ORIGINAL RESEARCH ARTICLE

Pigeon Pea: a companion crop for boosting maize growth and striga control in push-pull farming systems in Western Kenya

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Abstract

Crop diversification is one of the strategies for sustainable intensification that hold promise for reducing poverty and ending hunger in communities that derive livelihood from farming. Intensification of smallholder systems require identification of companion crops that are amenable to intercropping within existing crop and farming systems, add economic/marketable value, are a source of food, and provide ecosystem services not currently provided in existing crop or farming systems. Push-pull is a companion cropping system that involves intercropping cereal crops with forage legumes in the (e.g. Desmodium), and planting a forage grass (e.g. Brachiaria) around this intercrop to control stem borer, suppress witch weed (striga) in maize-based systems. This study evaluated the performance of push-pull system when further intensified with *Cajanas cajan* (pigeon pea). Four treatments were set up on farmers' plots in Kisumu, Siaya and Vihiga counties during the long and short rain seasons in 2021, 2022 and 2023: (1) conventional push-pull, (2) push-pull with (pigeon pea), (3) maize and pigeon pea, and (4) maize mono-crop. Crop growth and striga weed density were monitored in 20×10 m plots demarcated in each treatment during the growing season. Data on maize growth, number and vigour of striga weed were recorded on all plants within sub-plots measuring 2x2 m for four seasons. Results show that integration with pigeon pea further suppresses striga weed and does not affect growth and yield of maize. Pigeon pea could be a potential alternative crop for weed management in smallholder farming systems, where it can serve as a source of firewood and fodder.

Key words: Crop diversification, intercropping, sustainable intensification, witch weed

1.0 Introduction

The target to achieve global Zero hunger by 2030 is ambitious and requires strategies that improve food production and distribution systems as well as creation of social protection systems for farmers. Increasing food production can be achieved through sustainable agricultural practices (Kuyah et al., 2021). This is widely achieved by adoption of practices that build soil fertility and prevent soil erosion, increase carbon in the soil, enhance biodiversity, conserve water, increase resilience to extreme weather and avoid pollution of air and water (Brempong et al., 2023). Sustainable intensification practices are commonly practiced by smallholder farmers in Africa, who produce on small parcels (<2ha) and are faced by several

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challenges due to limited resources, improper infrastructure, lack of funding, gender biases, or other socioeconomic factors (Nyambo et al., 2022). In Kenya for instance, most smallholder farmers face the pressure to cultivate all crops for subsistence and sale from this same portion of land. Productivity on these small plots continues to dwindle because of soil degradation, emerging from intensive cultivation, mono cropping and lack of proper use of fertilizers (Dhillon & Moncur, 2023). The effects of climate change worsen the situation by contributing to further soil degradation, increased pests and diseases incidents and unpredictable precipitation patterns (Kimathi et al., 2023). This therefore means crop production must shift from conventional to suitable agro-ecological approaches that are adaptable for the current climate variabilities.

Cereals and legumes are the main food crop combinations with multiple benefits (Kermah et al., 2017). Maize (*Zea mays*) is the leading cereal crop grown in Kenya, currently grown on about 2.196 million hectares (Njeru et al., 2022) and found in almost all farming systems in Kenya i.e. maize mixed, agro-pastoral, highland perennial, root and tuber crop, cereal-root crop mixed, tree crop systems, irrigated, perennial mixed, urban and peri-urban systems (Dixon et al., 2019). Sorghum (*Sorghum bicolor*) and millets are also found in the region. Maize, sorghum and millets are commonly integrated with legumes, vegetables, tubers, fodder crops, fruit trees and shrubs, cash crops and oil crops (Buleti et al., 2023). The mode of crop integration is farm and region specific depending on the size of the farm and motivations of the farmer majorly income, subsistence, pest management or soil fertility improvement. Crop integration in western Kenya comprises of intercropping, crop rotation, agroforestry, mixed crop and livestock and kitchen gardens (Buleti et al., 2023); owing to the nature of small portions of land intercropping is a priority strategy as it attracts many benefits. Intercropping has previously been reported to improve soil fertility, reduce the risk of crop failure and have variable effects on pests and weeds, and crop growth, the study seeks to find out effect of intercropping pigeon pea for weed suppression and growth in smallholder farming systems.

