Macrothink Institute™

Journal of Agricultural Studies
ISSN 2166-0379
2025, Vol. 13, No. 1

Effects of Green Manure Cover Crops on Weed Suppression at Mashare and Liselo, Namibia

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Received: September 9, 2024 Accepted: October 28, 2024 Published: November 1, 2024

doi:10.5296/jas.v13i1.22356 URL: https://doi.org/10.5296/jas.v13i1.22356

Abstract

Small-scale farming communities in northern Namibia often encounter poor soil fertility and financial constraints. They don’t afford buying mineral fertilizers and herbicides, thus highlighting the need for cost-effective cropping systems that enhance productivity. While green manure cover crops (GMCCs) have been extensively studied elsewhere and shown to boost productivity, information on their use remains limited in Namibia. Experiments were conducted over two seasons (2016/2017-2017/2018) at Mashare Irrigation Training Center (MITC) and Liselo Research Station (LRS), which have different soil types, to explore the effects of rotating Pearl millet and maize with various GMCCs on crop weed populations. The experiments compared the effects of rotating nine different GMCCs with Pearl millet and maize separately against monocropping of Pearl millet and maize. Results showed that weed density varied across treatments and locations, with the highest densities observed in certain rotations, such as Pearl millet-pigeon pea and maize-pigeon pea, while the lowest densities were found in rotations involving lablab and velvet bean. This is indicative that lablab and velvet bean suppressed weeds better than all other GMCCs, while pigeon pea was vulnerable to weed infestation. Lablab exhibited the highest biomass yields. Overall, rotating Pearl millet and maize with cover crops demonstrated greater benefits compared to monocropping, emphasizing the need to identify suitable cover crops for specific niches to optimize productivity.

Keywords: Conservation Agriculture, Crop rotation, Green Manure Cover Crops, Mono cropping, Small-scale Farming, Weed density, Weed suppression

1. Introduction

Weed management is reported to be one of the biggest challenges facing smallholder farmers adopting and practicing conservation agriculture (CA). This was especially observed during the first three years of adopting CA farming system in Namibia (Goeb, 2013). Many authors argue that conservation agriculture promotes perennial grasses (Gan et al., 2008). In addition, they also argue that short weeds are more likely to emerge in minimal tillage systems because weed seeds are not deeply embedded in the soil (Légère et al., 1993).

Weed dynamics fluctuates as farmers switch to reduced-tillage practices. Hence, smallholder farmers need to be better informed about new weed species that may emerge under the new management system, in order to control them effectively (Derpsch & Friedrich, 2008). Some commercial farmers under CA chose to rely on using herbicides to control weeds for their first three years after the system is implemented in Namibia. However, chemical herbicides are expensive and they are not easily accessible to poor smallholder farmers (Wall, 2007). In fact, there is a need to identify different strategies that could help manage weeds in a way that is less labor- intensive and much more accessible to poorer small farmers. Over the years, a number of sources have reported that Green Manure Cover Crops (GMCC) are effective against a number of weed species. GMCC such as sunn hemp (*Crotalaria juncea*) and velvet bean (*Mucuna pruriens*) have vigorous growth habits that allow them to compete with various weed species (Teasdale et al., 2007). In addition, GMCC also have a choking effect on weeds, which can deplete weed seed banks and ultimately lead to weed species decline (FAO, 2010). The possibility of integrating these cover crops into Namibia's cropping system to facilitate weed control should be explored.

Smallholder farmers in north-central and north-east Namibia attribute their Pearl millet and maize yield losses to weed competition and poor soil quality (Kuvare, et al, 2008). These farmers are generally cash-constrained and situated in marginal areas where poor soil fertility and land degradation are predominant. It is normally difficult for these smallholder farmers to purchase mineral fertilizers and herbicides (Mhlanga et al, 2014). Hence, there is a need to identify cropping systems that are affordable and can improve their productivity. Therefore, this study will investigate different weed control measures, using different cover crops which have the potential to suppress weed growth, while improving the soil nitrogen content (Kaurivi *et al*., 2010).

1.1 Objectives

1.1.1 Overall Objectives

The purpose of this study was to evaluate the effectiveness of different leguminous and non-leguminous GMCCs/ fodder crops, grown in rotation with Pearl millet and maize, in ensuring suitable residue cover and significant fodder supply and to quantify their effects on weed suppression under CA.

1.1.2 Specific Objectives were to:

1. Determine the effect of different GMCCs on weed suppression;

2. Determine the weed species diversity, evenness and richness in the various GMCC treatments.

2. Literature Review

Green Manure cover crops are living ground cover crops that can be intercropped, rotated with the main crop or introduced into a cropping system when the main crop is about to die and normally killed before introducing the successive crop (Teasdale et al., 2007). Cover crops can either be annual or perennial, they may be conserved into the next season without replanting. Cover crops can be legumes or non-legumes. Leguminous cover crops are preferred because they contribute nutrients to the soil and cause less competition for nutrients compared to non-leguminous cover crops, which compete for both nutrients and moisture (Mhlanga et al., 2017).

Cover crops can be introduced into Pearl millet or maize cropping systems either by rotating them with the Pearl millet/maize or by relay cropping them when the Pearl millet/maize is about to die in order to improve the soil and environmental quality (Mhlanga et al., 2017). Different leguminous cover crops, depending on their quality, provide different benefits and there is no specific cover crop that will provide all the specific benefits (FAO, 2010). Hence, there is a need to identify a specific cover crop for a particular given role (Teasdale and Mohler, 1993).

In addition, cover crops have shown to have a smothering effect on weeds leading to reduced weed populations. Various leguminous cover crops such as black sunn hemp have allelopathic effects on a certain number of weed species such as the smooth pigweed (*Amaranthus hybridus L.*) (Mashingaidze, 2012). The different leguminous cover crops compete for necessary growth components such as light, water and nutrients with weeds subsequently leading to their reduction in numbers (Mall and Singh, 2014).

It is known that rotations with different green manure cover crops have shown to increase the weed species diversity due to reduction in the numbers of dominant weed species therefore preventing the dominance of certain weed species (Brainard *et al*., 2008). In the case of legumes, involving cover crops incorporated into a cropping system may add nitrogen to the system in the process increasing the fertilization costs (Kladviko, 2011). Leguminous cover crops help to fix nitrogen and this nitrogen may eventually benefit the subsequent crops in the following season (FAO, 2010).

3. Materials and Methods

3.1 Site Description

The experiments were conducted at two different sites; Mashare Irrigation Training Center (MITC) and Liselo Research Station (LRS). MITC (17.889300°S, 20.170258°E) is situated north of the town of Rundu in the eastern Okavango region. The station is roughly 44 kilometers from Rundu on the Trans-Kalahari Highway. It is situated 1050 m above sea level. The average yearly rainfall is 550-650 mm and the average daily temperature reaches up to 33°C. LRS (latitude 17.52 °S, longitude 24.23 °E) is situated around 7 km east of Katima Mulilo town on the Trans-Kalahari Highway. LRS is situated at an altitude of 964 m above sea level and is characterized by mixed sandy soil. Precipitation in the LRS ranges from 750 to 1000 mm, with daily temperatures reaching 35°C.

3.2 Background of the Trial

The trial was initiated in the 2016/2017 cropping season and all the plots were planted with GMCC across the two sites. In the following cropping season (2017/2018), Pearl millet (*Pennisetum glaucum*) and maize (*Zea mays* L.) (Plot 1) were planted along the previous crops in all plots where GMCC was grown, and another stage was established in the plots where GMCC was planted (Plot 2). Therefore, a two-phased rotation, where one part of the trial were GMCCs and on the other part of the trial was uniform Pearl millet and maize. The cover crops and the uniform Pearl millet and maize were rotated over seasons from then onwards. Therefore, this study provides data from two pilot seasons, 1 (2016/2017) and 2 (2017/2018).

