	882.0[b]
Slashing	639.0[b]
Salt	612.0[b]
Mulching	56.2[b]

[z] Plot sizes were 9 m^2.
[y] Pairwise difference between treatments were determined by Tukey's adjustment for multiple comparisons at P≤ 0.05.

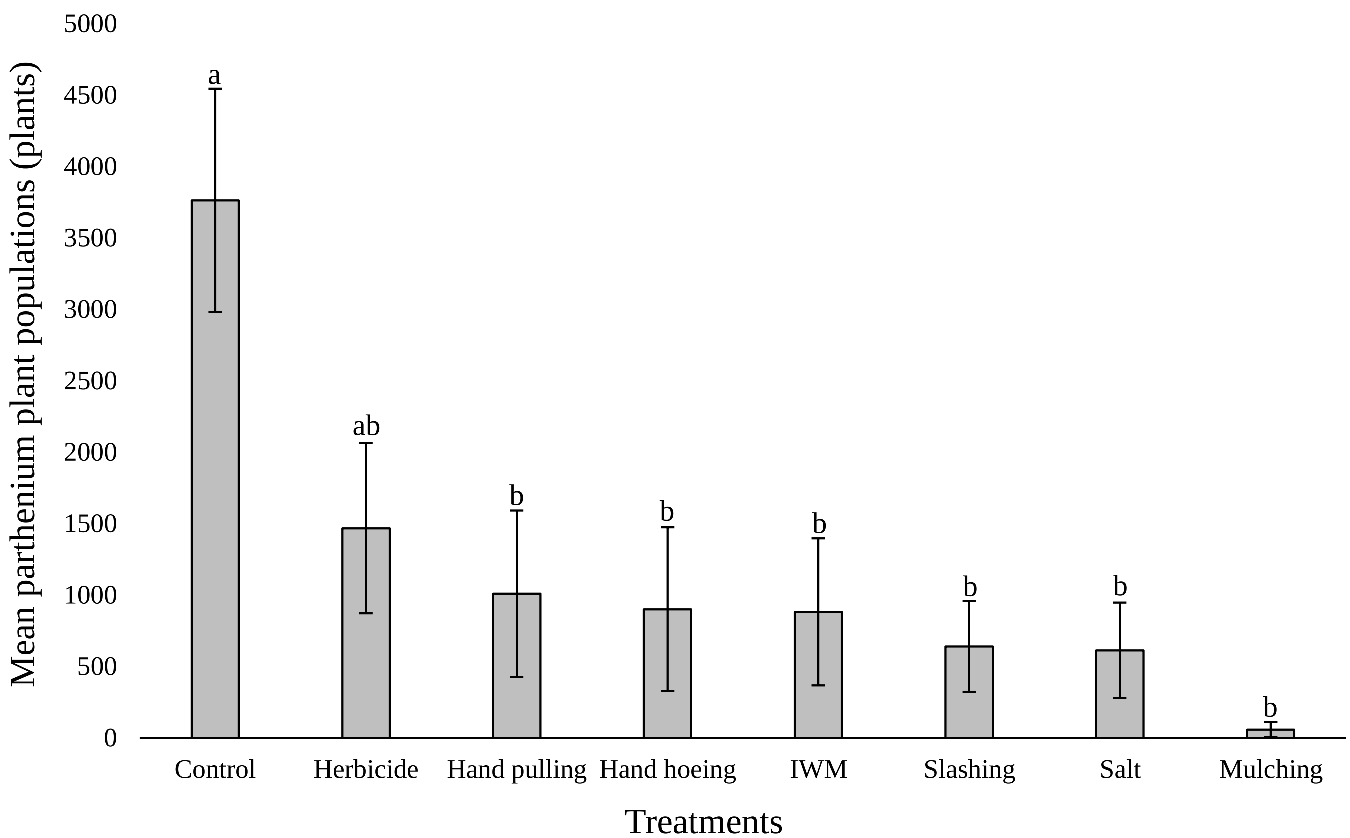

Figure 1. Mean parthenium weed populations for each treatment. Pairwise difference between treatments was determined by Tukey's adjustment for multiple comparisons at P≤ 0.05. Error bars represent the standard error of the mean.