Maize is the main staple and largely produced cereal in western Kenya (Ngonga et al., 2024) compared to sorghum and millets, yet its productivity continues to dwindle down due to poor soil fertility and effects of agricultural pests (e.g. maize stalk borer and fall armyworm) and striga weed (Njeru et al., 2022). Pest such as maize stalk borer can cause 20-40 % crop damage during cultivation and 30-90% yield losses post-harvest and during storage. Fall armyworm was recently declared a national major pest in Kenya. Crop losses due to fall armyworm are estimated to be 1 million tons per year in maize (De Groote et al., 2020). Striga weed leads to stunted growth and reduced crop yield (Wanda et al., 2019), and is acknowledged as the most serious of the challenges facing maize productivity in Kenya (Hailu et al., 2018). *Striga hermonthica* Benth is the most common species of striga in East Africa causing 100% yield losses in maize production when not managed (Midega et al., 2017). Striga competes with the host plant for nutrients and releases toxins that cause stunted growth and low grain yield. Effects of striga on crops vary depending on striga count, host crop species and genotype, current farming systems, soil nutritional status and rainfall patterns (Hailu et al., 2018).

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Several interventions are applied in controlling striga, including use of resistant crop varieties, herbicides, biopesticides, intercropping of cereals and legumes, crop rotation, use of trap crops that stimulate suicidal germination, application of manure and nitrogen fertilizer and push-pull technology (Kamara et al., 2020; Midega et al., 2017; Sibhatu, 2016). So far, no single management strategy has achieved complete striga elimination (Kanampiu et al., 2018). However, push-pull technology ranks highest in combating the tripled constraints to maize production. Push-pull system involves use of trap plants *Pennisetum purpureum* or Brachiaria cv *Mulato* (napier or brachiaria) (pull) which attract pests (stem borer) and repellants (*Desmodium* species) which repels the stem borer and aborts striga germination at the same time (Midega et al., 2017). Push-pull has also demonstrated ability to increase biomass and eventually yield of maize and better livelihoods for the adopters. However, application of push-pull technology has been limited to small plots and it is hindered by its labor intensiveness and the lack of diversity of food crops. The main components of push-pull i.e. *Desmodium* and *Brachiaria* are not edible, thus the need for other crops to be integrated within the system for nutritional security (Chidawanyika et al., 2023). In a recent needs assessment, participants proposed intercropping and crop rotation as options for further intensification of push-pull technology (Buleti et al., 2023). Crop rotation is constrained by the nature of small land sizes in western Kenya, suggesting intercropping as a suitable option for crop diversification in stallholder systems.

Pigeon pea was elected from a needs assessment as a candidate crop for further intensification of push-pull technology with potential to meet the need for diversified foods, fodder, firewood and income in western Kenya. However, there is need to determine innovative ways of integrating pigeon pea with limited to no risk of compromising performance of the current push-pull system. Therefore, the objective of this study was to determine the effect of including pigeon pea in push-pull system on the crop growth of maize and striga weed density and partly maize yield. The results may present opportunities for modifying the push-pull in order to improve its functionality, and customize it for the small-scale farmers.

2.0 Materials and Methods

2.1 Study site

The study was carried out in Kisumu, Siaya, and Vihiga counties in western Kenya. Kisumu study site was characterized by lake sediments, commonly with sand and clay soils and red-loamy soils. Siaya site was characterized by dry spells, flooding, and heat stress. Soil fertility in the study region varies, ranging from low in Vihiga to moderate in Siaya and Kisumu and generally non-responsive to mineral fertilization (Roobroeck et al., 2021). The Kisumu site was located at latitude 0°20'-0°50'S, longitude 33°20'-35°20'E, with an elevation range of 1134-1400 m; Siaya site was located at latitude 0°00-0°06’S, longitude 34°16’-34°23’E, with an elevation range of 1200-1500 m; Vihiga was located at latitude 0°00'-0°30'N, longitude 34°40'E-34°43'E, with an elevation range of 1300-1900 m (Buleti et al., 2023).

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Experimental fields were located in six villages: Lela and Kosio in Kisumu, Komonge in Siaya and Emusutswi, Emanyinya and Ebukhaya in Vihiga (Figure 1). These counties represent areas of contrasting socio-ecological conditions. The average farm size per person is 1 ha, 1.5 ha and 0.41 ha in Kisumu, Siaya and Vihiga respectively (*Vihiga County Integrated Development Plan 2018-2022*, 2018). Population in these study counties include; 1,155,574 people in Kisumu, with approximately, 554 people/km² County government of Kisumu, (2018), Siaya 993,183 people, with 393 people/km² while; Vihiga is densely populated with 590,013 people, 1,046 people/km² (County government of Siaya, 2018). Rainfall in the study region ranges between 1200 to 2763 mm per annum in Vihiga, 1000 and 1800 mm in Kisumu, and is variable in Siaya: the northern part of Siaya receives 1750 mm and above while the Southern area receives a range of 1000-1250 mm (County government of Siaya, 2013).

