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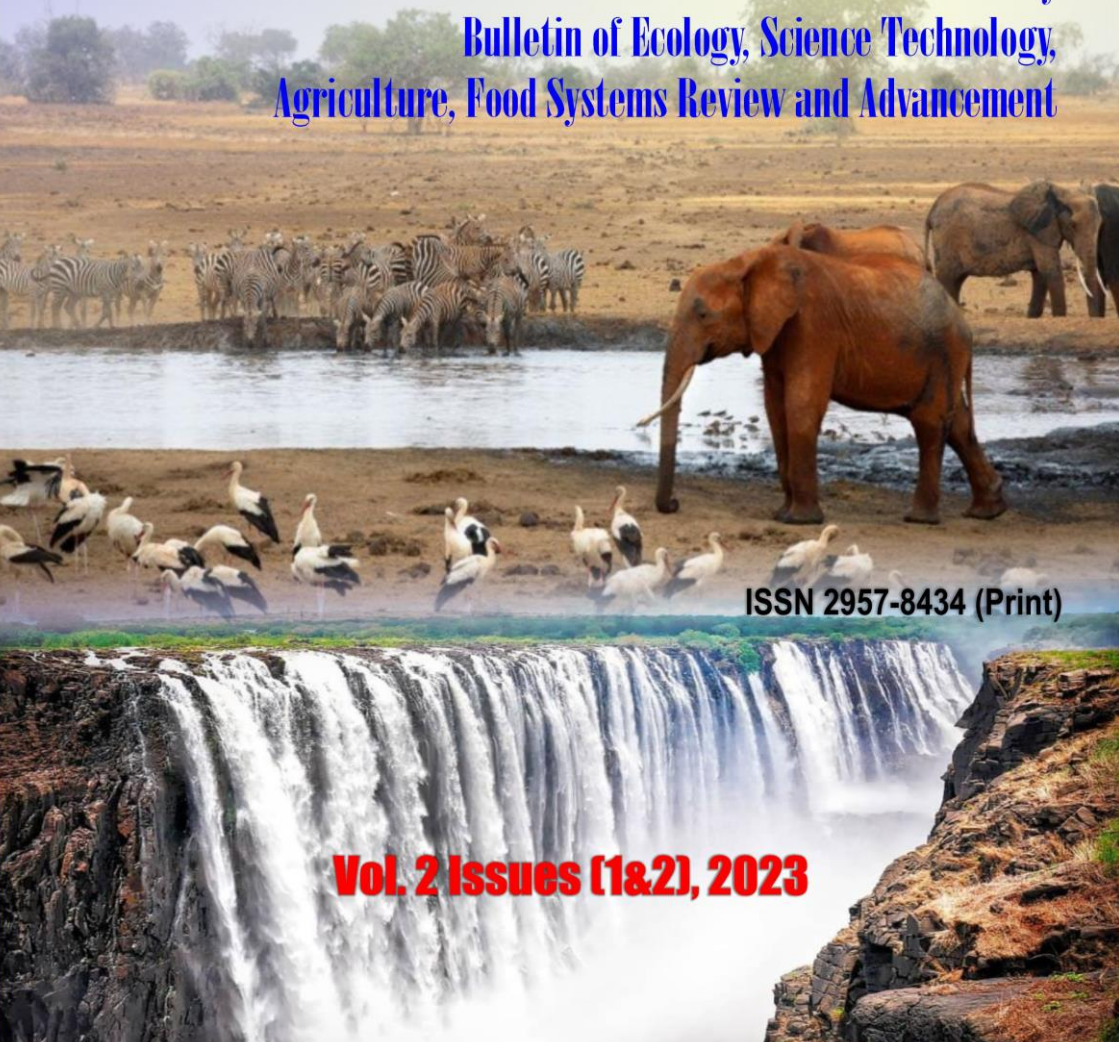

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The Herbicidal Activity of Spider Plant, *Cleome Gynandra* L., Plant Tissue on Weeds in Sweet *Pepper (Capsicum Annuum)* and Tomato *(Solanum Lycopersicum)*

FARAI SHELTON CHIHOBVU[1], ELIZABETH NGADZE[2], STANFORD MABASA[3], MAXWELL HANDISENI[4] AND INNOCENT CHIRISA[5]