3.3 Experimental Design

At MITC and LRS, field trials were conducted under a randomized complete block (RCBD) design, with the following 10 treatments (alternating homogeneous Pearl millet at MITC and maize at LRS) blocked four times at each site.

1a) Pearl millet (*Pennisetum glaucum*) (control): Row spacing was 75 cm, seeds were planted and thinned at every 25 cm interval (53,333 plants ha^{-1} target population; 5 kg similar to ha^{-1} seed).

1b) Maize (*Zea mays* L.) (Control) was planted with 90 cm between rows and 25 cm spacing to give a plant population of 44444 ha^{-1}.

2) Black sunn hemp (*Crotalaria juncea* L.) was sown at 45 cm intervals with 5 cm row spacing (approximately 20 kg ha^{-1} seed), yielding a plant density of 444444 ha^{-1} plants.

3) Pigeon pea (*Cajanus cajan* (L.) Millsp.) Was planted at 90 cm row spacing and at intervals of 25 cm (approximately 25 kg seeds/ha) to obtain a plant population of 44444 plants/ha.

4) Cowpea (*Vigna unguiculata* (L.) Walp.) was planted in rows at 45 cm and 25 cm intervals (approximately 80 kg seeds/ha) resulting in a population of 88,888 plants/ha.

5) Groundnut (*Peanuts* (A.)) was planted in rows 45 cm and trees 25 cm apart, to obtain a plant population of 44444 ha $^{-1}$.

6) Velvet beans (*Mucuna pruriens* (L.) DC) were arranged at 45 cm intervals and planted at 25 cm intervals (approximately 80 kg $^{-1}$ seeds), planting 88,888 ha $^{-1}$ trees.

7) Lablab (*Lablab purpureus* (L.) Sweet) was planted 45 cm apart at 25 cm intervals (approximately 80 kg seeds/ha^{-1}) planted 88,888 ha^{-1} plants.

8) Bambara nut (*Vigna underground* (L) 45 cm-spaced rows, trees planted 25 cm apart, 1 seed

per stem, 44444 ha^{-1} plants were planted.

9) Jack beans (*Canavia ensiformis* (L.) DC.) in rows 45 cm and 25 cm apart for 88,888 trees per hectare (approximately 80 kg seeds per hectare).

10) Fodder cocktails: (e.g. bellows (*Raphanus sativus* L.), red mold (*Crotalaria ochroleuca* G. Don) and summer velvet (*Mucuna pruriens* (L.) DC)) at 45 cm intervals and sow seeds at 5 cm intervals in no more than 5 rows, (approx. 20kg ha^{-1} seed), securing 444444 ha^{-1} planting area. Primer NPK (2:3:2) was applied at a rate of 150 kg ha^{-1} and 150 kg ha^{-1} urea was used as primer for all surface treatment. Weeds were controlled using herbicides at the start of the experiment. Weeding was performed by hand with manual loosening in all plots, except for the weed scoring quadrant where weeds were 10 cm tall or 10 cm perimeter for woody weeds.

3.4 Field Measurements

3.4.1 Weed Biomass and Density

Weed biomass and density were collected from a 0.5 m × 0.5 m quadrant randomly placed three times in each plot. All weed species within the quadrant were counted and identified. Weed data were collected at 30, 60, and 90 day intervals after planting Pearl millet and maize (that is, before each weeding). The quadrants were reduced in size to reduce weed counting errors when there are too many weeds per unit area.

3.4.2 Plot Management

Minimum tillage was done on all plots. The sowing of Pearl millet, maize and beans was done directly in the rip lines during the second week of December for both seasons and the rip lines were opened with hand hoe at MITC and with Magoye ripper at LRS. Planting was done by hand into the rip/hoe lines.

3.4.3 Fertilizer Application

At both sites of the experiment, basal fertilizer in the form of compound D (7 N:14 P_2O_5:7 K_2O) was applied at the rate of 7.0 kg N ha^{-1}, 6.1 kg P ha^{-1} and 5.8 kg K ha^{-1} i.e 100 kg ha^{-1} Compound D. At the LRS, the basal fertilizer in the form of Compound D (7 N: 14 P2O5: 7 K2O), was used at the rate of 10.5 kg N ha-1.9, 2 kg P ha^{-1} and 8.7 kg K ha^{-1} i.e 150 kg ha^{-1}. Compound D was applied when growing Pearl millet, maize and GMCC at both crop rotation stages. Maize with Pearl millet after Pearl millet treatment and maize only supplemented with urea at 150 kg ha^{-1} during both crop rotation periods, while the other treatments utilized nitrogen fixed by the preceding cover crops.

3.4.4 Weed Control

All plots were treated with glyphosate [*N*-(phosphono-methyl) glycine] at a rate of 2.5 l ha^{-1} (1.025 l ha^{-1} active ingredient) at Pearl millet and maize planting, followed by one hand weeding two weeks after planting. Subsequently, all plots were hand weeded every time weeds reached 10 cm in height or length of species with stoloniferous-rhizomatous growing habit.

3.4.5 Weed Count, Biomass and Species Composition

For weed density and biomass, a 50 cm x 50 cm quadrant was randomly placed three times in each plot before each weeding. Weeds in the standard plot were counted, then cut to the ground and fresh weight recorded. Weeds were air-dried for 168 hours to constant weight and the dry weight of the biomass was recorded. The weed species in the plots were identified according to the guidelines of Makanganise and Mabasa, (1999) and Botha, (2010), and were later counted and recorded. All weeds that are not found in the manual and are challenging to identify are classified as “other”. For perennial monocots, the number of stems is counted instead of the whole plant (Mashingaidze, 2012). Perennial grasses had been obtained from all genera because of the difficulty to identify them at the seedling stage. Weed species richness and Shannon-Weiner diversity and uniformity indices were used to determine weed species diversity.

The Shannon-Weiner diversity index (H') for each plot was calculated as follows (equation 1):

$H' = (N \ln N - \text{Sum}(n \ln n))/N$, [1] where: H' is the diversity of species equal to the rate of species richness. Higher values of H' mean greater diversity. N is the total population density/m^2 and n is the weed population of each weed species found at that site.

The homogeneity index is calculated as follows (Equation 2): $E' = H'/\ln N$, [2] where E' is the relationship between the number of species observed and the total number of species. Higher values of E' means greater homogeneity between species richness. The E' value varies between 0 and 1.0 indicating that there is no equality between species (i.e. only one species is present) and 1 indicates that all species are evenly distributed across the species umbrella (Muoni et al., 2013).

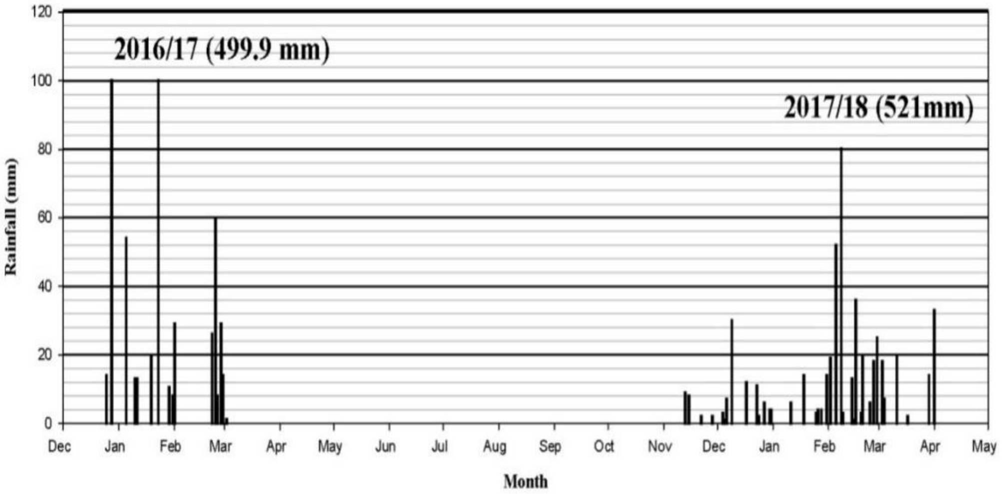
3.4.6 Statistical Analysis

Data were analyzed for variance (ANOVA) to determine the effects of crop season and GMCC on grain yield and biomass of Pearl millet and maize, as well as the contribution to PAN by GMCC. Additional biomass richness and weed composition using the statistical software package Statistix version 9 for PC (Statistix, 2009). All weed density data were checked for normality and, if required, transformed using square root (x+1) prior to analysis to guarantee uniformity of variance (Gomez and Gomez, 1984). The interactions between sites, seasons and treatments were evaluated using a linear mixed model where sites, seasons, and treatments were analyzed using the GenStat 6th Edition statistical package for Windows (VSN International, 2002), with location and treatment as fixed factors and season as random factors. If the treatments varied significantly, they were separated by the least significant difference (LSD) test at the probability level of 0.05.