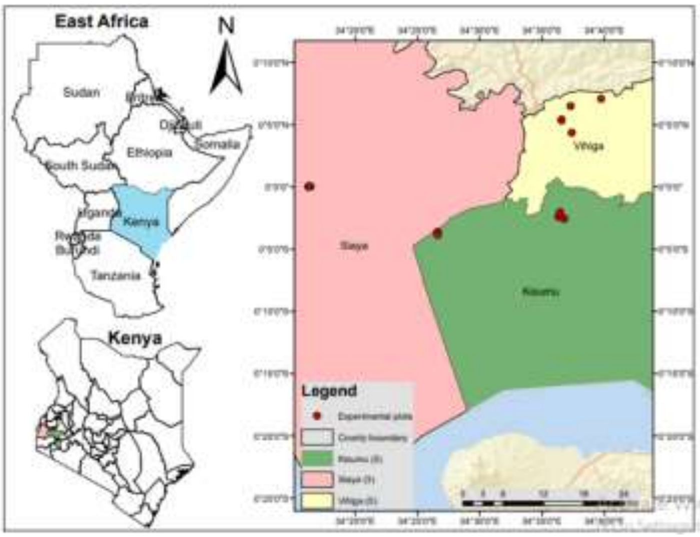

Figure 1. Location of test-fields in Kisumu, Siaya, Vihiga counties in western Kenya.

2.2 Farm selection

Participatory research involving focus group discussions (9 groups of farmers and 1 group of field technicians), interviews with key informants (n=25) and validation of the results with the farmers (n=99) was carried out to determine suitable intensification practices for integration in push-pull in Kisumu, Siaya and Vihiga prior to establishment of experimental fields. In this participatory research, respondents highlighted their aspirations such as need for further intensification of push-pull technology to diversify their productivity and meet requirement for firewood, fodder and food. Pigeon pea (*Cajanas cajan*) emerged as the most suitable crop for further intensification in push-pull to meet the three needs. Farms were visited to confirm conformity to selection criteria. From these participants the farms which met the criteria of having a history of striga, willingness of the farmer to allow use of the farm, poor soil fertility and proximity to the road for demonstration were selected for field experiments. A total of 15 test-fields were established on 25 farms (10 in Kisumu, 7 in Siaya and 8 in Vihiga) to test the effectiveness of the intensified system. The varying number of test-fields was because some

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farms were small and could not accommodate all the treatments. On each farm a selected field was used as a single plot or divided into two or more plots approximately 200 square meters in size per treatment. Where the farm accommodated two of more treatments, a 2 m path was left between the treatments to act as a buffer. The distance between treatments located on different farms was limited to 1 km to minimize variations in microclimate, soil characteristics and social attributes.

2.2 Experimental design

A randomized complete block design comprising of four treatments: (1) conventional push-pull, (2) push-pull with *Cajanas cajan* (pigeon pea), (3) maize and pigeon pea, and (4) maize monocrop was established. The treatments were denoted as MD, MDP, MP and MM respectively. Each treatment was established on approximately 200 square meters. A typical push-pull is a polyculture with maize intercropped with *Desmodium* (push crop) and *Brachiaria* or Napier grass on the boarder of the plot (pull crop). Each farm was considered a replicate. Improved maize variety recommended for the region was planted in all treatments across the seasons: 2021 short rain (season 1SR), 2022 long rain (season 2LR), 2022 short rain (season 3SR), and 2023 long rain (season 4LR). The long duration pigeon pea (MBAAZI II) was planted during the short rain seasons, initially in August 2021 and September 2022. Pigeon pea grow initially slowly as an intercrop, minimizing competition with the maize crop, and only grows rapidly after harvest as a sole crop. In this study, the pigeon pea-maintained crop cover during the dry season and was harvested during planting in the long rain season. The experiment was carried out for four seasons Table 1. Planting was carried out at onset of the rains for 4 seasons (2021 Short rain season, 2022 short and long rain seasons, 2023 long rain season). During the short rains season planting was carried out mid-August (Kisumu and Vihiga) to early September (Siaya) and during the long rain seasons mid-March (Kisumu and Vihiga) and early April in Siaya (Table 1). On average, 10 tons/ha of manure and 60 kg/ha of inorganic fertilizers were applied during planting. These rates represent the quantities commonly used by farmers in the region, although the recommended rates vary depending on the type of fertilizer. Push-pull farms were established accordingly as already described (Ndayisaba et al., 2020). Two maize seeds were planted at 30 cm between plants and 75 cm between rows; In the case of treatments involving pigeon pea, such as maize and pigeon pea the spacing was 75 cm between rows of maize and pigeon pea and 45 cm between pigeon pea plants. 4-5 seeds of pigeon pea were sown per hole due to their poor germination rate and thinning was later done 1 seedling at 3 weeks. Manual weeding was done once at 6 weeks. Top dressing was done using 60 kg/ha calcium ammonium nitrate (CAN) fertiliser when the plant was knee height (60 cm) approximately 6 weeks post planting

