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Research article

Distribution, characterization and chemical management of noxious shrub weed (*Dichapetalum stuhlmannii* Engl) in cashew in southeastern Tanzania

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A R T I C L E I N F O

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A B S T R A C T

Weeds are among the limiting factors that influence low production of economically important crops including cashew (*Anacardium occidental* L.). Shrub weeds attribute to inter-competition for resources, hinder harvesting and ultimately reduce cashew yields in Tanzania. The current study determined the distribution, characteristics and chemical control option of *Dichapetalum* Engl in Lindi and Mtwara regions, Southeastern Tanzania. The distribution study involved a survey for weed presence along the areas of Lindi and Mtwara regions. The characterization included distilling, and assessing the growth and development properties of shrub weed. Chemical herbicides; glyphosate 480g. ai/l, 2, 4 D - Dichlorirophenoxyacetic 720g. ai/l, triclopyr 160g a.i./l and 1:1 mixture of glyphosate 480g a.i./l plus triclopyr 160g a.i./L at 15, 20 and 25 mls of formulated product/L of water per 4 m^2 were tested on tender, mature and blooming growth stages of *D. Stuhlmannii* and three spraying frequencies. Findings revealed that the *D.stuhlmannii*, is a widely distributed shrub weed in Lindi and Mtwara regions. The weed was characterized with three main growth stages of seedling, mature and blooming with a long tap root and evergreen throughout the wet and dry seasons. The tested herbicides revealed the potential suppression of *D. Stuhlmannii* growth. Glyphosate and a mixture of glyphosate + triclopyr at 15 ml/L outperformed triclopyr and 2, 4 D across all the growth stages. Double spraying of glyphosate and its mixture bettered frequencies of triclopyr and 2, 4 D. The delayed regrowth of suppressed shrub weed took 90–120 days after application of herbicides. The current study recommends for single or double applications of glyphosate herbicides at 15 ml/L or 10,700 ml/ha on tender or mature *D. Stuhlmannii* in cashew farms. Further studies on the economic feasibility and effect on the microbiota of applied fungicides are required.

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1. Introduction

Weed is a plant that is competitive, persistent and pernicious, which interferes negatively with human activities [1–3]. Weeds are signing causative agent of yield reduction and an increased production cost if not properly managed [4–6]. For instance, in rice production, weeds are estimanaated to account for 9 to 32 percent of yield losses [6]. Worldwide, in citrus production, weeds account for 73 and 75 percent of the reduction of fruit yields and numbers respectively, and the potential total production cost of up to 20–25 percent with 150 million dollars in revenue losses [7,8]. Cashew (*Anacardium occidental* L.) Production in India succumbed to different annual and perennial weeds which cause yield reduction of as high as 60–70% per year [1,9].

In Tanzania, cashew is the economically important crop contributes to the income of the nation and more than 500,000 smallholder farmers [10,11]. Southeastern zone which includes Mtwara and Lindi regions is the mainly production zone with more than 70 percent of all cashew nut production, but with high infestation of the noxious shrub weed namely *Dichapetalum stuhlmannii* Engl [5,12]. Preliminary field observations by the Tanzania Agricultural Research Institute (TARI) Naliendele scientists indicated that noxious weed, inter-compete with cashew for soil nutrients, water and light, and ultimately reducing cashew crop yields [13]. The shrub weeds serve as a host of crop diseases, a shelter for insect pest and reducing the efficiency of mechanical harvesting because cashew is harvested after dropping to the ground [13–15]. The weed has been preliminary characterized with a tap root growing of more than 2 m length with many lateral roots (NARI, 2014 Unpublished report). The roots are prominent in the soil and act as a reproductive part of the weed [16,17]. Due to this, their effect becomes more severe in young cashew trees (<10 years), where the roots of the weeds and the cashew are in the same soil layer (NARI, 2014 Unpublished report). The shrub weed reproduces by seed and/or rhizomes (roots, which store carbohydrate reserves), thence grow throughout the year. Despite this, there is limited information on the distribution and botanical characterization of *Dichapetalum* sp that attack cashew crop in Tanzania. Hence triggered, the current study to characterize the distribution and botanical nature of the noxious shrub weed to contribute in the development of appropriate management techniques.

Different management practices of noxious shrub weeds have been established in different crops worldwide [7,9]. These include the use of cultural practices such as intercropping and mulching [9,18] and mechanical methods such as hand weeding or tractor ploughing [13,19]. In cashew cultivation, a majority of cashew farmers in the southern parts of Tanzania are widely using hand weeding in the management of weeds including noxious shrub weeds [14,15]. However, hand weeding method has been ineffective particularly for the management of *D. Stuhlmannii* weed. The ineffectiveness has been contributed of deep rooting exceeding the depth of hand hoe and vegetative re-growth nature of the weed [16,20; NARI, 2014]. Furthermore, hand weeding is limited by labour competition among different household activities. In this regard, farmers fail to timely weed cashew orchards, hence subjecting the crop to weed competitions [11,13]. Similarly, hand weeding triggers early shrub resprouting and domination in cashew orchards (NARI, 2014 Unpublished report).

Chemical (herbicides) method has been commonly used and considered as an effective in the management of annual and perennial weeds from different farming systems. For instance, Gover et al. [20], reported that a combination of glyphosate plus triclopyr managed both grass and shrub weeds in the state parks of Pennsylvania. During and Indaziflam are effective in the management of annual and perennial weeds in the Stone fruit tree crops [21]. Herbicides control annual and perennial weeds in forest trees [18]. Glyphosate and Paraquat are also effective in the management of weeds in the cashew cropping system in India [1,22]. In Tanzania, Glyphosate, a non-selective, post emergence herbicide at the rate of 10 mls per litre of water was found effective for controlling annual weeds in cashew orchards (NARI, 2015 Unpublished report). However, there is limited information on the appropriate chemical management practices of controlling the noxious shrub weeds. Therefore, this article presents the distribution. Botanical characterization and efficacy of herbicides on shrub weed in cashew orchards in Tanzania.

2. Materials and methods

2.1. Study area

We conducted this study in Mtwara and Lindi regions encompassing landscape of Makonde plateau and Coastal areas of Tanzania from 2016 to 2018 consecutively. The sites have dominant perennial shrub weeds; and according to Tenga et al. [23], they have deep sandy-loam and sandy clay soils. The area has a unimodal rainfall type, which starts from November/December to April/May. The mean annual rainfall ranges from 820 to 1200 mm [23]. The minimum and maximum mean air temperatures are 24.0 °C and 28.0 °C respectively, with relative humidity of 70 percent [24,25].