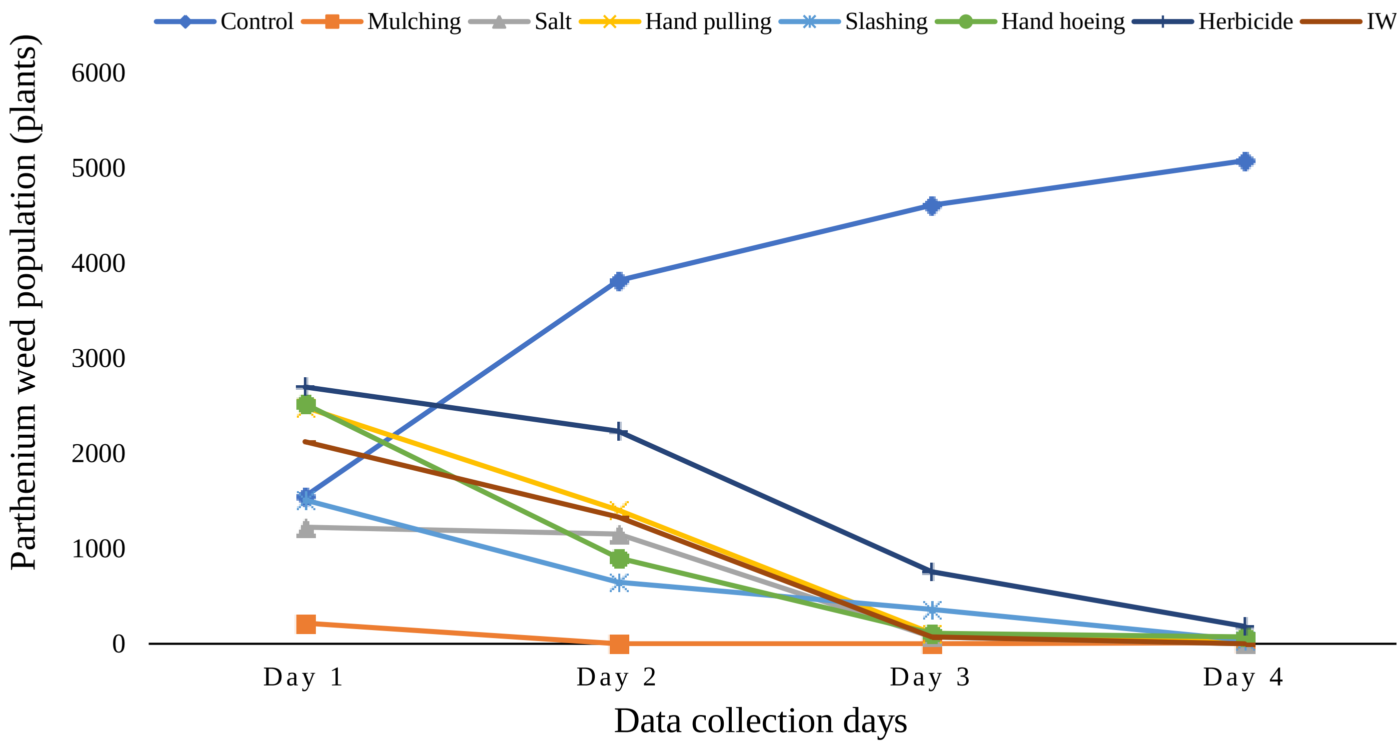

Figure 2. Trends of parthenium weed populations for each treatment on the four data collection days.