Table 1. Planting of maize was done for 4 seasons while pigeon pea for 2 short rain seasons at different times of the season. SR=short rain, LR=long rain

Site county	Season	Planting time for maize	Planting time for pigeon pea
Kisumu	2021 SR/2022SR	Mid-August	Mid-August

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Kisumu	2022 LR/2023LR	Mid-March	
Siaya	2021 SR/2022SR	Early September	Early September
Siaya	2022 LR/2023LR	Early April	
Vihiga	2021 SR/2022SR	Mid-August	Mid-August
Vihiga	2022 LR/2023LR	Mid-March	

2.3 Monitoring growth and striga

A sub plot measuring 2×2 m was randomly selected within the main experimental plot avoiding the border crops to be used for data collection. Plant height, leaf length and leaf width of fully expanded leaves of the same plant were measured as elements of growth. Leaf area was determined from the leaf length and leaf width values. Plant height, leaf length and leaf width were used as indicators of growth for maize plants. Number of maize plants within the plot were counted, and the height of each maize plant measured from the base of the plant to the tip of the plant using a ruler. The growth parameters were taken from the same plants. The number of emerged striga within the same sub-plot measuring 2 by 2m were counted from a radius of 12 cm around the base of each maize plant (Midega et al., 2017). Striga vigour was determined by measuring the striga height for 3 randomly selected striga plants. The data was expressed as the mean number of emerged striga per plant by dividing total striga population by total number of maize plants. The striga number obtained was used to determine the number of striga per square meter by calculating the striga number within a radius of 12cm.

2.4 Measuring yield

At maturity, all the maize plants in the sub plot were harvested from the plot and separated into cobs, and stover and their fresh weight determined using a weighing scale. Ten cobs were randomly selected per sub-plot and weighed. The 10 cobs were samples of all the cobs harvested in a 2m by 2m plot. They were then transported to Jomo Kenyatta to University of Agriculture and Technology in the Sino-Africa Joint Research Centre (SAJOREC) biodiversity laboratory. The dry weight of the samples was determined in the laboratory after oven drying to a constant weight at 70°C. Dry weight of 10 maize cobs, empty cob weight and weight of threshed grain weight were determined. Grain yield was determined using the formula by Ndayisaba et al., (2020).

$$\begin{aligned} &Grain\ Yield\ Kg/ha \\ &\quad = Cob\ fresh\ weight * \frac{Cob\ Sample\ dry\ weight\ with\ grain}{Cob\ Sample\ fresh\ weight\ with\ grains} \\ &\quad * Cob\ sample\ grain\ weight\ after\ threshing * \frac{10000m^2}{4m^2} \end{aligned}$$

2.4 Data analysis

Data were cleaned and checked for normality using Shapiro-Wilk test and box-plots. T-tests were carried out to determine difference in performance of the intensified system in the two treatments with pigeon pea (push-pull+pigeon pea and maize+pigeon pea). Linear models were run for ANOVA to determine the effect of site, treatment and season on growth. Means

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were separated using Tukeys Honestly Significant Differences (HSD) test to assess treatment effects on the different parameters. Analysis was carried out in R software version 3.2.2.

3.0 Results

3.1 Effect of treatment and site on growth

Pigeon pea intensification did not compromise the growth of maize across counties. Push-pull+ pigeon pea enhanced leaf length in Siaya better compared to other counties. Effect of pigeon pea +maize on leaf length was the same across counties. Pigeon pea intensification did not seem to compromise growth across counties generally.