2.2. Distribution and botanical description of shrub weeds

The field surveys were conducted during the rainy (January to April) and off rainy (June to August) seasons of 2016 along the villages of Makonde Plateau and Coastal area. We conducted observations on cashew farms selected from the four cardinal directions of north, south, east and west of surveyed villages. The modified list quadrat method of Maszura et al. [26], was used and when targeted shrub weeds were observed at a density of at least one plant per 9 m^2 area, it was considered as the presence of the weed. The density was selected considering the nature of weed of growing scatted in some area and traceability for the weed occurrence as used by Cooksey and Sheley, [27]. Thereafter, the distribution of targeted shrub weed was counted on basis of weed presence per quadrat. The coordinate geometries of the covered area with targeted shrub weeds were recorded. Distribution information was transferred into a digital map using Geographic Information System (GIS) software, ArcGIS [27].

The botanical characterization study was conducted at TARI-Naliendele site (Makonde Plateau) in four different cashew orchards and repeated in both wet and dry season. The cashew orchards were cleared, burnt and ploughed. The shrubs sprouting were monitored and recorded, thereafter, six shrub stools were selected per field, and then tagged for botanical data collection. Shrub height, canopy cover, the number of stools per shrub, shrub stems, leaves, flowers and seed characteristics were measured and recorded. Then the collected botanical descriptions were compared with Breteler [28–32] for identification and classification of the weed.

2.3. Efficacy of herbicides and application rates at three growth stages

The efficacy study was conducted on-station at TARI-Naliendele, Mtwara region in two different cashew fields, during rainy seasons in January to June of 2016 and repeated in rainy season of 2017. The fields were cleared, burnt and then ploughed. Experiment area of 72 m by 24 m was measured and demarcated using ranging pegs. A split plot design was used with a main factor of three weed growth stages with plot size of 24 m by 24 m and sub-factor of factorial of chemical fungicide and application rates with plot size of 2 m by 2 m were. Three weed growth stages were tender, mature and blooming, whereby the first growth stage was imposed after 21 days of sprouting, then after 42 and 63 days, the second and third growth stages were respectively superimposed. Four herbicides; Glyphosate 480g a.i./l, 2, 4 D – Dichlorirophenoxyacetic 720g a.i./l, Triclopyr 160g a.i./l and 1:1 mixture of Glyphosate 480g a.i./L plus Triclopyr 160g a.i/l at three application rates was used after construction using a 4 × 3 factorial as in Table 1. A herbicide diluent mixture of I litre was sprayed once on the foliar of the shrubs per plot. Motorized blower powered at 5HP and 3 level valve opening with oblique down mist nozzle (for dense penetration) was used for spraying calibration volume of 10 L/ha. A split plot in a randomized complete block design with three replications was used per experiment field and repetition. Weed damage data were collected by scoring on six selected shrub stools (densely canopy) per plot at an interval of 7 days for five score rounds using a modified scale of Patton et al. [33], as shown in Table 2. Then, the weed damage scores were subjected to equation (1) below;

$$\text{Weed damage } (\%) = \frac{\sum (\text{No. of damage score x Mid percentage})}{\sum (\text{Total number of shrubs per plot})} \times 100 \tag{1}$$

Weed density was collected by counting the number of total alive weeds after herbicides application per unit plot according to Maszura et al., [26]. Dead root length data were collected after 42 days of herbicide application, whereby shrubs were uprooted, then the length of the dead root measured using 5 m tape measure. Weed resprouting ability was recorded by visual observation of post weed damages data collection.

2.4. Effect of frequency of herbicides application

The frequency of herbicide application was conducted from April to September of 2017 and repeated in 2018 at TARI-Naliendele, Mtwara. A promising chemical herbicides including Glyphosate 480g a.i./l, 2, 4 D – Dichlorirophenoxyacetic 720g a.i./l and Triclopyr 160g a.i./L, application rate of 15 ml/L per 4 m^2 and mature growth stage of *D stuhlmannii* from the study of 2016–2017 were selected and subjected to the study of frequency of application. Cashew fields dominated with shrub weed were cleared and ploughed. A split plot in a randomized complete block design with three replications and plot size of 6 m × 6 m for main-factor and 2 m × 2 m for sub-factor were used. Three frequencies of herbicide applied namely, single (Spraying one round), double (Spraying two rounds of the 14 days interval) and triple (spraying three rounds of the 14 days interval) spraying were used as a main factor. Three chemical herbicides of Glyphosate 480g a.i./l, 2, 4 D – Dichlorirophenoxyacetic 720g a.i./l, Triclopyr 160g a.i./L at a concentration of 15 ml/L per 4 m^2 were assigned as a sub-factor. After 42 days of shrubs sprouting, treatments were applied on the foliar of weed using a backpack motorized sprayer with obliquely down mist nozzle in an interval of 14 days for more than one spraying frequencies. Prior to spraying, six shrubs per plot were tagged with loop labels for the net area for data collection. Weed damage data were collected by scoring the selected shrub stools at an interval of 7 days using score scale in Table 2. The scores were then subjected to equation (1). Weed density data were collected by counting the number of shrub stools available during pre- and post-herbicide application following a method

Table 1
List of herbicides and their concentration.

Herbicides	Application rate (mls of formulated product/L per 4 m^2)	Application rate mls of formulated product/ha	Treats codes
2,4- Dichlorirophenoxyacetic 720g a.i/l (2, 4D)	15 (Low)	10,700	T1
	20 (Medium)	14,300	T2
	25 (High)	17,850	T3
Triclopyr 160g a.i./L	15 (Low)	10,700	T4
	20 (Medium)	14,300	T5
	25 (High)	17,850	T6
Glyphosate 480g a.i./L	15 (Low)	10,700	T7
	20 (Medium)	14,300	T8
	25 (High)	17,850	T9
Glyphosate + Triclopyr (G + T)	15 (Low)	10,700	T10
	20 (Medium)	14,300	T11
	25 (High)	17,850	T12

Table 2
Weed damage scale for herbicides efficacy on shrubs.

Damage level	Mid Percentage	Damage status	Characteristic
0	0	No weed control	Weeds not damaged
1	25	Poor weed control	Green and yellow leaves on shrub
2	50	Moderate weed control	Yellow leaves on shrub
3	75	Good weed control	Leaves and stems killed
4	100	Excellent weed control	Stems and roots completely killed

developed by Maszura et al., [26]. Performance on root was collected by uprooting the shrubs and measuring the length of a dead portion of a root after eight weeks (56 days) per spraying frequency.