4. Results

(Figure 1) illustrates the 2016/2017 cropping season recorded 499.9 mm of rain at the Liselo Research Station (LRS), whereas the 2017/2018 cropping season recorded 521 mm. Mashare Irrigation Training Center (MITC) recorded 715.2mm of rain in the 2016/2017 cropping season and 530mm in the 2017/2018 season.

LISELO RAINFALL MEASUREMENTS



MASHARE RAINFALL MEASUREMENTS

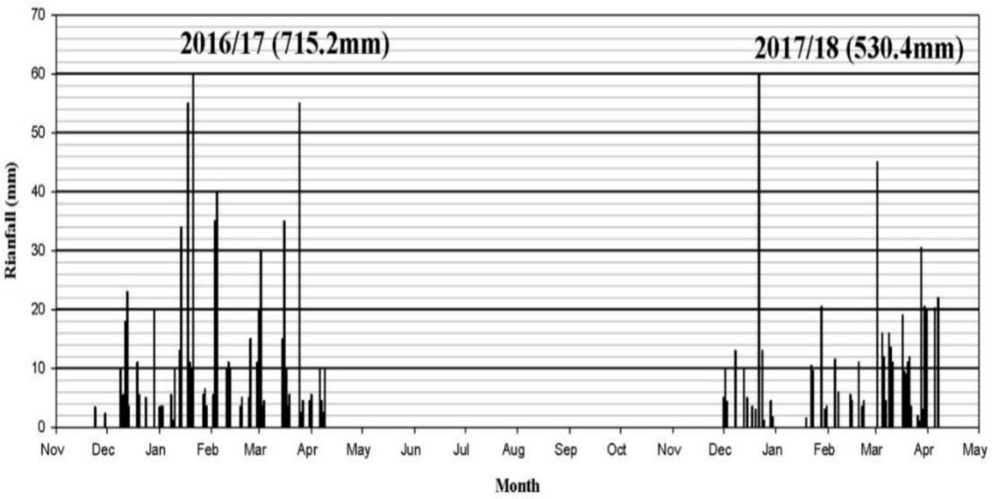


Figure 1. Precipitation recorded at LRS and MITC

The results below are based on the cropping season from 2016/2017 to 2017/2018, at both sites (MITC and LRS).

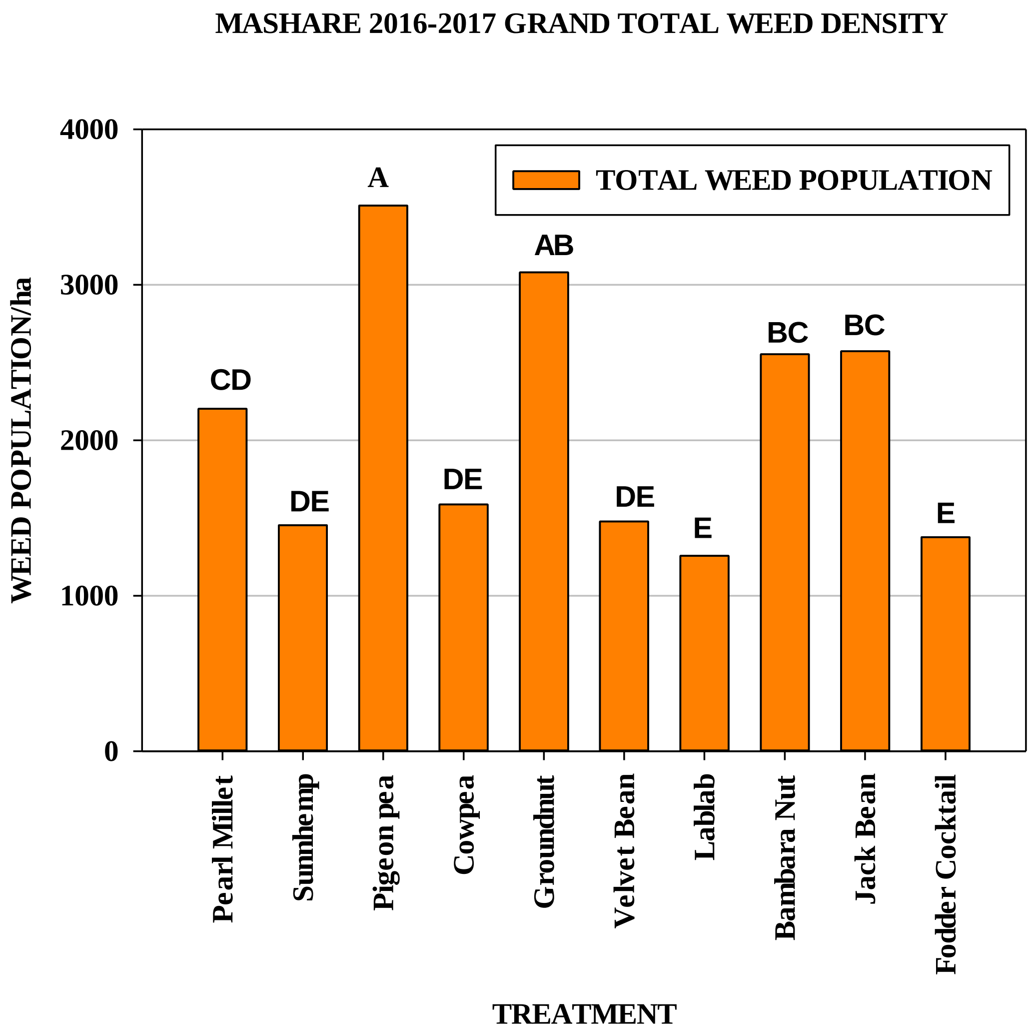


Figure 2. Effect of Pearl millet-cover crop rotations on total weed density at MITC in 2016/17 season of data collection

Different columns represent the difference in the impact of different GMCCs ($P < 0.05$) on first season total weed density.