Abstract

The indiscriminate use of synthetic fumigants is hazardous to farmers, consumers and the environment at large. This provided an interest in, and research on, biofumigation using different spider plant, *Cleome gynandra,* plant tissue on weeds in the laboratory and field trials. Two different biofumigant crops (green and purple spider plant) and four weed species (*Rottetboelia cocchinensis, Setaria verticillata, Amaranthus hybridus* and *Bidens pilosa*) were studied as model organisms in the laboratory. The other set of experiments was done in the field and inoculated with various weed species. In the laboratory study, the herbicidal activity of *C. gynandra* plant tissue was studied using three different levels on weight to volume basis, using a completely randomised design. The results showed that *Setaria verticillata, Amaranthus hybridus* and *Bidens pilosa* were significantly reduced in their early growth and biomass by the different *C. gynandra* plant tissues. In the field, the use of *C. gynandra* plant tissue as treatment increased field yields of the crop plants infected with different weed species. The weed species in the field were significantly reduced on the weed evenness on plots which had *C. gynandra* plant tissue as

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compared to the untreated controls. This study provides important information for choosing a green manure crop with the purpose of managing weeds.

Key words: bio fumigation, methy isothicyanate, crops

1.0 INTRODUCTION

Weed management remains one of the major constraints in crop production. Plant diseases, insects and weeds decrease the production of all the crops produced worldwide by 36% (Yuliar, 2014; Saquee *et al*., 2023). Generally, weeds are severe and often a limiting factor in conventional production systems (Prasad *et al.,* 2015), but are even worse in sustainable agriculture systems in which the use of chemical herbicides are limited to protect the environment for the future. Herbicides are persistent in nature, negatively impacting beneficial animals and may be directly toxic to farmers and consumers (Grace *et al*., 2016). Some of these herbicides have been scheduled under the Montreal Protocol on substances that degrade the ozone layer and has left famers with limited available alternatives for pre-plant soil treatments (Agostini, 2011; Karavina and Mandumbu, 2012). Most resource-poor smallholder farmers cannot afford herbicide weed control options and often their crop yield is heavily impacted negatively by weeds. Therefore, there is need to develop affordable and effective biological weed management options, such as biofumigation.

Biofumigation is the incorporation of glucosinolate-containing plant tissue to suppress soil-borne pathogens and weeds (Angus *et al.,* 1994; Matthiessen and Kirkegaard, 2006; Agostini, 2011; Handiseni *et al.,* 2011; Grace *et al.,* 2016.). It is a novel pest management technique presenting a potential alternative (Lord *et al.,* 2011). The use of plant tissue biofumigants in the soil has been shown to significantly reduce a wide range of weeds (Henderson *et al.,* 2009; Agostini, 2011; Handiseni *et al.,* 2011; Karavina and Mandumbu, 2012; Gopi *et al.,* 2016; Grace *et al.,* 2016;). Despite the success of biofumigation being reported, adoption of this technology is still a challenge. One major limiting factor is finding the ideal crop species for biofumigation. Although the Brassica species have biofumigation potential, they do

not always grow well in some areas, resulting in low-plant biomass production. It is, therefore, important to select a biofumigation crop that is adapted in each environment to maximise plant biomass production, thus ensuring the incorporation of enough dosages of glucosinolates for biofumigation. In most areas of Zimbabwe, especially in the southern part of Zimbabwe, *C. gynandra*, an indigenous vegetable plant, is well adapted and grows in abundance as a volunteer crop. It contains a glucosionale group, which has Methyl-glucosinolate in its profile and can produce Methyl ITC when used as a biofumigant. This was also found in Brassicas which suppress weeds (Vaughn *et al.,* 2005). Methyl ITC is known to be used as a commercial soil fumigant and its residues must be degraded before planting the following crop to avoid phytotoxicity (Angus *et al.,* 1994; Brown and Morra, 1995). Methyl ITC suppresses growth and germination of many weed species (Brown and Morra, 1995).

The main objective of this study was to evaluate the efficacy of *C. gynandra* species on broad -leaved and grassy weeds under laboratory and field conditions. Four weed species, namely *Rottboellia cochinchinensis*, *Setaria verticillata*, *Amaranthus hybridus* and *Bidens pilosa,* which are economically important in horticultural crops in smallholder farms, were chosen as model organisms or test plants for this study. Two species of *C. gynandra* (green and purple variants) were compared with a non-biofumigant control for their efficacy on weeds.

MATERIALS AND METHODS

STUDY SITE

The research was carried out at the Horticulture Research Centre ($18^0$11'S and $31^0$28'E), near Marondera, which is at an altitude of 1630 m above sea level. The Centre has an average day-length of 13.2 hours in summer and 11.1 hours in winter (Vincent and Thomas, 1962; Mhazo, 2011). Hot summer is between September and December with October being the hottest month of the year, with maximum temperatures above 30^0C (*ibid/*). Slightly more than two thirds of the total rainfall normally falls during the months of December, January and February (Mhazo, 2011).