2.5. Statistical analysis

The data from experimental repetitions per year were homogeneous tested by Bartlett's test [34,35]. A parametric analysis of variance at 95 percent confidence level was performed on mean data on weed damage, weed density and dead root length. Thereafter, Turkey test was performed for mean separation and presented graphically. All the analyses were performed using the Origin Pro V19b statistical software.

3. Results

3.1. Distribution and botanical characterization of shrub weeds

Distribution of shrubs weeds was recorded from different surveyed areas in Makonde Plateau and Coast areas as shown in Fig. 1. The shrubs were widely observed from different cashew fields in Naliendele, momma, Mailikumi, Mbawala, Nanguruwe, Mdui, Mkunwa and Mtopwa villages on Makonde plateau. The distribution was further observed from Dihimba, Msijute, Hingawali, Mnolela,

Fig. 1. Distribution of *D. Stuhlmannii* in Makonde Plateau and Coast areas of Tanzania.

Simana and Mpapura villages in the Coastal areas. The growth of shrub weed was observed during both wet and dry seasons. The shrubs were evergreen in all seasons during the survey.

Botanical characteristics of shrub weeds were potentially recorded from Naliendele in Makonde Plateau as presented in Fig. 2 and Table 3. The growth of shrub weeds was recorded during both wet and dry seasons for cashew. The sprouting growth of noxious weed was recorded after 20–21 days of post slashing and burning in different fields. The shrubs were observed with three growth stages, namely, seedling, maturing and blooming stages. Seedling stage comprised the average of seven to ten early photosynthetic active leaves, which were coloured pale greenish (Fig. 2A). The seedlings were characterized with hairy, herbaceous and pale brownish colourized stem. The mature growth stage was characterized by greenish leaves, hairy, herbaceous and brownish stem (Fig. 2B). The

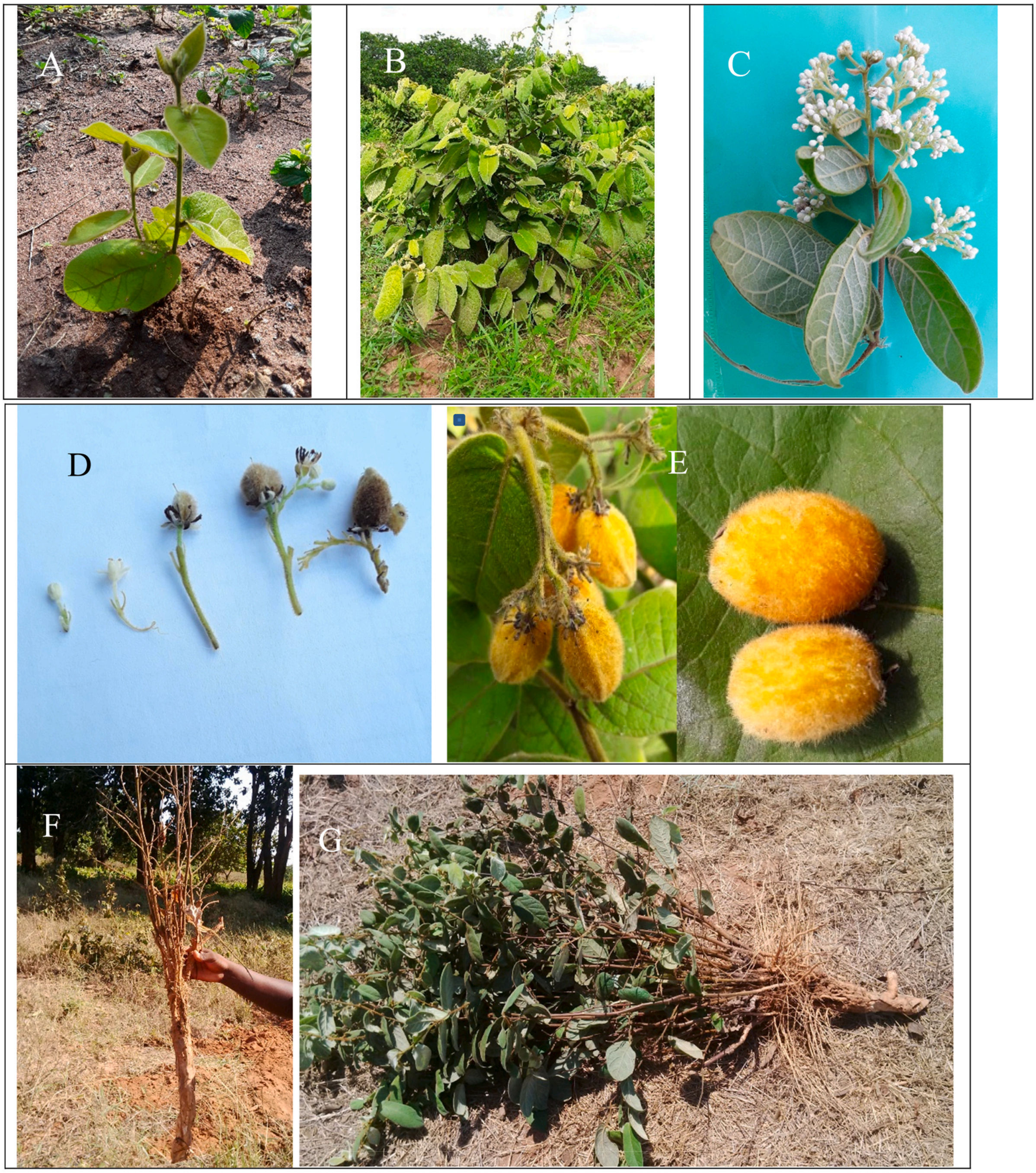

Fig. 2. Botanical characteristics of *Dichapetalum stuhlmannii:* A). Young sprouted seedling B). Mature plant C). Blooming of a plant D). Seed development stages, E). Mature and Ripen fruit F). Taproot and G). Lateral roots attached on tap root.

Table 3
Botanical Description of *Dichapetalum stuhlmannii* in cashew orchards at TARI-Naliendele.