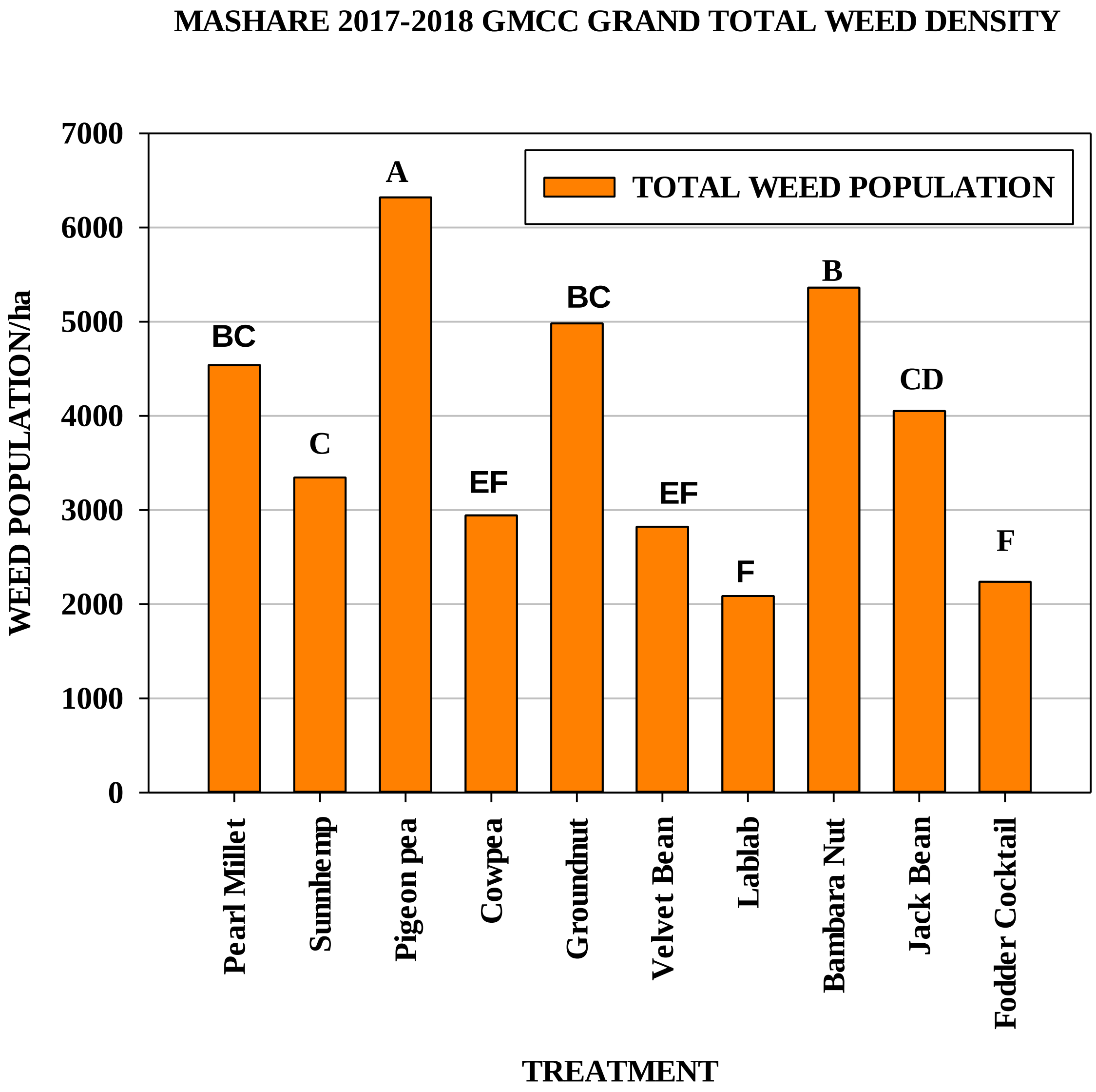


Figure 3. Effect of different Pearl millet-cover crop rotations on total weed density at MITC during the 2017/18 season of data collection

Different columns represent different effects of different GMCC ($P < 0.05$) on total weed density in the second crop (2017/2018).

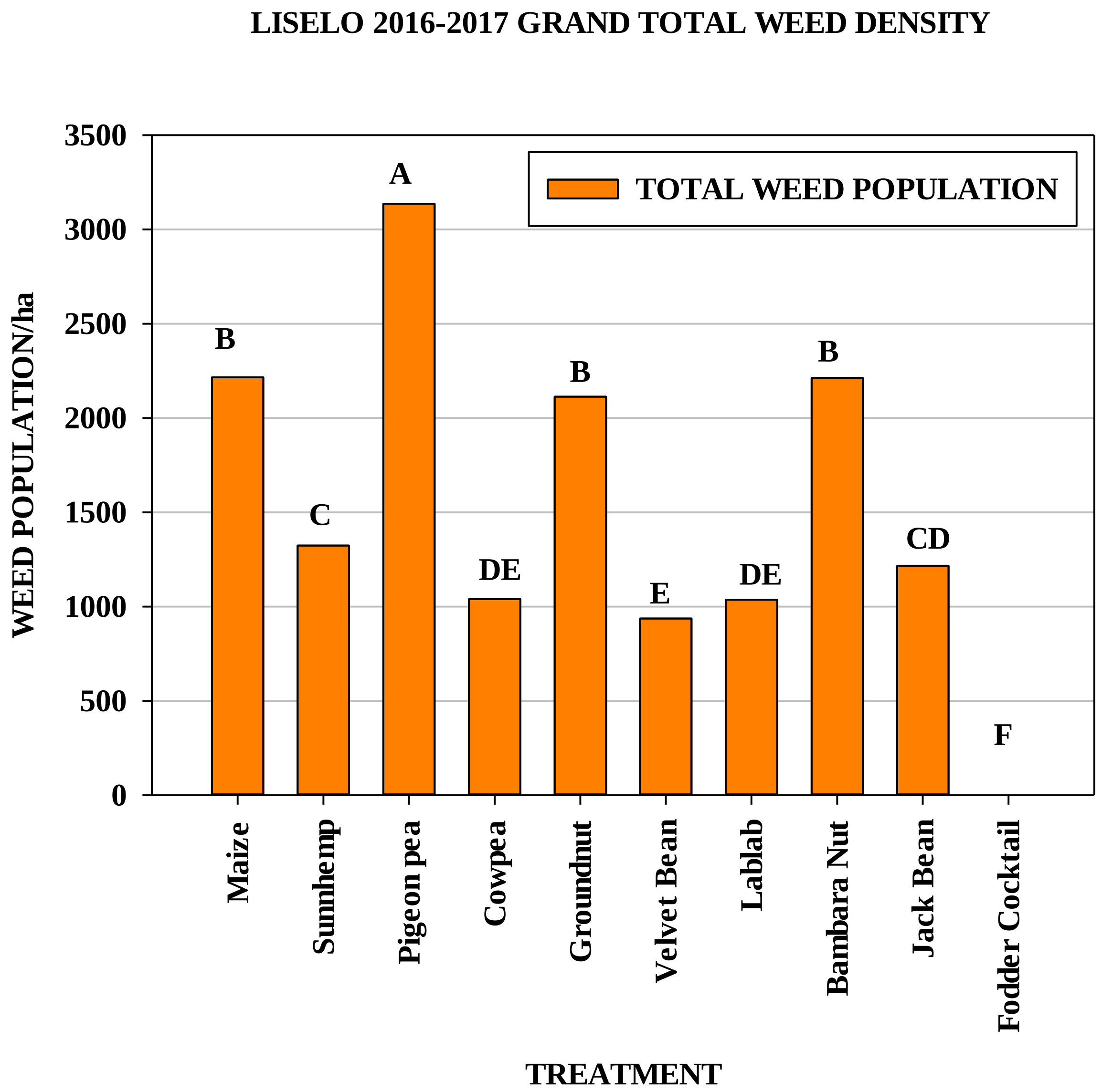


Figure 4. Effect of different Pearl millet-crop rotations on total weed density at MITC during the second season of data collection

Different columns represent different effects of different GMCC ($P < 0.05$) on total weed density in the second crop (2016/2017).