CLEOME GYNANDRA ACCESSIONS GLUCOSINOLATE PROFILING

C. gynandra seed was collected from the Horticulture Research Centre gene bank in Marondera. Two types of *C. gynandra*, the green-stem and purple-stem, were used in the experiments. Five seeds from each accession were sown, each in a planting pot (25cm x 20cm x 15cm). At full flowering time, the plant above ground biomass was harvested, weighed, frozen at -80^0C and subsequently freeze dried in an Edwards Minifast freeze-drier (from -40^0C to $+18^0$C in eight hours with a vacuum of 10^{-1} mbar). The freeze-dried materials were homogenised in a mortar, ground into fine powder and stored at 25^0C. The materials were sent to Dr Jack Brown's lab at the University of Idaho, to determine glucosinolate content using the methe modified method described by Daun *et al*. (1989) to determine glucosinolate content.

WEEDS LABORATORY TRIAL

Sandy-loam soil was collected from the Horticulture Research Centre small nursery and autoclaved prior to use in the experiment. The *C. gynandra* plants were grown up to flowering stage. The wet pasteurised soil was weighed and used as media. *C. gynanadra* tissue was applied at a rate of 0, 5, 10 and 15% per weight (w/w) of plant tissue and the soil (potting mix) per treatment. Pots were filled with pasteurised soil. The soil treatments were either amended or non-amended with either green or purple stem *C. gynandra* plant tissue. All the weed seeds were scarified using 1% of hydrochloric acid for eight hours, rinsed thouroughly with distilled water and allowed to dry at room temperature for 24 hours. A total of 20 weed seeds were planted in each petri dish containing growth media. The petri dishes were filled with an additional little amount of soil. The control consisted of weed seed planted in petri dishes containg pasteurised soil without *C. gynandra* plant tissue amendment. Each treatment consisted of four petri dishes planted with 20 seeds The experiment was arranged in randomised complete block design. The petri dishes were incubated at 25^0C. Each petri dish was watered with 500 ml of distilled water immediately after planting and an additional 100 ml after three days. After 21 and 28 days after planting, weed seedling emergence and biomass were measured, respectively.

FIELD EXPERIMENT

A split plot design was used in the field experiment, with biofumigant crop treatments (glucosinolate containing green-stem and purple-stem *C. gynandra,* a non glucosinolate containing kale crop, and zero biofumigant (control)) as the main plots. Main plots were 4.5 m by 1.8 m and each cover crop treatment was replicated four times. The subplot factor was the weeds species. Within each plot, crop species' alocations were randomly assigned. The biofumigant plants (*C. gynandra* and kale crops) were transplanted from seedlings grown for six weeks in the nursery. The tomato and sweet pepper plants were drenched a day after planting after the first irrigation with the chemical Actara (Thiamethoxam) for the control of cutworms, aphids and leaf miners. The plants were grown with a basal dressing of 10 grams per plant of Compound C (N5%:P15%:K12%) fertilizer and a top dressing was done using 10 grams of Ammonium nitrate (34.5% N), split applied at three and five weeks after planting. The biofumigant crop treatments were grown up to flowering stage, mowed and incorporated by use of a tractor drawn disc harrow to a depth of 15cm. Before mowing and incorporation, biofumigant crops were sampled, freeze dried, ground into powder using a grinding mill and the glucosinolate content was determined. Above ground, biomass of the biofumigants was assessed in the field by collecting biomass from two quadrants per plot measuring 0.5 m x 0.5 m. Samples were dried for seven days at 65°C and weighed. Two weeks after biofumigant incoporation, four lines, with a spacing of 0.9 m by 0.3 m, were made in each main plot and six week-old tomato and pepper seedlings were transplanted. Control plots which had no biofumigants were incoporated. The tomato and sweet pepper plants were grown with a basal dressing of 20 grams per plant of Compound C (N5%:P15%:K12%) fertilizer and a top dressing was done using 10 grams of Ammonium nitrate (34.5%N), split applied when the fruits were marble size (six weeks after planting). Insecticide treatments were done across all plots using Actara (Thiamethoxam) at planting and, also Dynamec (Abamectin), Ampligo (lamda-cyhalothrin), Dimethoate (Dimethoate) and Proclaim (Emametin benzoate) chemicals at 14-day intervals using the recommended application rates on product labels. The main target pests were aphids, white flies, cutworms, leaf miners, bollworms and locusts. Fungicide treatments

were done as necessary after scouting. Scouting for forlia diseases was done weekly.