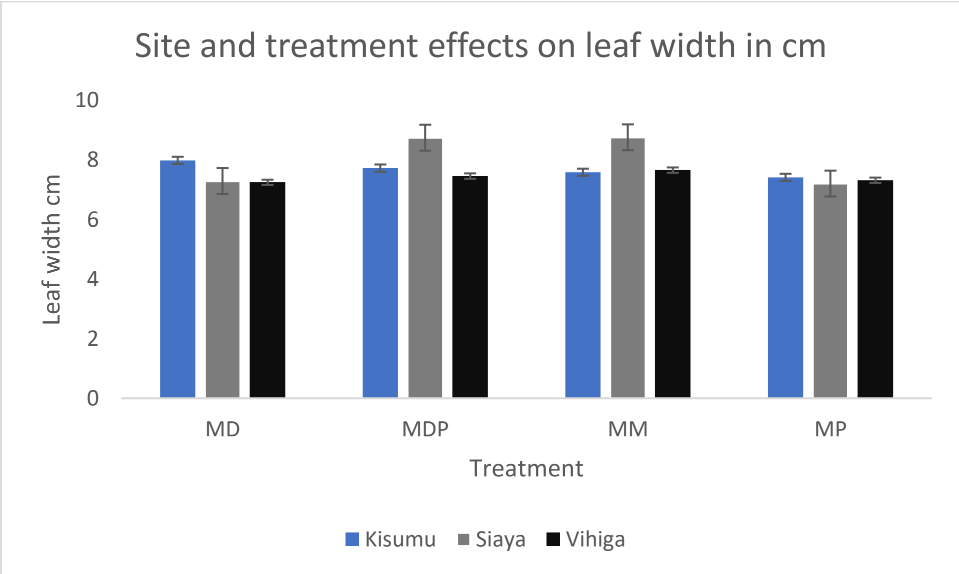

Figure 2. Integration with pigeon pea maintained leaf length across site and treatment MD=push-pull, MDP=push-pull +pigeon pea, MM=Maize monocrop, MP=maize+pigeon pea

Leaf width was highest in Siaya for push-pull +pigeon pea

3.2 Effect of site and treatment on striga weed density and striga vigour

Mean Striga number per plant was highest in Kisumu (3.51) followed by Siaya (2.02) and Vihiga (1.07) respectively and Kisumu and Vihiga were significantly different (Figure 3).

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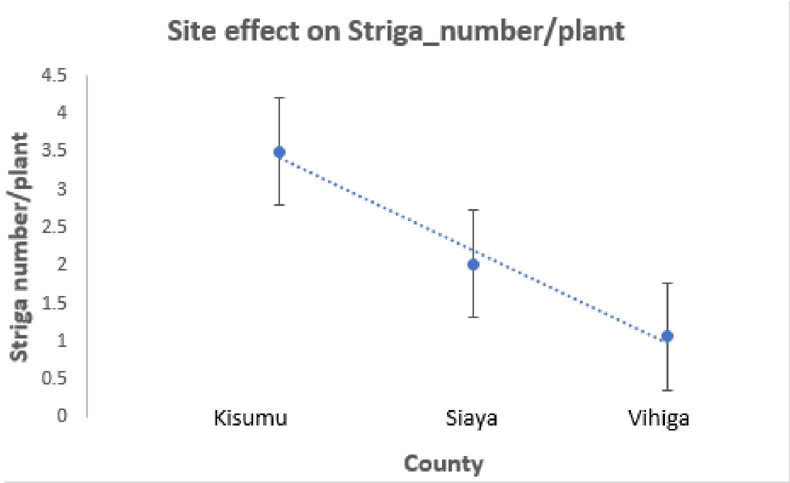

Figure 3. Variation in Striga density across

Across treatments, maize monocrop significantly had the highest mean striga number per plant (3.44), while maize +pigeon pea had the lowest mean striga number per plant (1.87). Push-pull and push-pull+ pigeon pea had (2.28 and 2.13 mean striga number) per plant as shown (Figure 4).

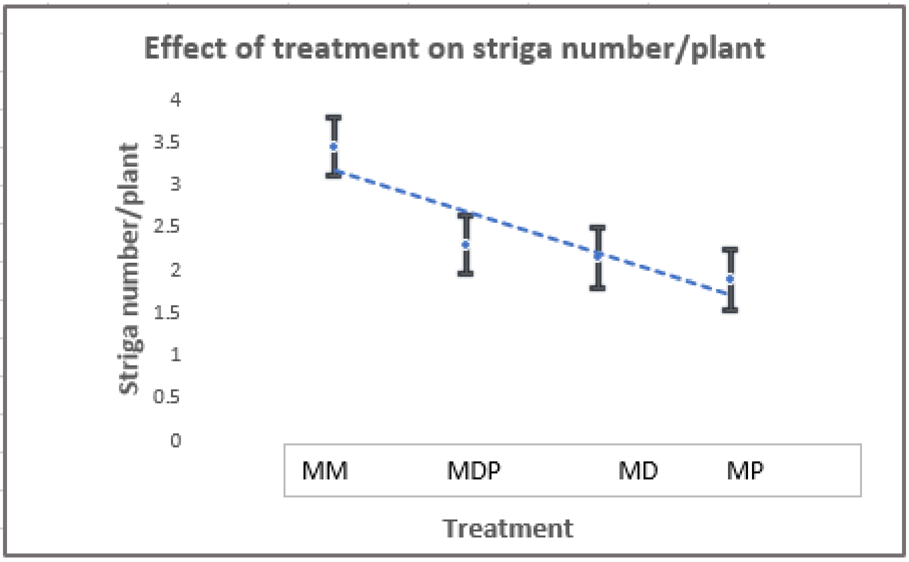

Figure 4. Treatment effect on striga density MM had the highest striga density which was significantly different from MP (MD=push-pull, MDP=push-pull+pigeon pea, MM=maize monocrop, MP=maize+pigeon pea).