LISELO 2017-2018 GRAND TOTAL WEED DENSITY

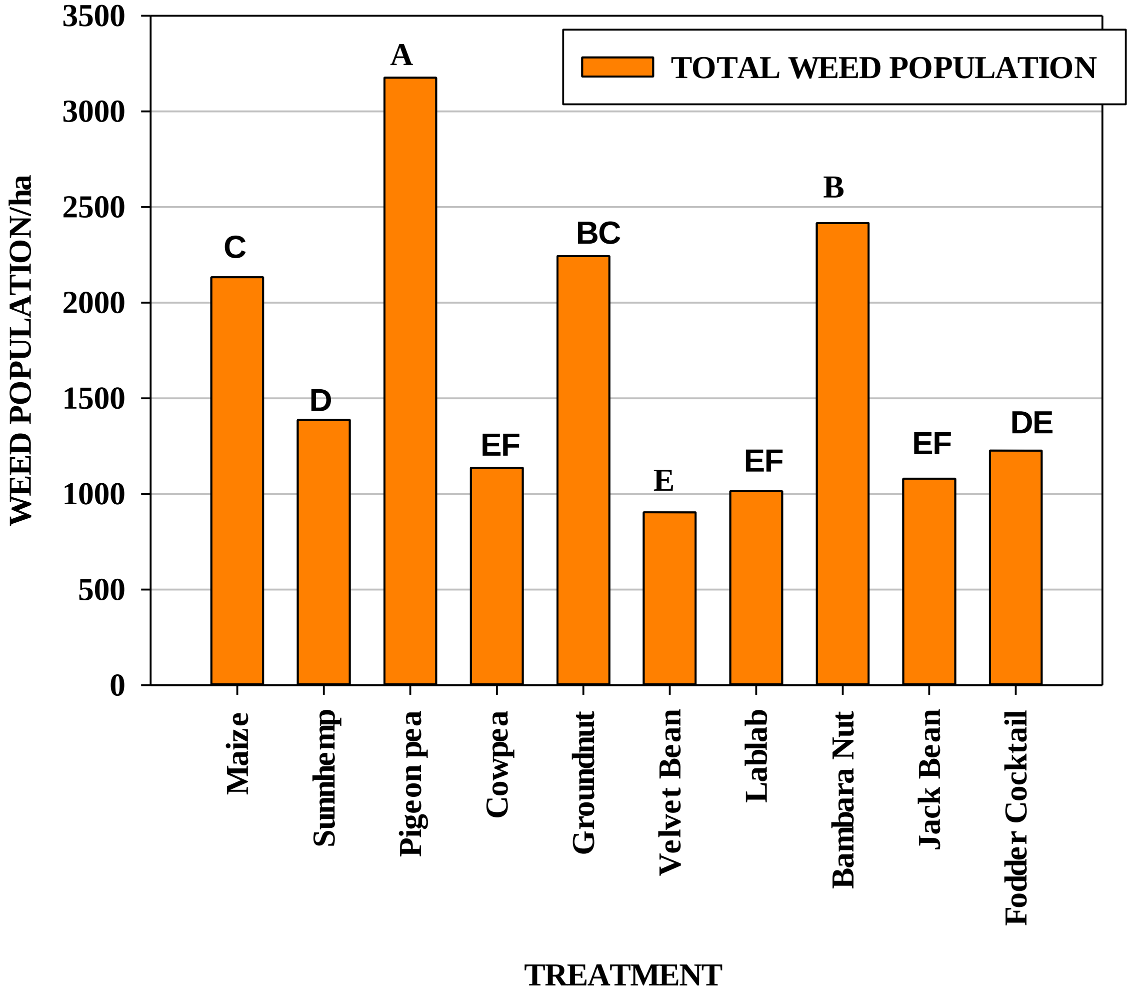


Figure 5. Effect of different maize- cover crop rotations on total weed density in the LRS during the second season of data collection

Different columns represent different effects of different GMCC ($P < 0.05$) on total weed density in the second crop (2017/2018).

Table 1. Linear mixed models (spliced models) computes total weed density, total weed biomass, weed species diversity, weed species homogeneity, impact of other crop rotations (treatment method) and position of Pearl millet and maize coatings on species richness results at MITC and LRS in both seasons

Total Weed Density				Total Weed Biomass		Weed species Diversity		Weed Species Evenness		Weed Species Richness	
Source	DF	F	P	F	P	F	P	F	P	F	P
Site	1	7.81	0.006	8.31	0.01	30.59	<0.001	19.7	<0.001	85.02	<0.001
Treatment	9	3.18	0.002	4.21	0.04	1.59	0.129	0.79	0.628	1.5	0.16
Site*treatment	9	2.32	0.02	2.98	0.03	0.58	0.812	0.67	0.733	0.93	0.501

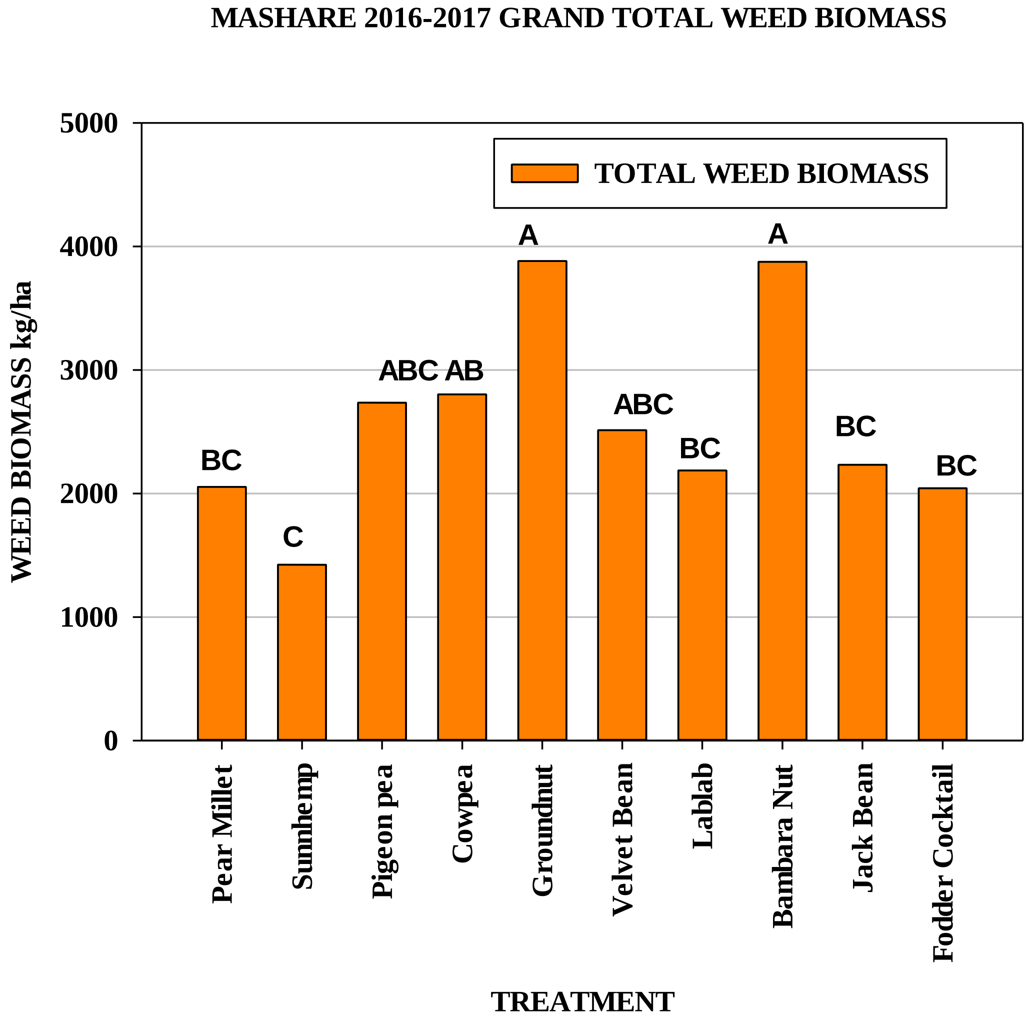


Figure 6. Effect of different Pearl millet- cover crop rotations on total weed biomass at MITC during the first season of data collection

Figure 7-10 below show the effects of different maize and Pearl millet cover crop rotations on weed species richness at MITC and LRS over the two seasons of data collection. The different columns represent different effects of different rotations ($P < 0.05$) on weed species richness at two sites and over a period of two seasons. The other figure (Figure 11) shows the dominant weed species at MITC and LRS in all the treatments for both seasons.