DATA COLLECTION

WEED LABORATORY TRIAL

The weed emegence counts was done at 7, 14, 21 and 28 days after sowing for all weed species, and weed fresh biomass was done at 28 days after sowing for all weed species . The dry biomass data was collected two weeks after the fresh biomass was collected.

FIELD TRIAL

Field weed emergence was assessed by counting the number of weeds emerging by species category in 0.5 m x 0.5 m quadrant at eight weeks after transplanting. In addition, all the weeds, seperated by their species in the quadrant, had their above ground plant biomass harvested, dried at 65°C for 14 days and weighed. This was immediately followed by weeding the whole plots. The quadrants were thrown systematically following a W pattern in a plot to collect weed counts at eight weeks after planting. The weed species in the quadrant were identified, counted and recorded. The number of weeds per square metre was determined. The number of different weed species in a given plot is known as weed species richness and is represented by **S**. Other parameters calculated were Shannon-Weiner Index **(H)** and weed species evenness **(E)**. Shannon-Weiner Index was determined as follows: **$H= -\sum pi \ X \ In \ (pi)$**. This gives a negative number and must be multiplied by -1 to make it positive. Weed species evenness **$(E) = H/In(S)$**. **Pi** is the number of each weed species, divided by the total number of weeds per quadrant and **In** represents the natural logarithm. The weed density, **S**, **H** and **E** for this field were determined. At maturity, the crops were harvested, counted, graded and weighed.

DATA ANALYSIS

Data was subjected to Analysis of Variance using the Genstat 17th edition (VSN International, 2015). Significant differences between treatments means were examined using Fishers protected LSD multiple range test (VSN International, 2015).

RESULTS

CLEOME GYNANDRA GLUCOSINOLATE CONTENT ANALYSIS

The *C. gynandra* used in this study contained total glucosinolate content of 19 and 7 µmol g^{-1} for purple stem *C. gynandra* accession and green stem *C. gynandra* accession. respectively (**Table 1**). The primary glucosinolate in both the green and purple stem *C. gynandra* is methyl-glucosinolate.

Table 1: *C. gynandra* accessions glucosinolate profiling

Plant type	Glucosinolate type	Amount per gram of dried green tissue (µmol g^{-1})
Purple stem C. gynandra accession	methyl-glucosinolate	19
Green stem *C. gynandra* accession	methyl-glucosinolate	7

BIOFUMIGANT EFFECTS ON WEED SEEDLING EMERGENCE UNDER LABORATORY CONDITIONS.

The F probability values obtained after doing the analysis of variance are shown in Table 2. The interaction of Biofumigant type x Application Rate had significant effects ($p<0.05$) on the emergence of *S. verticillata* only. This interaction had no significant effect on seedling emegence of *A. hybridus*, *B. pilosa* and *R. chochinchinensis*. The main effect of Biofumigant appplication rate had significant effects ($p<0.05$) on the emergence of seedlings of *A. hybridus*, *B. pilosa* and *S. verticillata*. In contrast, Biofumigation rate had no significant effect on *R. cochinchinensis* emergence. The main factor of Biofumigant had siginificant effect ($p<0.05$) on *S. verticillata* only.

The effects of varying the Biofumigant rates on the test weed species are shown in Table 2. The application of Biofumigant at 1.5g/30g soil significantly ($p<0.05$) reduced *A. hybridus* count compared to the control treatment. However, further increase in the Biofumigant rate did not significantly decrease the *A. hybridus* counts compared to the 1.5g/30g soil. The effect of changing Biofumigant rates on *B. pilosa* counts was similar to the response given by *A. hybridus*. The application of Biofumigant at 1.5g/30g soil significantly ($p<0.05$) reduced *S. verticillata* counts, compared to the control treatment. The Biofumigant rates of 1.5 and 3.0g/30g soil had similar effect on *S. verticillata* counts. However, the Biofumigant rate of 4.0g/30g soil significantly produced the lowest *S. verticillata* count. The application of Biofumigant had no effect on the *R. cochinchinensis* counts (Table 2).

Table 2: Analysis of variance (*p* value) for the effects different biofumigants and rate of application on weeds seedling emergence at 28 days after planting for *A. hybridus, B. pilosa*, *S. verticillata* and *R. cocchinensis*.

Source	D.F.	Seedling emergence			
		A. hybridus	*B. pilosa*	*S. verticillate*	*R. cocchinensis*
Rate of application (R)	3	<0.001	<0.001	<0.001	0.580
Biofumigant spp (B)	1	0.828	0.651	0.011	0.588
R x B	3	0.965	0.197	0.015	0.855

S. verticillata was significantly affected by the rate of application, the biofumigant species used and the interaction between the rate of application (Table 3).