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3.3 Interaction effects of site, treatment and season on growth and striga density and vigour

Overall significant differences were noted across site, treatment and season. Significant interaction was observed between treatment and county, and season and treatment for striga number and striga vigour in cm (Table 2).

Table 2. Interaction effect of treatment site and season on striga density

	Striga number				Striga vigour			
	df	sumsq	Fvalue	Pvalue	df	sumsq	Fvalue	pvalue
Treatment	3	661	220.2	P< 0.001	3	1732	577	P<0.001
County	2	2705	1352.4	P< 0.001	2	17739	8869	P<0.001
Season	3	2876	958.8	P< 0.001	3	32571	16285	P<0.001
Treatment: County	6	1737	289.6	P< 0.001	6	1758	293	P<0.01
Treatment: Season	9	2498	277.5	P< 0.001	9	3142	524	P<0.001
Treatment: County×Season	22	3673	167.0	P< 0.001	12	2133	178	P<0.05

Significant interaction was observed for striga number and vigour at p=0.01

A significant interaction was noted between site and treatment. In all treatments, the mean population of striga per treatment and per square meter in Kisumu was double or more than double that of Vihiga. For push-pull, Siaya had the highest striga number compared to Kisumu and Vihiga. Maize+pigeon pea had the lowest striga number per square meter in Vihiga (Table 3).

Table 3. Population of striga per maize plant and per square meter across treatments in Kisumu, Siaya and Vihiga

County	Push-pull	Push-pull+ pigeon pea	Maize monocrop	Maize + pigeon pea	Push-pull	Push-pull+pigeon pea	Maize monocrop	Maize + pigeon pea
	Striga number per plant				Striga number per sqm			
Kisumu	2.37a	2.38a	6.64a	3.1a	52.14b	52.36a	146.08a	68.2a
Siaya	3.19a	1.74ab	0.59b	1.6b	70.18a	38.28ab	12.98c	35.2b
Vihiga	1.42b	1.11b	1.23b	0.6c	31.24a	24.42a	27.06a	13.2b

Letters represent significant levels. Numbers with different letters compared vertically per treatment the table (across treatments) are significantly different at p=0.05. Highest striga was recorded in maize monocrop in Kisumu, lowest striga number was recorded maize+pigeon pea in Vihiga

The effect of season and treatment on striga number was evidently different. In season 1 the striga number were not different across treatments, in season 2LR, maize monocrop had significantly high striga number per plant and per square meter. In season 3SR and 4 LR push-pull and maize monocrop had higher striga incidence compared to push-pull+ pigeon pea. For MDP striga number reduced consistently except for season 3SR (Table 4).

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*Table 4. Seasonal*Treatment interactive effect on population of striga per maize plant per treatment*

Season	Push-pull	Push-pull+pigeon pea	Maize monocrop	Maize + pigeon pea	Push-pull	Push-pull+pigeon pea	Maize monocrop	Maize + pigeon pea
	Striga number per plant				Striga number per sqm			
Season1SR	2.46a	2.96a	3.77a	3.31a	54.12a	65.12a	82.94a	72.82a
Season2LR	1.72bc	2.61b	6.09a	1.01c	37.84bc	57.42b	133.98a	22.22c
Season3SR	8.43a	3.2b	3.29b	3.29b	185.46a	70.4b	72.38b	72.38b
Season4LR	0.47a	0.008b	0.388a	0.038b	10.34a	0.176b	8.536a	0.836b

Season 1SR (2021), Season 2 and 3 represent long and short rain seasons on 2022, Season 4 represents long rains season of 2023. Letters represent significant levels. Numbers with different letters across the table (across seasons) are significantly different at p=0.05

There was a negative correlation between the height of maize crop and the number of Striga plants. Striga number was also significantly different across site and treatment. The strongest negative correlation between the height in maize crop and striga number was recorded in Kisumu, followed by Siaya and Vihiga respectively (R^2=0.45). A negative correlation between striga number per plant and height was observed (Figure 5). This effect was most observed in maize monocrop (Figure 5).

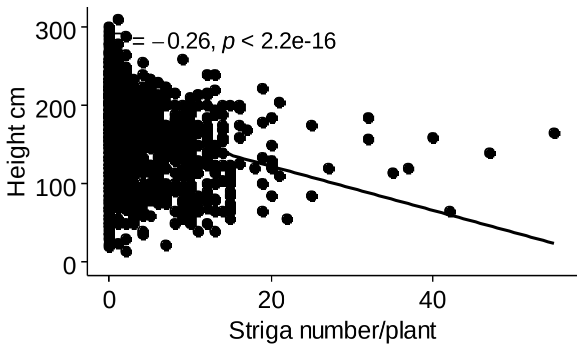

Figure 5. Effect of striga on height of maize across counties.