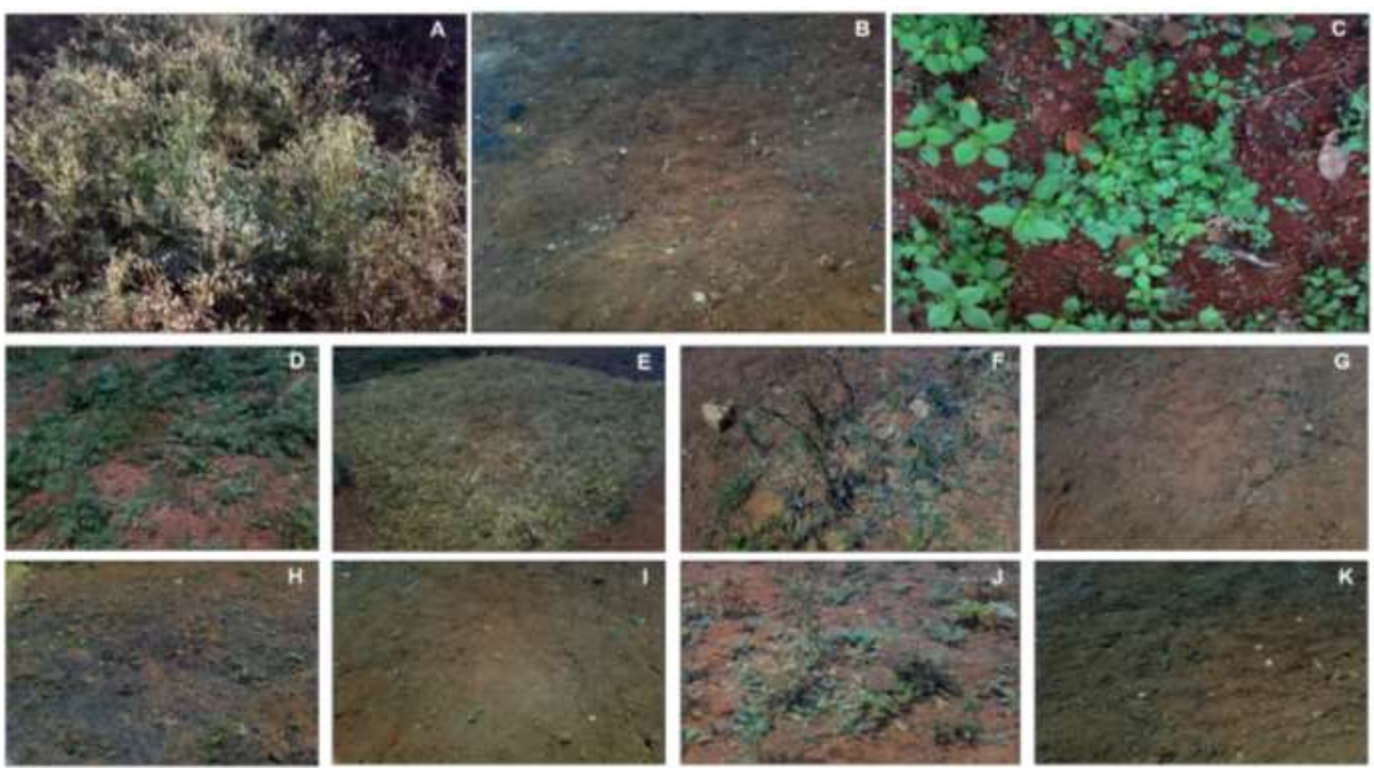

Figure 3. Photographs of the experiment. A) At the start of the experiment before deep ploughing; B) After deep ploughing but before treatments; C) Three weeks after deep ploughing (stage at which parthenium weed was at the rosette growth stage and weed control treatments were started); D-K) Plots at the end of experiment: Control (D), mulched (E), salt-treated (F), hand-pulled (G), slashed (H), hand-hoed (I), herbicide-treated (J), and (K) IWM-treated.

of the mulched plot.

Treatment of parthenium weed with a 15% table salt solution was effective and parthenium plants completely wilted and died after application of the salt solution (Figure 3F). Previous literature also reported that in non-cropped areas, open wasteland along railway tracks and roadsides, spraying of table salt solution at 15-20% concentration effectively controlled parthenium weed (Mekonnen, 2017). Application of table salt solution is suitable for controlling parthenium weed in Uganda because salt is affordable, does not pose health risks and application does not require any skill. However, other weed species such as star grass, Wandering Jew and milk weed were not killed by the salt solution which makes salt application a less suitable strategy for controlling parthenium weed in cropped areas.

In our study, hand pulling was effective for parthenium weed management (Figure 3G). Manual uprooting has been widely used for parthenium management by farmers. Hand pulling should be done before flowering and seed setting to prevent further spread. However, the downside of hand pulling is the risk of contact dermatitis (Kaur et al., 2014). Therefore, careful caution must be taken, and personal protective equipment worn when hand pulling parthenium weed to prevent allergic reactions. Additional constraints of hand pulling are its laborious nature and if the soil is dry, the entire root system may not be plucked out yet from these roots new plants can emerge. When plucking parthenium plants, all the root system should be removed to prevent re-growth (Abdulkerim-Ute and Legesse, 2016). Hand pulling is effective in areas where a minimum amount of disturbance is desired, parthenium plants are few, very close to the crop stand, or scattered to warrant use of other more costly methods (Onwueme and Sinha, 1991). Other weed species on this plot were milk weed, *Malvaceae* species and Wandering Jew.