Table 3: The effect of rate of amendment with *C. gynandra* species (at rates 0, 5, 10 and 15 % weight to volume) on weeds seedling emergence % at 28 days after planting

Rate (g/30g soil)	*A. hybridus*	*B. pilosa*	*S. verticillate*	*R. cocchinensis*
0	51.9 [a]†	64.4 [a]	73.1 [a]	33.8
1.5	16.9 [b]	41.9 [ab]	31.2 [b]	23.8
3.0	5.6 [b]	32.5 [b]	17.5 [b]	27.5
4.5	5.0 [b]	31.9 [b]	13.1 [c]	26.9
LSD (5%)	12.15	24.81	15.57	NS

†The means followed by the same letter in a column are not significantly different
NS: Not significant

BIOFUMIGANT EFFECTS ON WEED DRY SHOOT BIOMASS UNDER LABORATORY CONDITIONS.

The main effects of Biofumigant rate, Biofumigant species and their interactions on shoot biomass is shown in Table 4. The Biofumigant rate x Biofumigant species interaction effects were significant ($p<0.05$) on the shoot biomass of *B. pilosa* and *S. verticillata*. However, these effects were not significant on the shoot biomass of *A. hybridus* and *R. cochinchinensis*. The effect of the rate of Biofumigant application were significant ($p<0.05$) on shoot biomass of *A. hybridus*, *B. pilosa* and *S. verticillata*. These effects were not significant on the shoot biomass of *R. cochinchinensis*. The main factor of the Biofumigant species was only significant on shoot biomass of *S. verticillata*.

Table 4: Analysis of variance (*P* value) for the effects different biofumigants and application rate on weeds seedling shoot dry biomass at 28 days after planting for *A. hybridus, B. pilosa*, *S. verticillata* and *R. cocchinensis*.

Source of variation	d.f.	shoot biomass			
		A. hybridus	*B. pilosa*	*S. verticillate*	*R. cocchinensis*
Rate of application (R)	3	<0.001	<0.001	<0.001	0.461
Biofumigant spp. (B)	1	0.286	0.674	0.019	0.425
R x B	3	0.402	0.045	0.005	0.322

The effect of the Biofumigant rates on shoot biomass of the weed species is summarised in Table 5. The addition of Biofumigant at 1.5g/30g soil significantly ($p<0.05$) reduced *A. hybridus* shoot biomass when compared to the control treatment (0g/30g soil). Increasing the Biofumigant rate from 1.5 to 3.0g/30g soil further decreased the shoot biomass of *A. hybridus*. However, there were no significant differences between 3.0 and 4.5g/30g soil on *A. hybridus* shoot biomass. The effect of the Biofumigant rate on *B. pilosa* was similar to that of *A. hybridus* (Table 5). The addition of 1.5g/30g soil of Biofumigant significantly ($p<0.05$) reduced the shoot biomass of *S. verticillata* compared to the control treatment (0g/30g soil). It was noted that increasing the rate of Biofumigant from 1.5 to 4.5g/30g soil caused no significant change in the biomass of *S. verticillata*. The Biofumigant rates did not affect the shoot biomass of *R. cochinchinensis*.

Table 5: The effect of rate of amendment with *C. gynandra* species (at rates 0, 5, 10 and 15 % weight to volume) on weeds shoot biomass (g) at 28 days after planting

ate (g/30g soil)	. *hybridus*	. *pilosa*	*verticillata*	. *cochinchinensis*
	08[a]†	13[a]	12[a]	04
5	05[b]	07[b]	05[b]	04
0	01[c]	06[c]	03[b]	05
5	01[c]	06[c]	02[b]	08
5D	03642	0324	03511	S

†Means followed by the same letter in a column are not significantly different

NS: Not significant

The Biofumigant rate x Biofumigant species interactions on shoot biomass of *B. pilosa* and *S. verticillata* are shown on Table 5. The addition of Green *C. gynandra* at 1.5g/30g soil significantly ($p<0.05$) reduced shoot biomass of *B. pilosa.* Further increase in the Biofumigation rate beyond 1.5g/30g soil did not bring about significant change in shoot biomass of B. pilosa, lthough the effect of Purple *C. gynandra* gave effects on shoot biomass of *B. pilosa* as those of Green *C. gynandra*. The rate of 3.0g/g soil produced the lowest amount of *B. pilosa* biomass.