Field	Sprouting Time (Days)	Weeds height (cm)	Canopy cover (cm)	No. Of early active lives	No. Of stools/ Shrub	Total shrubs/plot	Shrubs trunk status		Shrubs leaves status
							Young	Old	
Field 1	21	100.0	44.6	7.7	6.6	8.0	Pale Brown	Brown	Green
Field 2	21	110.1	47.0	9.9	4.9	6.0	Pale Brown	Brown	Green
Field 3	18	97.5	61.3	9.9	13.90	8.0	Pale Brown	Brown	Green
Field 4	20	106.8	59.4	10.9	10.8	7.0	Pale Brown	Brown	Green
Mean	**20.0**	**103.6**	**53.1**	**10**	**9**	**7.0**	**Brownish**		**Green**

matured shrub had an average height of 0.9–1.1 m, canopy cover of 0.4–0.6 m and the number of stools of 6–13 per shrub. The shrub was characterized with broad leaves with a network veined on both abaxial and adaxial blades. The leaves were hairy and arranged in an alternate mode on the stem of the shrub stool. The blooming stage was observed after 63 days from sprouting, comprising whitish to mix flowers (Fig. 2C). The flowers were in patch pattern containing about 20–25 flowerets. The development of a shrub fruit took three to four weeks from flowerets fertilization to seed maturation (Fig. 2D). The fruits were characterized with oval shaped fruits, coloured pale brownish during the immature stage (Fig. 2D) to deep yellow when ripen/matured (Fig. 2E). The fruits were unseeded after development. The root pattern of the shrub had a long tap root (Fig. 2F) averaged 1.5–2.0 m length with many fibrous roots (Fig. 2G). The roots were acting as rhizome for food storage and vegetative reproduction of the shrub. The roots stayed active at post ploughing on both wet and dry seasons, then sprouted for new shrub growth.

3.2. *Efficacy of herbicides and application rate at different growth stages*

Efficacy of chemical herbicides from experimental runs, revealed potential suppression of the *D. Stuhlmannii* growth as presented in Table 4. Glyphosate herbicides and the mixture of glyphosate + triclopyr had significant suppression effects of 100 and 97.2 percent respectively, followed by 2, 4 D (61.1 %) and Triclopyr (55.6%), herbicides ($P \leq 0.001$, CV%: 24.5) across three growth stages. However, variation in efficacy of chemical herbicides was noted when subjected to different rates across growth stages after 28 days of application.

Efficacy of application rates of chemical fungicides on three growth stages is presented in Figs. 3–5. High, medium and low application rates of glyphosate and the mixture of glyphosate + triclopyr outperformed that of 2, 4 D and triclopyr on weed suppression (Fig. 6A–C) during tender growth stage (Fig. 3, $P \leq 0.001$, CV%: 16.6, LSD: 10.237). On mature growth stage (Fig. 4), significant suppression of weed was recorded from low (91.7, 100%), medium (100%) and high (100%) of glyphosate and the mixture of glyphosate + triclopyr (Fig. 6D–F, $P > 0.05$), nexted by high and medium application rates of 2, 4 D and triclopyr. On blooming growth stage presented in Fig. 5, significant suppression of weed was noted from high (25 ml/L), medium (20 ml/L) and low (15 ml/L) application rates of glyphosate and the mixture of glyphosate + triclopyr (Fig. 6G–H) followed with high, medium and low application rates of triclopyr and 2, 4 D ($P \leq 0.001$, CV%: 13.5, LSD: 12.494). The efficacy of herbicides and application rates across three growth stages increased with increasing time from day zero to 28 days of herbicide application. Low herbicide efficacy was noted after 7 days of application and high efficacy of herbicides was noted after 28 days of herbicide application.

The potential root damage was exhibited by chemical herbicides as presented in Table 5 ($P \leq 0.001$, CV%: 29.3, LSD: 3.29). Glyphosate and the mixture of glyphosate + triclopyr herbicides had a high length of damaged root of 19.2 and 26.8 cm compared with 0 cm of both 2, 4 D and triclopyr. Low, medium and high application rates of glyphosate and the mixture of glyphosate + triclopyr had significant high length of damaged shrub roots compared to that of triclopyr and 2, 4 D. Moreover, the potential damage of shrub root was increased with an increase of time from 28 to 42 days after herbicide application.

Table 4
Efficacy of herbicides on *D. Stuhlmannii* in cashew orchards.

Herbicides	Weed damage (%)			
	7DAA	14DAA	21DAA	28DAA
2,4, D	41.67b	47.2b	50b	61.1a
Glyphosate + Triclopyr	50b	69.4c	75c	97.2b
Glyphosate	25a	47.2b	72.2c	100b
Triclopyr	27.78a	27.8a	33.3a	55.6a
LSD	4.073	9.27	9.43	6.95
CV%	11.5	19.8	16.7	9.1

Similar letter across the column shows no significant difference ($P > 0.05$): DAA-Days After Application.

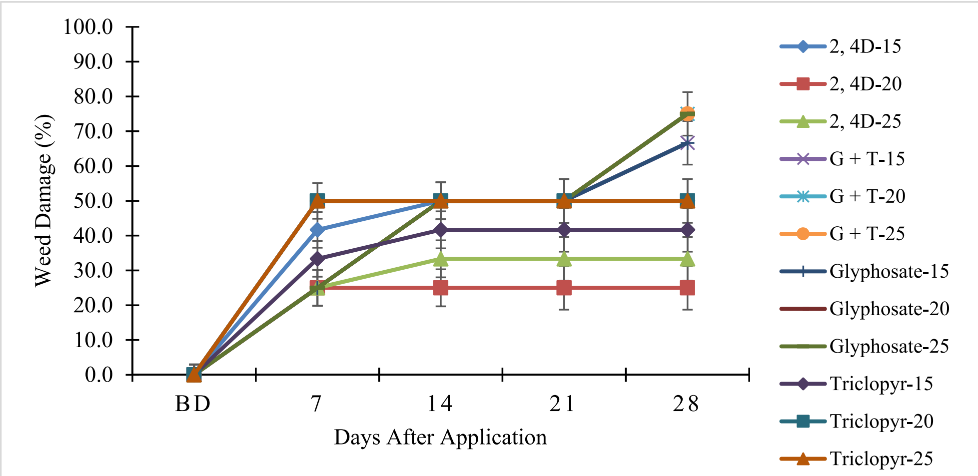

Fig. 3. Efficacy of application rates of herbicides on tender growth stage of *Dichapetalum stuhlmannii* in cashew orchards. BD: Baseline data (Day 0), Bars: Standard error of differences of means (SED).