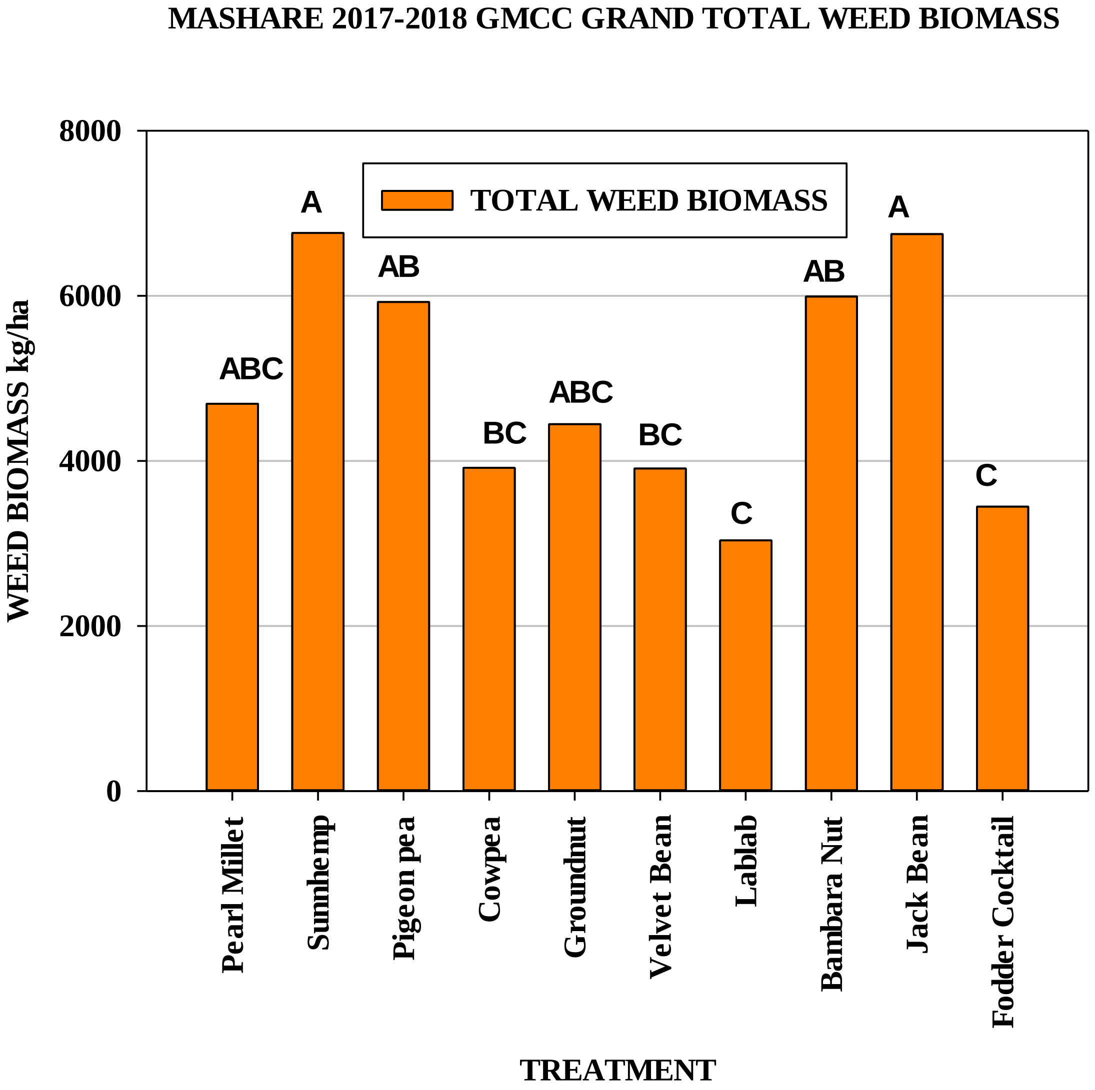


Figure 7. Effect of different Pearl millet-cover crop rotations on total weed biomass at MITC during the second season of data collection

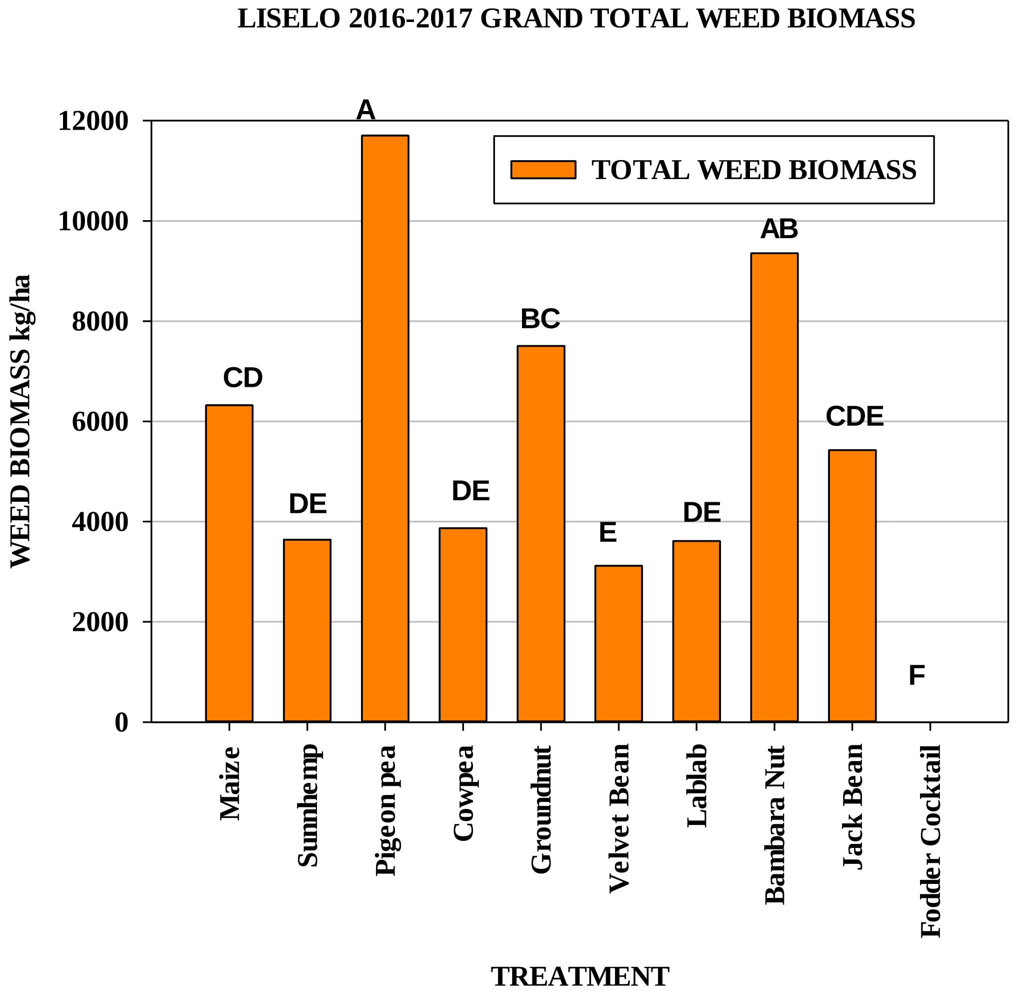


Figure 8. Effect of different maize-cover crop rotations on total weed biomass in the LRS during the first season of data collection