The addition of Green *C. gynandra* at 1.5g/30g soil significantly ($p<0.05$) reduced shoot biomass of *S. verticillata.* Further increase in the Biofumigation rate beyond 1.5g/30g soil did not bring significant changes in shoot biomass of *S. verticillata*. Although the effects of Purple *C. gynandra* gave effects on shoot biomass of *S. verticillata* as those of Green *C. gynandra*, the rate of 3.0g/g soil produced the lowest amount of *S. verticillata* biomass (Table 6).

Table 6: The effect of rate of amendment and the *C. gynandra* species type on emergence of broad leaved weeds

	S. verticillata		**B. Pilosa**	
Rate (g/30g soil)	**Green C. gynandra**	**Purple C. gynandra**	**Green C. gynandra**	**Purple C. gynandra**
0	53.80 [a]†	50.00[a]	73.80[a]	55.00[a]
1.5	17.50[b]	16.20 [b]	43.80[b]	40.00 [b]
3.0	6.20 [b]	6.20 [b]	36.20[b]	28.80[c]
4.5	3.80 [b]	5.00 [b]	22.50[b]	41.20[b]
LSD	17.18	17.18	24.81	24.81

†The means followed by the same letter in a column are not significantly different

FIELD TRIAL

Trials were done on the herbicidal activity of different *C. gynadra* variants on sweetpepper and tomato plants. The herbicidal activity of green and purple *C. gynandra*, rape (*B. napus*) and a non-biofumigant control, showed significant differences ($p<0.05$) on overall yields, number of fruits and number of surviving on sweet pepper (Table 7). The effect of the different biofumigant effects showed significant differences on the total number of surviving plants on tomato. Sweet pepper yield was shown to have been affected significantly ($p<0.05$) by the application of biofumigation treatments. Purple *C. gynandra* treatment was shown to positively affect the overall yield and fruit number compared to the standard control of rape and a non-biofumigant chemical control in sweet pepper plants (Tables 7, 8). Tomato yields was shown to have not been affected by the application of different biofumigant treatments and no significant ($p<0.05$) differences were found in the overall yield and total number of fruits, except for total number of surviving plants (Tables 7, 8).

Table 7: Analysis of variance of the effect of the herbicidal activity of green and purple *C. gynandra*, rape (*B. napus*) and a non-biofumigant control on number and yield of sweet pepper and tomato

		Sweet pepper		**Tomato**	
		Overall yield	**Fruit number**	**Overall yield**	**Fruit number**
Source of variation	**D.F.**	**P. value**	**P. value**	**P. value**	**P. value**
Biofumigant (B)	3	0.002	0.045	0.168	0.293
Weed (W)	1	0.249	0.981	0.212	0.036
B X W	3	0.964	0.177	0.766	0.661

Table 8: The effect of biofumigant herbicidal activity on the yield of sweet pepper and tomato

Biofumigant	Overall yield	Fruit number	Overall yield	Fruit number
Green C. *gynandra*	2939.00†[b]	49.90[b]	17956.00	358.00
Non-biofumigant	5293.00[a]	74.90[a]	15070.00	309.00
Purple *C. gynandra*	5064.00[a]	70.40[a]	24947.00	419.00
Rape	5022.00[a]	75.90[a]	17492.00	414.00
LSD	1415.00	19.37	NS	NS

†The means followed by the same letter in a column are not significantly different from each other according to the LSD value.
NS: Not significant

The mean weed species richness (S) for the four biofumigants quadrant samples collected ranged from 4.62 (green *C. gynandra*) to 6.00 (non-biofumigant control) in the sweet pepper plots and there were no significant differences noted ($p \leq 0.05$) (Tables 9,10). The Shannon-wiener Diversity index (H) for sweet pepper plots ranged from 1.049 for rape to 1.329 for purple *C. gynandra*. Shannon-wiener diversity index values of 1.118 and 1.148 were for non-biofumigant control samples and green *C. gynandra* samples, respectively. There were no significant differences ($p<0.05$) noted on sweet pepper fields for species evenness. The species evenness (E) ranged from 0.62 for Quadrats with green *C. gynandra* to 0.79 for sweet pepper plots (Table 10).

The mean weed species richness (S) for the four biofumigants quadrant samples collected ranged from 4.75 (Rape) to 6.38 (purple *C. gynandra* and non-biofumigant control) in the tomato plots. There were significant differences ($p<0.05$) observed on tomato fields (Table 10) for species evenness. The species evenness (E) ranged from 0.64 for Quadrats with green *C. gynandra* to 0.84 for tomato plots (Table 10).