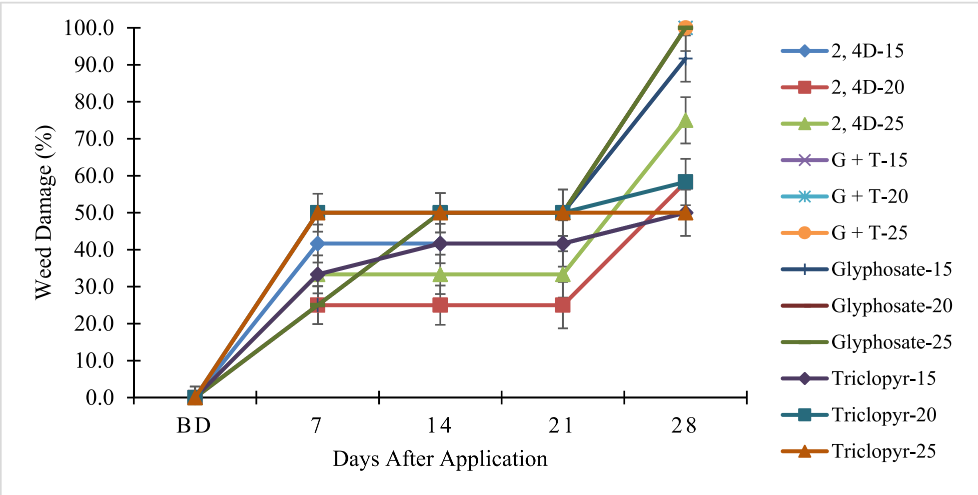

Fig. 4. Efficacy of application rates of herbicides on mature growth stage of *D. Stuhlmannii* in cashew orchards. BD: Baseline data (Day 0), Bars: Standard error of differences of means (SED).

3.3. *Efficacy of herbicides at different spraying frequency*

Potential weed damages by chemical herbicide at different spraying frequencies were noted from pooled experimental runs as presented in Fig. 7. The spraying frequencies of herbicides had a significant variation ($P \leq 0.001$, CV%: 18.9, LSD: 6.52) on weed damages. Triple and double spraying had high weed damages of 61.6 and 56.2 percent compared to a single spraying frequency (35.9%). Glyphosate herbicides out performed 2, 4D and Triclopyr on weed damages across single, double and triple spraying with 68.8, 75 and 75 percent respectively. The efficacy of herbicide and different spraying frequencies increased with an increase of time from zero to 28 days of application.

The significant weed density reduction was exhibited from chemical herbicides at different spraying frequencies ($P<0.05$, CV%: 74, LSD: 2.28) after 28 days of application as shown in Fig. 8. All chemical herbicides at different spraying frequencies had a low weed density (0–1 shrubs/plot) compared to control (8 shrub/plot) after 28 days of application.

3.4. *Post-effects of herbicides application*

After the application of chemical herbicides on all two experiments (herbicides and application rate at three growth stages and frequency of spraying), different post-effects were macroscopically observed and recorded as shown in Fig. 9. After 63 days of application, wilted shrub stems were decomposed with macro-organisms such as termites (Fig. 9A). The decomposition of shrubs was

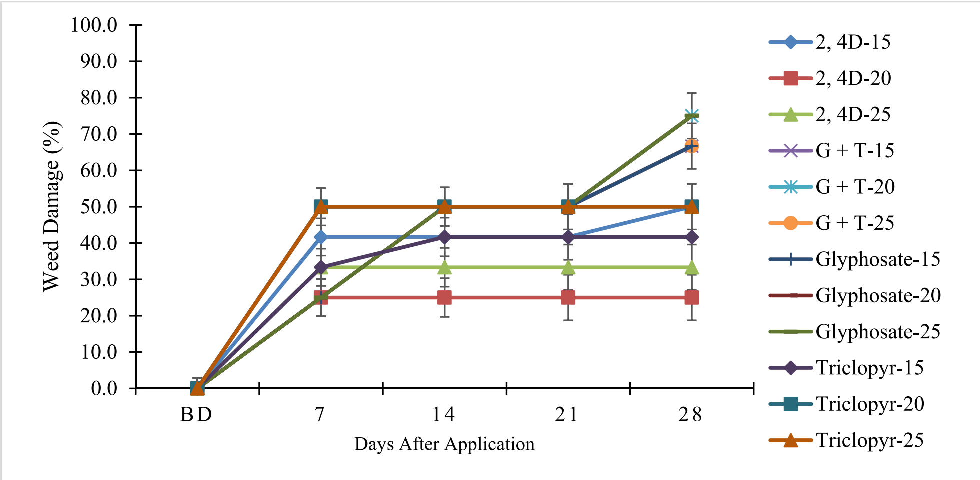

Fig. 5. Efficacy of application rates of herbicides on blooming growth stage of *D. Stuhlmannii* in cashew orchards. BD: Baseline data (Day 0), Bars: Standard error of differences of means (SED).