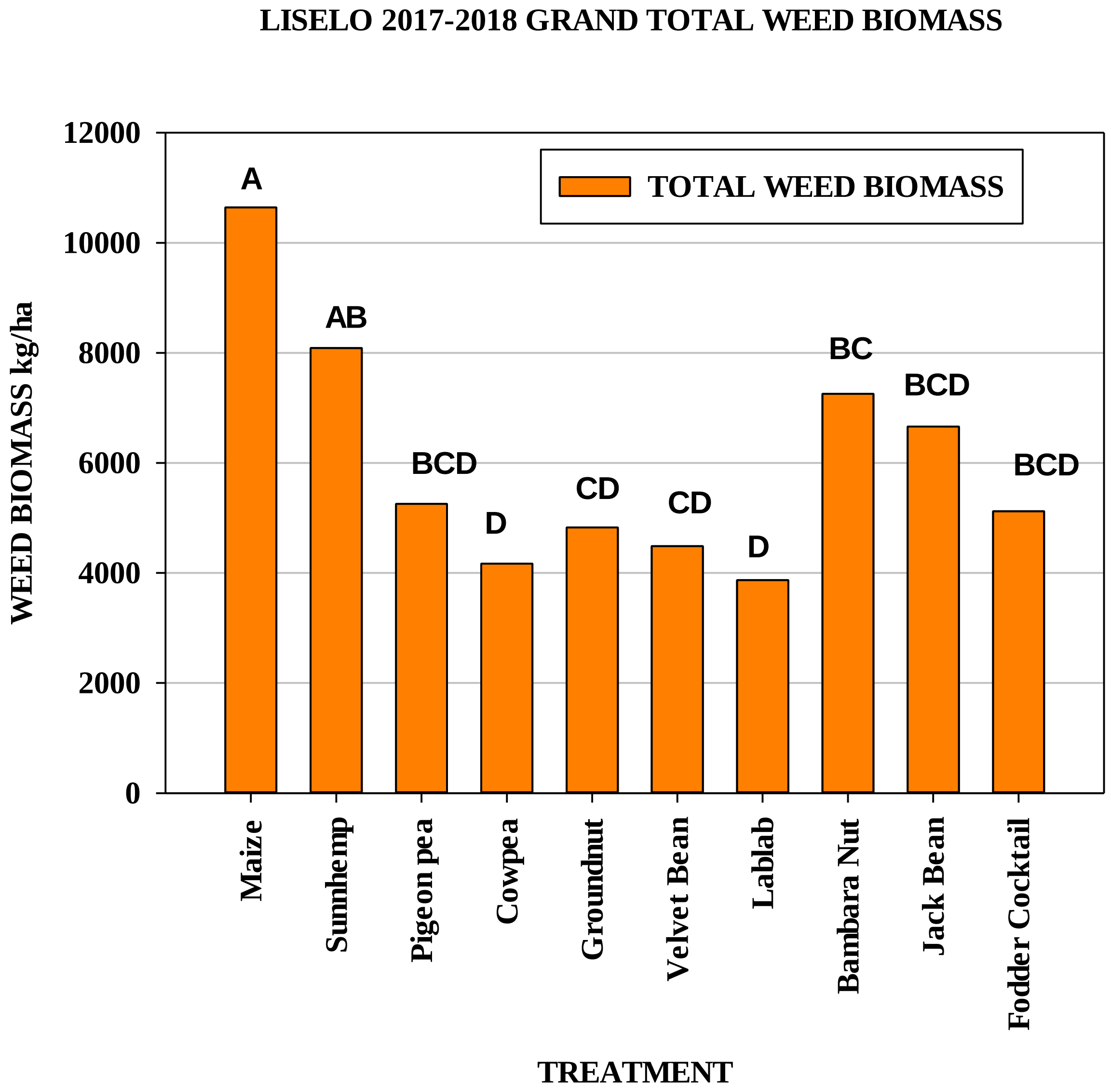


Figure 9. Effect of different maize-cover crop rotations on total weed biomass in the LRS during the second season of data collection

Table 2. Effect of different Pearl millet-cover crop rotations and maize-cover crop rotation on weed species diversity (Shannon index "H") and weed species homogeneity (Shannon index "H" E") at MITC and LRS

	MITC		LRS					
	Weed Diversity Species Weed Species Evenness		Weed Diversity Species Weed Species Evenness					
Treatment	Season 1 Season2	Season 1 Season 2	Season 1 Season 2	Season 1Season 2				
Pearl Millet after pearl millet (Mono-cropping)	1.42 2.25	0.30 0.49						
Maize after maize			1.25 1.27	0.25 0.27				
Millet after Sunnhemp	1.01 1.90	0.23 0.46						
Maize after Sunnhemp			0.92 1.2	0.19 0.27				
Pearl Millet after Bambaranut	1.33 1.73	0.28 0.37						
Maize after Bambara			1.27 1.57	0.28 0.33				
Millet after groundnut	1.20 1.86	0.27 0.46						
Maize after groundnut			1.10 1.24	0.22 0.29				
Millet after velvet bean	1.31 1.79	0.30 0.37						
Maize after velvet bean			1.19 1.39	0.31 0.33				
Millet after pigeon pea	1.56 2.14	0.37 0.38						
Maize after pigeon pea			1.27 1.52	0.29 0.35				
Millet after lablab	1.20 1.72	0.26 0.40						
Maize after lablab			1.09 1.21	0.27 0.24				
Millet after cowpea	1.44 1.34	0.27 0.33						
Maize after cowpea			0.91 1.39	0.20 0.33				
Millet after cowpea	1.33 1.78	0.33 0.47						
Maize after cowpea			0.58 1.49	0.12 0.36				
Pearl Millet after fodder cocktail	1.25 1.58	0.24 0.37						
Maize after fodder cocktail			1.19 1.17	0.25 0.28				
P-value SED	NS NS 0.38 0.33	NS NS 0.071 0.09	NS NS 0.23 0.23	NS NS 0.08 0.07				

5. Discussion

5.1 Total Density of Weeds

Weed density results were collected approximately at 30, 60 and 90 days after planting the second season of GMCC. At MITC, Pearl millet was planted and at LRS maize was planted. As it can be shown from the results of the linear mixed model ($P < 0.05$) (Table 1), two plots, different crop rotations of Pearl millet and maize cover crops, and their interactions were significantly different between MITC and LRS. Both maize and Pearl millet rotations had significant effects on total weed density ($p < 0.05$) at both locations. Furthermore, at MITC, Pearl millet-pigeon pea and Pearl millet-groundnut rotations had the highest total weed density (3,500 weeds/ha) and (3,100 weeds/ha), respectively (Figure 2).

Pigeon pea rotations with Pearl millet and Pearl millet (Mono-cropping), fodder cocktail and rotations with Pearl millet and red sunn hemp had the highest weed densities in the first season (Fig 2). There have been mixed reactions to the amount of weed observed in the second season in the same location. Interchanging Pearl millet and fodder cocktail in the second season resulted in a minor decrease, nevertheless, the other treatments indicated larger decreases. The largest increase in total weed density, up to 54.7%, was observed when Pearl millet was rotated with pigeon pea (i.e., from 3500 ha in 2016-2017 to 6400 ha in 2017-2018, a decrease in maximum weed density) (Fig. 7). The smallest increase of 61% was seen in the Lablab treatment with Pearl millet (i.e. from 1300 weeds in 2016-2017 to 2100 weeds/ha^{-1} in the 2017-2018 growing season). This treatment resulted in the lowest weeds in the second season (Fig. 3).

Maize rotation at LRS had a significant ($P < 0.05$) effect on overall weed density in season 1 (Table 3). Straw grass (*Hyparr heniahirta*) and wandering yew (*Tradescantia fluminensis*) were the dominant weed species at LRS in both seasons. Maize rotations with pigeon pea and bambara nut had the highest total weed densities in season 1, with 3200 ha^{-1} and 2450 weed ha^{-1}, in that order (Fig. 8). Maize rotated with velvet bean and lablab rotated with maize and cowpea showed relatively low overall weed densities in the first season (2016/2017): 900 weeds per ha, 1100 weeds ha^{-1} and 1100 weeds ha^{-1}, respectively (Fig 4). There have been diverse reactions to the amount of weed seen in the second season in the same location. Pearl millet with jack bean rotation decreased considerably, while other treatments increased significantly. The highest weed density was detected in the Pearl millet-pigeon pea rotation at an acreage of 3200 weeds/ha^{-1} and this treatment had the highest weed density in season 2 (Fig. 5). The lowest weed density at 800 ha^{-1} was witnessed in the Pearl millet-velvet bean rotation, which was the lowest weed density in season 2 (Fig. 5).