Table 9. Mean squares from the ANOVAs of sweet pepper and tomato plot weed counts at 8 weeks after planting.

		Sweet pepper			Tomato		
Sweet pepper		E	H	S	E	H	S
Source of variance	df	SS	SS	SS	SS	SS	SS
Block	3	0.06445	0.11802	2.375	0.01148	0.2981	10
Block X MP treat							
Main plot	3	0.15031	0.34257	9.125	0.20778*	1.39782	14.25
Residual	9	0.21634	1.78367	29.375	0.1167	1.71442	44.25
Block X MP treat X SP treat							
Split plot	1	0.00478	0.00138	0.125	0.02192	0.00284	8.000*
Main plot X split plot	3	0.04043	0.73728**	15.125	0.01784	0.10119	2.25
Residual	12	0.25033	0.4701	22.75	0.17561	0.56231	16.75
Total	31	0.72664	3.45302	78.875	0.55138	4.07167	95.5

†* 0.01<p<0.05; ** 0.001<p <0.01; *** p<0.001; all other mean squares were not significant.

E: species evenness; the population that each species comprises of the whole, H: Shannon Weiner diversity index, S: Species richness

Table 10: The herbicidal activity of Green *C. gynandra*, Purple *C. gynandra*, Rape (*B. napus*) and a non-biofumigant control of sweet pepper and tomato fields at 8 weeks after planting.

	Sweet pepper			**Tomato**		
Main plot	E	H	S	E	H	S
Green C. gynandra	0.77	1.15	4.62	0.64[b]	1.13	6.00
Non-biofumigant	0.62	1.12	6.00	0.82[a]	1.51	6.38
Purple C. gynandra	0.79	1.33	5.62	0.84[a]	1.53	6.38
Rape	0.67	1.05	5.00	0.72[a]	1.08	4.75
LSD	NS	NS	NS	0.13	NS	NS
CV%	15.40	27.10	24.00	10.70	23.50	26.70

†The means followed by the same letter in a column are not significantly different from each other according to the LSD value.

NS: Not significant

DISCUSSION

The findings of this work suggest that plant tissue biomass from *C. gynandra* can suppress weed emergence. *C. gynandra* plant tissue residues had an inhibitory effect on weed seed emergence. This confirms work done before which proved that biofumigation has been shown to suppress weed emergence and biomass. However, the level of response observed is dependent on both the ITC and the pest involved (Sarwar *et al.,* 1998; Kirkegaard *et al.,* 2001; Manici *et al.,* 2004). The suppression may be attributed to glucosinolate hydrolysis products from *C. gynandra* plant tissue. Brown and Morra (1995, 1996) attribute lettuce emergence inhibition to water soluble compounds from *B. napus* defatted seed meal and those from *B. napus* leaf tissue. These water-soluble glucosinolate products from *Brassica* seed meals are probably involved in the inhibition of germination (Brown and Morra, 1995; Mazzola *et al*., 2007; Handiseni *et al*., 2013, 2011;). The differences in the suppressive effect of the two *C. gynandra* species types observed in this study can sometimes be attributed to different methyl-glucosinolate content between the two *Cleome* species. The amount of methyl-glucosinolate found in in this study, both the purple and green *C. gynandra* accessions, were 19 and 7 μmol g^{-1} per gram of dried green tissue, respectively. Bohinc *et al.* (2012) report that glucosinolate content varies between plant species. The study devised that the same plant material may affect different weed species in a different manner (Brown and Morra, 1995; Bohinc *et al.,* 2012; Handiseni *et al.,* 2013). It was also observed that the suppression of soil-borne pests using Brassica spp. will be aided using varieties possessing high glucosinolate content and those which supply sufficient volumes of moisture to promote the release of isothiocyanates (Taylor, 2013).

In this study it observed that different levels of weed emergence are exerted by different amounts of *Cleome* spp. plant tissue applied. Dhingra *et al*. (2004) previously showed that high concentrations of Allyl-ITC can be found within some mustard, horseradish and wasabi species. However, a high degree of variation exists between cultivars of the same species (Taylor, 2013). The mechanism of volatility, toxicity and effectiveness differs with type of the ITC R-group. However, reasons for differences in toxicity are not always clear.

The non-suppressive effect of *C. gynandra* on *R. cocchinensis* was also similar to the findings by Handiseni *et al.* (2011) in which they report that the use of Brassicaceous residues for the control of weeds and soil-borne pests has not been widely implemented due to inconsistencies in performance across varied production systems. However, results in this study suggest that pre-plant soil incorporation of *C. gynandra* has the potential to act as an effective alternative to chemical herbicides for the control of the weeds in *B. pilosa, A. hybridus* and *S. verticillata*.