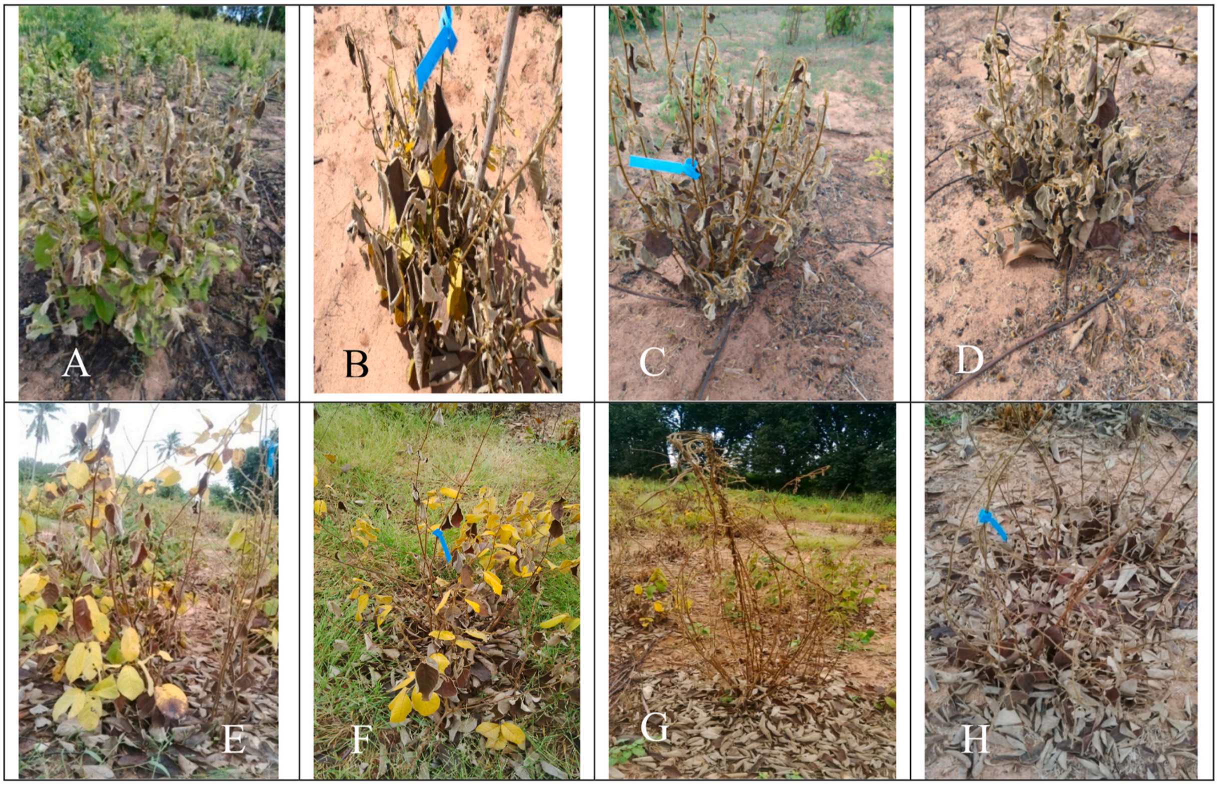

Fig. 6. Damages on *Dichapetalum* sp. After the application of different herbicides for tender (A: 2, 4D, B: Triclopyr C: Glyphosate, D: glyphosate + triclopyr) and Mature (E: 2, 4D, F: Triclopyr. G: Glyphosate, H: glyphosate + triclopyr) growth stages.

observed from glyphosate and the mixture of glyphosate and triclopyr sprayed areas. Post 90 days of single and 120 days of double and triple herbicide applications, regrowth of shrubs was observed (Fig. 9B). The re-grown shoots had weak and unhealthy stems accompanied with shrined leaves. The delayed re-growth of shrub was mostly observed from glyphosate and the mixture of glyphosate + triclopyr at all application rates, 2, 4 D and triclopyr at 25 ml/L. On 15 and 20 ml/L of 2, 4 D and Triclopyr, shrub yellowing was observed after 90 days of application. The growth of other weeds such as leguminous weeds (Mucuna) was noted after 90 days of herbicide application (Fig. 9C). The growth of Mucuna covered the wilted shoots of *Dichapetalum* sp. Shrubs, with time the shrubs, also completely decomposed.

Table 5
Efficacy of herbicides on root of *Dichapetalum stuhlmannii* in cashew orchards.

Herbicides	Length of Dead Root	
	28 days	42 days
2,4, D	0a	0a
Triclopyr	0a	0a
Glyphosate	18.5b	19.2b
Glyphosate + Triclopyr	5.9b	26.8c
LSD	14.1	10.4
CV%	8.3	29.3

Similar letter across the column shows no significant difference ($P > 0.05$): DAA-Days After Application.

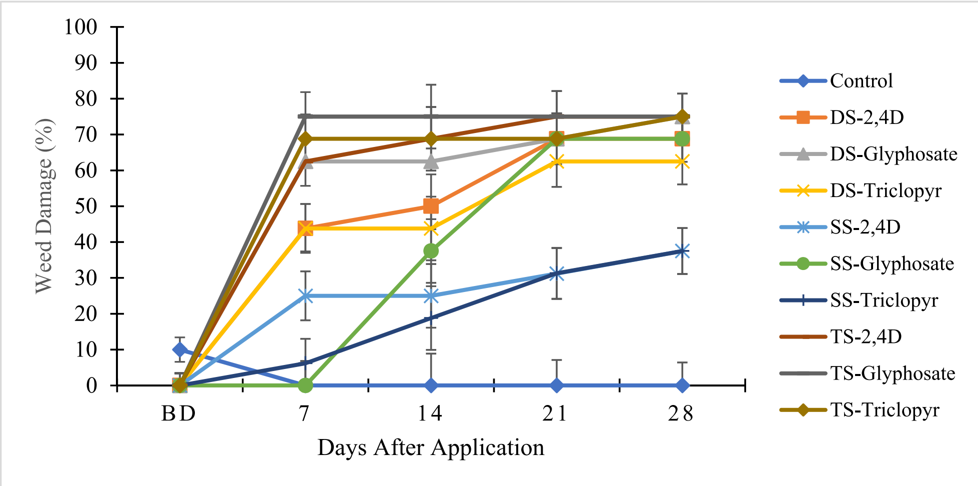

Fig. 7. Potential efficacy of herbicides at different spraying frequency on *Dichapetalum stuhlmannii* in cashew orchards. DS: Double spray, SS: Single spray, TS: Triple spray, BD: Baseline data (Day 0), Bars: Standard error of differences of means (SED).

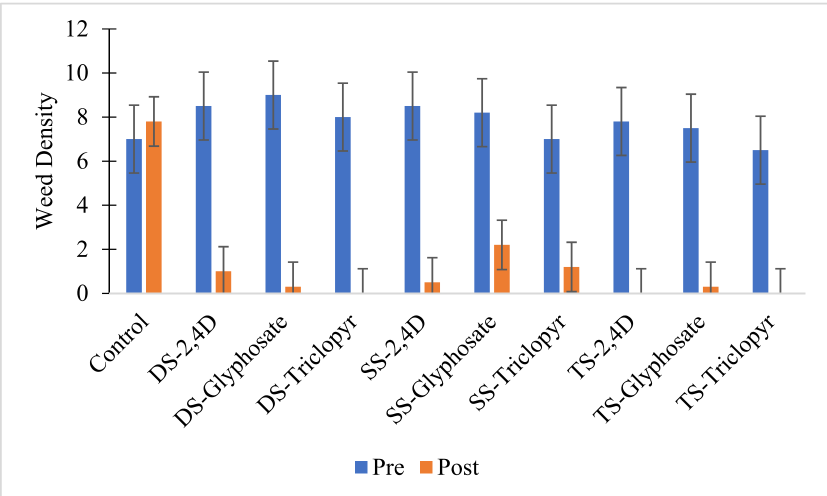

Fig. 8. Weed density reduction of herbicides at different spraying frequencies in cashew orchards. DS: Double spray, SS: Single spray, TS: Triple spray, Bars: Standard error of differences of means (SED).