The highest striga vigour was observed in treatments with push-pull (push-pull treatment and push-pull+ pigeon pea) but was not significantly different at p=0.05 (Figure 6).

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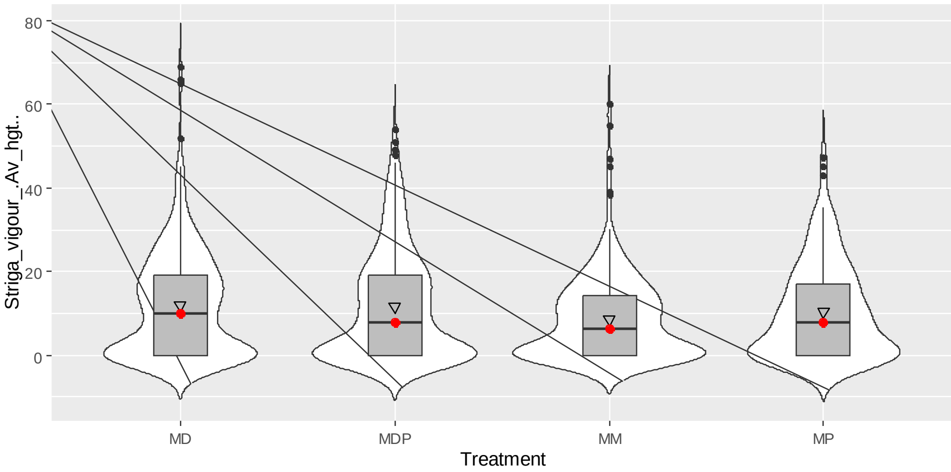

Figure 6. Treatment effect on striga vigour (cm)

Where: MD=push-pull, MDP=push-pull +pigeon pea, MM=Maize monocrop, MP=maize+pigeon pea

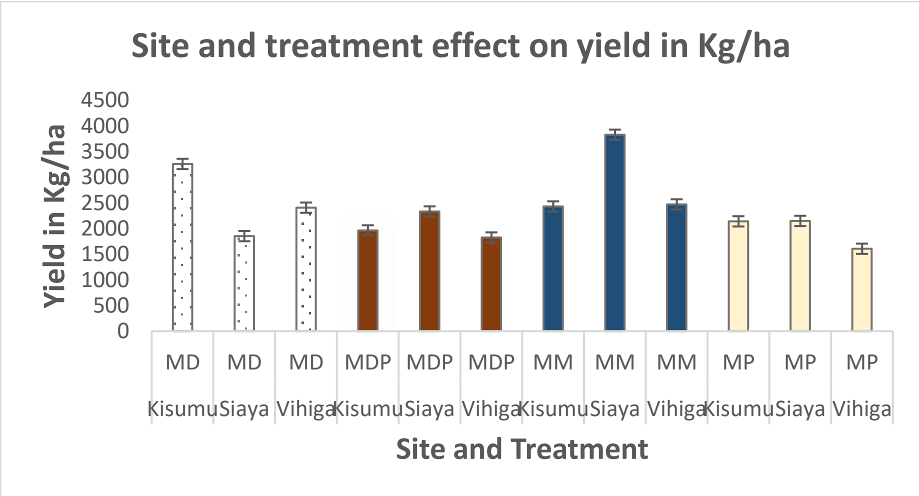

Figure 7. Effect of the site on grain yield across treatment

MD=*push-pull, MDP=push-pull +pigeon pea, MM=Maize mono-crop, MP=maize+pigeon pea*

Generally, the grain yield of maize in MP and MDP were not significantly different across the counties

4.0 Discussion

4.1 Effect of treatment and site on growth

Significant effects and interaction effects among site, season and treatment were observed for growth Figure 2 and Figure 3. The effects are associated but not limited to nexus between pre-existing and emerging soil fertility status and climate variabilities in the study region. The rainfall pattern in parts of Kisumu and Vihiga is highly predictable and reliable compared to

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Siaya. Conventional push-pull system (maize+desmodium) and push-pull+ pigeon pea enhanced growth in Kisumu and Siaya respectively, which had moderate soil fertility. Cropping seasons and cropping systems affect growth of companion crops significantly; intensification of pigeon pea in push-pull resulted in better growth of maize (height and leaf area) in seasons 1 and 3, Similar growth enhancement resulting from intercrops of maize and pigeon pea have been reported though without desmodium (Kermah et al., 2017). Double legume combinations such as pigeon pea and groundnut intercrops with maize, were reported to have enhanced height of maize compared to maize monocrops in Zambia (Mwila et al., 2021), such was the case for maize, pigeon pea and desmodium intercrops in the current study. Pigeon pea intensification enhanced efficiency of push-pull on impacting growth of maize except in season 4LR where height of maize was compromised as a result of excessive rainfall and extreme windy conditions. This excessive windy condition resulted in bending of pigeon pea hence causing a shading effect. Despite this, pigeon pea has proven superior to peanut, and soybean in such growth enhancements (Oswald & Ransom, 2001). Better growth in push-pull +pigeon pea and push-pull could be attributed to soil improvement and conservation strategies such as nitrogen fixation, reduced soil erosion and reduced effect of striga as a result of presence of desmodium and pigeon pea. In this experiment, integration with pigeon pea did not compromise any of the growth parameters. This was consistent for all the counties as well. Despite the differences in precipitation and soil fertility in the regions, performance of maize growth in pigeon pea integrated with push-pull or pigeon pea +maize was maintained.