The results in this study showed that the application of *C. gynandra* plant tissue biofumigants has an effect on overall yield and the overall fruit counts. The results obtained in this experiment could be as a result of the allelochemical effects of GSLs on the weed species as what has been previously reviewed by Brown and Morra (1997) in. It is also reported that GSLs may greatly influence weed growth and are suspected to be the major suppressors of weed growth (Handiseni *et al.,* 2011; Bohinc *et al.,* 2012; Grace *et al.,* 2016).

In this study, the biofumigation with the purple and green *C. gynandra* increased the yields of both tomato and sweet pepper in the trials and it was comparable to the control treatments. These results supports the findings of Handiseni *et al.* (2011) and illustrates the potential of biofumigation for suppressing the growth of *Avena fatua, Amaranthus retroflexus* and *Lactuca serriola*. The findings indicate that biofumigation of fields by incorporation of *C. gynandra* plant tissue affect weed evenness in the field. This represents a useful reduction in weed species for farmers (Agostini, 2011; Karavina and Mandumbu, 2012).

The study shows that yields varied significantly between the non-biofumigant control, the green and purple *C. gynandra* plant tissue biofumigants. Different biofumigant effects were shown to vary significantly in sweet pepper yields and number of fruits. This suggests that the glucosinolate concentration of the tested *C. gynandra* accessions have variable effects as biofumigants on weed activity. Overall, the results of this study suggest that the candidate purple and green *C. gynandra* are effective in suppressing weed species activity and this was comparable to check treatments under field conditions.

Green *C. gynandra* plant tissue, as a treatment, had low levels of glucosinolates and it has been increasing yields comparatively with the chemical controls, which are effective in weed suppression. The results indicate that weed suppression is not always associated with high production of glucosinolates (Brown and Morra, 1995; Gimsing and Kirkegaard, 2009). In the present study, the mechanisms behind any suppressive effects of green manure *C. gynandra* crops were not investigated, but since the *C. gynandra* had specific suppressive effects, it can be concluded that green *C. gynandra* glucosinolates had a suppressive factor in this case, even at low levels (Soldevilla-Martinez, 2009).

The results indicate that biofumigation using *C. gynandra* from the field trials was not consistent on the tomato trials. However, the use of different cultivars which possess glucosinolate profiles more resistant to the effects of abiotic factors, including moisture and temperature, may produce different results. The high volatility level of ITCs has often been highlighted as an aspect which may limit the efficiency of a biofumigation system (Gimsing and Kirkegaard, 2009). However the biofumigation principal works on the 'mustard bomb' effect, releasing a short blast of isothiocyanates at high concentrations which aims to kill weeds within the soil (Agostini, 2011). It is also hoped that this approach will limit any adverse effects on non-targeted soil organisms. However, investigating an incorporation method which will best seal ITCs into the soil, and limit their initial depletion, will allow them to come into contact with increased numbers of weeds within the soil (Handiseni *et al.,* 2011).

The weed species in the field are primary sources of future weed populations and this provides seed bank, a unique source for predictive management studies (Karavina and Mandumbu, 2012; Grace *et al.,* 2016). Species richness (S) quantifies how many different types, weed species, are contained in the field under study, the number of different species in the corresponding list ranging from 4.62 to 6.38. Weed richness (S) is different from weed abundance, as it is different from diversity. Species evenness refers to the proportion that each species comprises of the whole. The results above show that the diversity is high on all the quadrats sampled. The diversity index is a

quantitative measure reflecting how many different weed species are there in the field under study and, simultaneously, takes account of how evenly the weed species are distributed among the types.

CONCLUSIONS

The most important result of this study was that *C. gynandra* biomass incorporation suppressed germination and early seedling growth of *Setaria verticillata, Amaranthus hybridus* and *Bidens pilosa,* but not *Rottetboelia cocchinensis.* These results are very interesting and indicate possible alternative potential for use in cropping systems to suppress weed growth by smallholder farmers. For the biofumigant accessions investigated, purple *C. gynandra* proved to be more effective at suppressing the weed species tested.

The result demonstrate that the application of *C. gynandra* plant tissue had a herbicidal effect and can suppress the growth of weeds species in the field studied. The results also conclude that the effects between different *C. gynandra* biofumigants and weed species can vary depending on the combination of *C. gynandra* plant tissue type and weed species. However, the use of different *C. gynandra* species, which possess more glucosinolate concentrations, more resistant to abiotic stresses, including moisture and temperature, may produce different results.

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