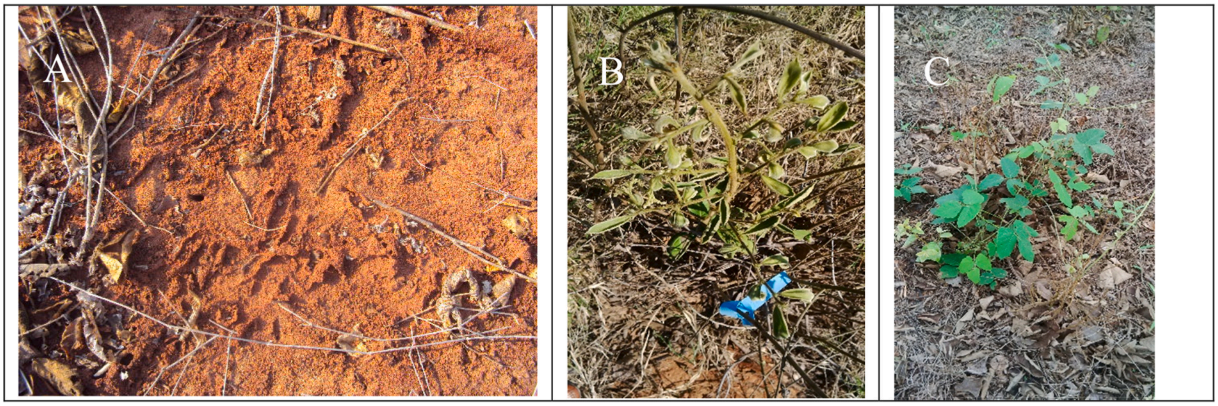

Fig. 9. Post-herbicide application effects on *Dichapetalum ship* after 120 days. A). Decomposition of wilted stem by termites B). Re-growth of weed plant C). Growth of leguminous plant (Mucuna).

4. Discussion

4.1. Distribution and botanical characterization of shrub weeds

Distribution of D. Stuhlmannii was studied in Makonde Plateau and Coast zones of Lindi and Mtwara regions. Shrub weed was dominantly found in different villages across Makonde Plateau and Coast zones. The occurrence and wide distribution of D. stuhlmannii in the Makonde plateau were also reported by Dondeyne [36], and Howell et al. [16], implying that, the Makonde plateau and Coast zone are an evergreen landscape and vegetatively characterized with potential tree cropping. In fact, the shrub is dominant not only in the southeastern flora of Tanzania, but also in Mozambique and Zambian flora [37–39]. The shrub domination in cashew cultivated fields hinders other agronomic practices including nut harvesting.

During wet and dry seasons, three botanical growth stages ′of D. Stuhlmannii in the study area were observed. These were seedling, mature and blooming. The observations of three growth stages complied with Breteler [31,32], who described the botany of the African Dichapetalacea family. The occurrence during both wet and dry seasons, indicates that, the growth of shrub weed adapts to different weather conditions [17]. The growth of first stage took 21 days of sprouting at post slashing and the fire burning. Fire burning of Dichapetalum species and other weeds influences the early and fast sprouting in different topographical or weather conditions [17,40]. The seedling growth stage comprised seven to ten early photosynthetic active leaves coloured with pale greenish and hairy, herbaceous and pale brownish colourized stem. The presence of these features implies that the shrub manufactures its own food at an early stage, thence attributes of fast growth [17,31]. Mature growth stage comprised broad, network veins and hairy leaves with deep green colonization. The blooming stage possessed mix to whitish flowers with 20–25 flowerets. The botanical nature of D. Stuhlmannii contributes to its occurrence and wide distribution in the southeastern Tanzania [36,28,29]. The root pattern of the shrubs exhibited a long tap root with a few lateral roots. The roots are the primary source of food reserve and vegetative reproduction of the shrub. Due to high root length, the shrub grows vigorous, withstanding environmental stresses, intensive cultivation and remaining evergreen throughout wet and dry seasons [16,17,36,41]. The characteristics of D. Stuhlmannii of the southeastern Tanzania are in accordance with Dichapetalacea family found in Mozambique, Zimbabwe and Uganda flora [37–39]. Moreover, D.stuhlmannii has been named in different vernacular names including "Chikwaya" by Makonde Indigenous people [36].

4.2. Efficacy of chemical herbicides on D. Stuhlmannii

This study evaluated the potential efficacy of chemical herbicides in the management of noxious shrub weed in cashew orchards. The evaluated herbicides included 2, 4 D, glyphosate, triclopyr and 1:1 mixture of glyphosate + triclopyr. Herbicides exhibited potential control of D. Stuhlmannii Engl in cashew orchards congruently with several studies in different crops [1,19,42]. The suppression of D. Stuhlmannii helps in the reduction of weed-plant inter-competition of resources, easing nut harvesting and ultimately increasing the production and productivity of cashew. However, the weed management varied among the evaluated chemical herbicides at different application rates, growth stages and frequencies of application. On weed damage, glyphosate and the mixture of glyphosate + triclopyr exhibited the potential control of D. Stuhlmannii since it performed better at low application rate of 15 ml/L and single spraying across all the growth stages followed by triclopyr and 2, 4 D at high application rate. On root system, glyphosate at 20 and 25 ml/L of water, outperformed the mixture of glyphosate + triclopyr, 2, 4 D and triclopyr in all rates on root damaging. The root damaging is the important aspect in D. Stuhlmannii management since they are a source of food and vegetative reproduction [2,17]. The efficacy variation of the applied chemical herbicides on shrub weed could be attributed by the growth stages, frequency of spraying and inherent nature of herbicides.

The performance of chemical herbicides varied across weed growth stages. The first (tender photosynthetic active leaves) and second (matured photosynthetic active leaves) stages influenced the potential efficacy of chemical herbicides compared to the third (blooming) growth stage. The first growth stage comprised tender leaves, leaves which burn easily, hence even contact herbicides including 2, 4 D managed the weed [2,3,20,43]. However, low root suppression of herbicides on tender leaves was recorded, implying lack of downward translocation within tender or young shrub seedlings. Mature photosynthetic active leaf stage influences the downward movement of the weed sap through which herbicide translocation to the other parts became possible, congruenting with the findings of Lingenfelter and Hartwig, [2]. The blooming stage comprised mature, lignified leaves and dense canopy. The features attribute to low efficacy of herbicides in comparison to tender and mature growth stages. During blooming, herbicide absorption and canopy penetration became cumbersome regardless of whether it involved systemic or contact herbicides [2,41].

Several studies [44–46] indicate the influence of application frequency on herbicide efficacy in different crops. Double and triple spraying frequencies influenced high weed damages across herbicides compared to single spraying. According to Scholars, the management of shrub or noxious weeds require "two or more" herbicide application frequencies [1,8]. The performance of triple and double spraying attributed by increasing herbicide concentration within the plant tissue [8,47]. However, glyphosate herbicide congruently controlled the shrub weed across single, double and triple spraying frequencies with 68.8, 75 and 75 percent respectively. Glyphosate performance is influenced by its non-selectivity and systemic mode of action, implying that the influence of spraying frequency depends on the type and inherent nature of herbicides [46,48].