5.2 Total Weed Biomass

As displayed by the results of the mixed linear model ($P < 0.05$) (Table 1), the two sites, with different crop rotations of Pearl millet and maize cover and their interactions, had a significant effect on the total weed density during the season. Generally, total weed biomass was reduced at both sites from crop 1 to crop 2 (Figures 5, 6, 7, 8 and 9). Different crop rotations did not significantly affect the total weed biomass at the two sites over two seasons ($P > 0.05$).

5.3 Weed Species Composition (Weed Species Diversity, Evenness and Richness)

There were significant differences in the diversity, uniformity and richness of weeds across both seasons, as illustrated by the linear mixed model output at both sites ($P < 0.001$ for all) (Table 1). There was a significant difference in weed species composition between the two sites. The different Pearl millet and maize rotations did not significantly affect the diversity and homogeneity of weed species at both sites in all seasons ($P > 0.05$). Nonetheless, species diversity and uniformity increased from season 1 to season 2 at both locations (Table 2). At MITC, different Pearl millet-cover crop rotations had a significant effect on species richness in season 2 only ($P < 0.05$). Amongst the 18 weed species ha^{-1}, the highest number of weed species was observed in the maize-pigeon pea rotation treatment, while the lowest number of weed species was observed in the maize-black sunn hemp, maize-cowpea corn and maize-jack bean rotations (Figure 9). At LRS, maize-cover crop rotation had no significant effect on the number of weed species present in both seasons (Figures 9 and 10).

5.4 Total Weed Biomass

The decline in weed biomass at both sites might be attributed to a decrease in weed density. In addition, different rotations across all seasons in both sites did not significantly affect weed biomass, perhaps due to the effects of hand hoeing (Mhlanga et al., 2017). Weeds have different biomass production capacities. Since weeding is done at the same time intervals for all treatments, it permitted for weeds at this site to grow to the same height and weight before weeding; therefore, there were no significant differences observed on the weights of the weeds (Muoni *et al.*, 2013).

5.5 Weed Composition (Diversity, Evenness And Richness of Weed Species)

Weed species diversity, evenness, and richness will differ in every site's seed bank. Reactions in terms of diversity, uniformity and abundance are different for each community of weed species. Mall and Singh (2014) recommended that differences in weed densities observed at different sites may be due to different seed banks established at those sites. According to (Teasdale and Mohler, 1993), crop residue retention, irrespective of its type, changes the microenvironment surrounding weed seed banks by promoting or inhibiting weed seed emergence.

Stevenson et al. (1997) further acknowledged that increases in weed diversity and uniformity are due to decreases in the numbers of some dominant weed species. Furthermore, (Teasdale and Mohler, 1993) stated that there are weed species that require more light to undergo phytochrome-mediated germination prior to germination, and that these species are less likely to survive in the presence of cover crops. When Pearl millet and maize are introduced on the second crop, it is expected that coverage will be reduced and these weeds will develop. Weed species such as *Trianthema portulacastrum (L.)* Purslane emerged in the system over time, reducing the dominance of some weed species. This has increased diversity, unity and richness. These weeds also contributed to increasing species richness at both sites. The increase was most prominent in the Pearl millet after Pearl millet, maize after maize, as well as in the maize after pigeon pea rotation treatments due to the nature of the cover crop residue, which leave more internal spaces allowing more access of light, by the weed seeds. A similar trend of results was also reported by (Ulber, L., Steinmann, H.-H., Klimek, S., Isselstein, J, 2009), where the number of weeds in the ecological crop rotation system increased over time.

6. Conclusion

Changing from conventional agriculture to conservation agriculture often results in increased weed pressure, leading to an additional labor problem for smallholder maize and Pearl millet farmers in northern Namibia. This study intended to fill a knowledge gap by evaluating the effectiveness of different leguminous and non-leguminous GMCC/ fodder crops, grown in rotation with pearl millet and maize, in guaranteeing adequate residue cover and significant fodder supply and weed suppression. No single cover crop was observed to be ideal for all the areas investigated, some cover crops outperformed others.

The study highlighted that rotations combined with well-timed weeding reduce weed densities over a given period of time. Equally important, an increase in weed species diversity indicated that rotations are capable of reducing numbers of dominant weeds to levels of the other non-dominant weeds and this reduces the existence of a few problematic weeds resulting into a less intensive weeding plan. Moreover, rotations have different effects on the components of weed diversity and eventually leading to reduced weed populations. A reduction in the number of weeds was also realized in the continuous Pearl millet and maize plots, suggesting that residue retention combined with timely weeding can also reduce weeds in a cropping system even if a farmer cannot practice rotations.

Weed control through cover crop rotation is predominantly based on the cover crop's ability to suppress weeds. In addition, cover crops, either as live cover crops or remnants, use different weed control mechanisms, even though live cover crops are much more effective. The response to the number of weeds is determined by the type of cover crops. Furthermore, weed control in the second crop (the season after the cover crop) depends mainly on the quantity and nature of different cover crop residues. Residues of jackbean, velvet beans and lablab produced nitrates during decomposition, promoting the emergence of some weed species, leading to an increase in weed populations in the crop. Moreover, black sunhemp had an allergenic effect on some weed species such as *Amaranthus hybridus* L., which contributed to worrisome weed numbers observed in the second season which could explain the large decrease in weed density reduction with maize-legume treatment perhaps due to higher biomass production in cover crops, resulting in higher cover rates.

Acknowledgments

I would like to extend my deepest gratitude to my academic supervisors, Prof. Fisseha Itanna and Dr. Awala Simon Kamwele, for their invaluable guidance, mentorship, and generosity with their time, which were instrumental in shaping this work and nurturing my potential. I am especially grateful to Dr. Alexander Schöning for inviting me to be a part of the ACN Project and for his unwavering support throughout this study. My heartfelt thanks go to Prof. Fisseha Itanna, whose early recognition of my potential motivated me to undertake this research. His support from organizing funding for my tuition to closely reviewing this work has been invaluable. His constructive feedback and insightful contributions have greatly enriched this study. I am forever indebted to him for his commitment to excellence, which helped me refine this work into its final form. I would also like to thank Dr. Christian Thierfelder for his energy, enthusiasm, and encouragement, and for his thoughtful guidance throughout the research process. My appreciation goes to Mrs. Margret Bartels for her technical and logistical support, which was essential to the success of this study. I am grateful to the Ministry of Agriculture, Water and Reform in Namibia for recognizing the value of my research. To my grandmother and the entire Amakali family, whose prayers and unwavering support sustained me through challenging times.

Author's contributions

Simon Amakali Simon and Prof. Fisseha Itanna were responsible for the study design and its subsequent revisions. Simon Amakali Simon carried out the data collection and prepared the initial manuscript draft, which was then revised by Prof. Fisseha Itanna. Both authors reviewed and approved the final version of the manuscript. No special agreements regarding authorship were made, and both authors contributed equally to the study.

Funding

This study was funded by GIZ under the Adaptation to Climate Change in Namibia. Project number: ACN20161212-2.

Competing interests

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.

Informed consent

Obtained.

Ethics approval

The Publication Ethics Committee of the Macrothink Institute.

The journal's policies adhere to the Core Practices established by the Committee on Publication Ethics (COPE).

Provenance and peer review

Not commissioned; externally double-blind peer reviewed.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data sharing statement

No additional data are available.

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