Slashing was a suitable method for controlling parthenium weed and other weed species (Figure 3H). Our results are in agreement with Onwueme and Sinha (1991) who reported that slashing reduces growth of new plants by preventing seed production for most weeds and starving the underground parts. In our study, the roots left behind after slashing sprouted into new plants, which makes slashing not a very effective control measure if used on its own. Other weed species present in the slashed plot at the end of the experiment were oxalis, pig weed, and *Malvaceae* species.

Hand hoeing effectively controlled parthenium and other weed species (Figure 3I). Hand hoeing affects weed populations by harming weeds and also by greatly influencing the number, distribution, dormancy and viability of weed species (Ross and Lembi, 1985). For Ugandan farmers, hand hoeing is suitable for parthenium management because hoes are affordable, readily accessible and no skill is needed to use hoes. Similarly, Tamado and Milberg (2004), reported that hand hoeing was effective for controlling parthenium weed in smallholder farming systems in Eastern Ethiopia. Other weed species that co-existed with parthenium weed in the hand-hoed plot were black-jack, milk weed, sodom apple, Wandering Jew, star grass, oxalis, and *Malvaceae* species.

In our study, herbicide application did not significantly ($P>0.05$) control parthenium weed compared to the other management strategies but the trends showed reduction in parthenium plant populations (Table 2, Figures 2 and 3J). Our results suggest that parthenium weed could have some level of resistance to Gramaxone. Similar studies have also reported ineffectiveness of certain herbicides for parthenium control. For instance, Odero (2012) reported that parthenium weed was resistant to glyphosate. However, in contrast with these findings, herbicides such as Saflufenacil and Primextra gold effectively controlled parthenium weed (Khan et al., 2014; Odero, 2012). Therefore, when selecting herbicides for application, herbicides that are known to control parthenium weed should be used. Herbicide application is not very suitable for farmers in Uganda because herbicides are expensive, require skill for successful use, and can harm humans if not used as per manufacturer’s recommendations (Aktar et al., 2009). For instance, glyphosate has been reported to be carcinogenic in humans and other organisms (Van Bruggen et al., 2018). Other weeds on the herbicide-treated plot were oxalis, milk weed, star grass, sodom apple, Wandering Jew, and sweet potatoes.

Integrated weed management was effective in controlling parthenium weed (Figure 3K). Combining multiple weed control measures overcomes limitations of other methods when used singly. For instance, roots left behind after hand pulling and slashing can be removed by hand hoeing. Mechanical methods of parthenium weed management can be utilized first and chemical control among the last options. In IWM, one should consider all available control measures, that is, cultural, mechanical, biocontrol, chemical, promoting competition from native plants, grazing, fire, and solarization (Adkins and Shabbir, 2014; Adkins et al., 2010; Tu et al., 2001). Together with parthenium weed, oxalis, black-jack, milk weed, nutsedge, and pig weed were present in the IWM-treated plot.

CONCLUSIONS AND RECOMMENDATIONS

This study highlights weed management strategies that can be included in farmer education programs to control parthenium weed, while avoiding the negative effects of parthenium on humans and livestock. Therefore, extensionists in Uganda should train farmers and other stakeholders on specific management practices for parthenium weed and other noxious invasive weed species. Based on the findings of this study, the authors recommend that a combination of multiple weed control measures should be utilized for effective management of parthenium weed in Uganda to reduce the limitations of specific methods when used singly. Control measures for parthenium weed should also be applied in before seed set to avoid further spread. In order to prevent harmful effects of parthenium weed on human health, personal protective equipment should be utilized when applying control measures.

Strengths and future perspectives

Our study tested multiple control measures for parthenium weed, informing farmers, the general public, and researchers on ways to effectively manage this noxious weed, reducing its devastating effects on human health, and agriculture. Since our study was conducted on a non-cropped site, future studies should test effective strategies in cropped sites and pastures to determine location-specific control measures. Experimental studies should be done to examine mechanisms by which other weed species that co-existed parthenium weed reported in this study survived allelopathy. Additional experiments should also be conducted to examine allelopathic effects of parthenium weed on crop traits of economic importance such as plant growth rate and yield.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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