The inherent nature of chemical herbicides influences the efficacy variation on weed man.gement in different cropping systems. Glyphosate herbicide possesses amino acid biosynthesis inhibitor, systemic and non-selective mode of action [49–51]. In this respect, glyphosate was reported to control different noxious weeds including Cyperus rotundus and Pennisetum polystachyon in cashew [1, 52], Cyperus esculentus in citrus [44,48] and Ligustrum sinense in reserved forest [47]. The glyphosate herbicides damaged the root of the shrub regardless of the concentration. This suggests that, the translocation of amino acid biosynthesis inhibitor herbicides does not depend on the concentration rather than on the inherent chemical nature [50,53].

The efficacy of 2, 4-D herbicides has been reported in different weeds such as Cyperus iria in rice [54], Senna obtusifolia in soybean [55] and Striga species in maize [56]. In cashew orchards, 2, 4 D herbicides managed tender D. Stuhlmannii. The herbicides inhibit the plant growth through Auxin mimic, contact and broad leaf selectivity mode of action [50,51,57]. The activities of Auxin mimic (Indole-3- Acetic Acid) and leaf epicuticular penetrant are effective during pre and early mature leaves, due to the presence of high IAA and less thick cuticle with varying the chemical composition of leaf [58–60]. However, it is less effective on weed leaves and roots during both matured and blooming growth stages, which is attributed by low activity of IAA and thick epicuticle wax [53,59,61].

The potential efficacy of triclopyr on D. Stuhlmannii was exhibited at a tender growth stage and at a double and triple spraying frequency. The efficacy was increasing with an increase of the application rate and frequency, complying with the results of other studies [33,62,63]. Efficacy of triclopyr on shrub weed was congruent with the efficacy on Cyperus sp. In Rice [6,63], Viola sororia Wilding Lawns [33] and Cynodondactylon on Turf [64]. Triclopyr work through selectivity of woody and herbaceous broadleaf plants, systemic movement and Auxin mimicking [53,65]. High accumulation and activity of Auxin (IAA) during the tender growth stage influences the potential efficacy of triclopyr through mimicking auxin hormone [63,66,67]. Nevertheless, less accumulation and activity of IAA during mature and blooming stages, reduces efficient performance of triclopyr [47,68]. In addition, the noted low performance on root damage of triclopyr was probably attributed to poor translocation during all the growth stages. As observed by Gorrell et al. [69], and Street et al. [63], the translocation and efficacy of triclopyr are species and growth stages dependent.

Tank-mixture of glyphosate and triclopyr provided good efficacy on weed damage and root killing across all growth stages. Gover et al. [20], and Wehtje et al. [70], reported the efficacy of a mixture of glyphosate plus triclopyr on Euonymusalata and Toxicodendron radican respectively. The tank mixture surpassed the efficacy of single triclopyr herbicide, which indicate the possible synergistic effect of glyphosate plus triclopyr. The synergism of glyphosate and triclopyr have been observed on different weed species [20,33,70]. In addition, the synergism of glyphosate and other auxin mimic/synthetic auxin have been reported in various weeds management practices [55,71–73]. On the other hand, the efficacy of the mixture of glyphosate plus triclopyr was found to be at par with the efficacy of a single glyphosate. The similarity of the efficacy of the mixture and a single glyphosate might have been attributed to the mixture ratio of 1:1, since Wehtje et al. [70], obtained high performance of the herbicide mixture at 9:1 ratio.

4.3. Post-effects of herbicides application

Microscopically, studies on post effect of herbicide application revealed decomposition of shrubs shoots and regrowth after 90 days of a single, and 120 days of double and triple applications. This implies that, the cashew fields could be free from shrub weed infestation for three to four months, allowing low inter competition of resources including nutrients [74]. Opoku-ameyaw et al. [52], reported the regrowth of weeds after three to four months of double herbicide application. Bauer et al. [71], described a single application of herbicides as influencing early regrowth of certain weeds including Digitaria insularis. Growing of leguminous plants such as Mucuna shows low residual effect of herbicides and soil fertility due to low intra-weed competition [75,76]. Of the tested herbicides, glyphosate has 47 day half-life period in the soil, triclopyr has 30 days and 2, 4 D has 30 days [53]. Moreover, the observed activities of macro-organism such as termites after the application of herbicides, shows low toxicity nature of the applied herbicides; the results are in line with findings of a study by Maji et al., [76]. Macro and micro-organisms have the ability of degrading herbicides and utilizing them as a source of biogenic elements for their own physiological processes [53,74,76].

5. Conclusion and recommendation

Botanical characterization studies revealed that a wide distributed and dominant weed in Makonde plateau and the coastal areas is the noxious shrub weed called D.stuhlmannii Engl "Chikwaya." The weed characterized by broad hairy and network venated leaves with green colonization, flowers with 20–25 flowered and tap root of about 2 m long. These characteristics help in the selection of the management practices of the shrub weed in cashew orchards. Chemical control method revealed a significant effect on the control and delaying regrowth of the shrub. Glyphosate at 15 mls/L and the mixture of glyphosate + triclopyr at 15 ml/L were potential in controlling the growth of D. Stuhlmannii on seedling and mature growth stages. Moreover, double application methods potentially influenced good efficacy of chemical fungicides and delayed regrowth of shrub weed. Therefore, this study suggests for the use of glyphosate at 15 ml/L (10700 mls of formulated product/ha) on the tender and mature photosynthetic active leaves growth stages with double application frequencies. Moreover, studies should be done to establish the effect of the applied herbicide on microbiota and economic feasibility of its application for the betterment and continued control of D. Stuhlmannii in cashew production.

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Disclosure statement

The authors declare no conflicts of interest or personal relationships that could have influenced the work reported in this paper.

Data availability

No data was used for the research described in the article, however all data generated or analysed during this study are included as electronic materials and will be available in https://figshare.com.

CRediT authorship contribution statement

William V. Mbasa: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Fortunus A. Kapinga:** Funding acquisition. **Wilson A. Nene:** Supervision, Formal analysis, Data curation. **Andrew K. Kabanza:** Writing – review & editing, Supervision, Project administration. **Abdallah R. Makale:** Writing – review & editing, Investigation. **Kasiga N. Ngiha:** Writing – review & editing, Investigation. **Ramadhani A. Bashiru:** Writing – review & editing, Investigation, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix ASupplementary data

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