Striga effect was significantly different across sites (Figure 3). Striga number was highest in Kisumu, followed by Siaya then Vihiga. This could be attributed to the fact that Kisumu has the most suitable characteristics that enhance striga growth and development. It has been reported that elevation of 1000 -1400 m, precipitation range of 1500 –2000 mm, and soil organic content between 3 and 5 g/kg form suitable conditions for striga infestation (Kimathi et al., 2023). The same research also showed that the disparities in temperatures and unpredictable rainfall patterns as the case in Siaya County drastically affect the occurrence of Striga (Kimathi et al., 2023). Current elevation and precipitation status for the 3 counties is : Vihiga, elevation 1300 - 1900 m, and precipitation, 1200 and 2763 mm, Kisumu elevation 1134 - 1400 m and 1000 and 1800 mm, Siaya elevation 1200 - 1500 m and precipitation 1000 - 1250 mm, some parts are 1750 mm. Overall these counties are still at risk of expansion of striga infestation hence the urgency for more integrated strategies of control that are resilient and suitable for the region in the future (Kimathi et al., 2023). To date no single stand-alone strategy has been successfully applied to mitigate Striga effect on maize growth and yield, not even across site and time (Kamara et al., 2020). Research has proven that the best option for reducing impact of striga on households is applying integrated approaches which entail use of improved varieties, good agronomic practices, biological control and intercropping (Sibhatu, 2016).

Intercropping for pest and weed suppression is a common practice in smallholder farming systems (Silberg et al., 2020). Research on application of cereal legume intercropping as a

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management strategy for striga weed has been carried out for desmodium (*Desmodium* species), cowpea (*Vigna unguiculata*), ground nut (Arachis hypogaea L.) and crotalaria (*Crotalaria* species), and it was established that desmodium was the most effective in lowering striga density in maize and sorghum (Midega et al., 2014; Ndayisaba et al., 2020). Similarly, in our study, maize monocrop overall had a significantly high striga infestation compared to intercrop treatments (Figure 5). Differences across counties were observed whereby in Kisumu maize monocrop had the highest striga number, Siaya push-pull had the highest striga and in Vihiga maize+ pigeon pea had the lowest striga numbers. It has been suggested that the efficiency of intercropping is achieved by decreased availability of light for weed growth, some act as trap crops (desmodium and cowpea), causing suicidal striga germination and in other cases through manipulation of microclimate under the canopy which causes inconsistency in striga development (Oswald et al., 2002).

Significant differences were noted for striga vigour across treatments and seasons. Striga vigour in treatments where desmodium was present was noted to be higher compared to where desmodium was absent (maize monocrop and maize+pigeon pea). This could mean that presence of desmodium accelerates the growth of striga but the impact of striga on growth parameters is restricted. Contrary to this, in the current study, striga vigour was noted to be higher in push-pull +pigeon pea and push-pull (Figure 6) though the effect on maize growth (height) was not significant. The results agree with a study which showed that intercropping desmodium with cereals such as millet did not result in striga weed suppression in short and long rain seasons across different sites (Makete et al., 2018). No previous research has been done to demonstrate whether pigeon pea can be intercropped with maize for management of striga weed. However, maize and pigeon pea rotations previously suppressed striga weed density compared to maize rotations with peanut and soybean (Oswald & Ransom, 2001). Crop rotation is however only viable to farmers with large pieces of land which is not the case in the study sites in western Kenya. Intercropping maize with pigeon pea and push-pull led to a significant reduction in striga vigour compared to maize monocrop. The ability of legumes to increase nitrogen fixation could be a contributing factor to the low striga vigour. This is because the soils in western region are characterized by intrinsic low levels of nitrogen and also because farmers in the region apply limited nitrogen-based fertilizers due to limited cash resources. The ability to integrate pigeon pea in farming systems holds a potential for integrated management of striga weed, which is a promising possibility for its management.

Effect of season on striga population was not consistent during the study period but striga number was the lowest in season 4 (long rain season in 2023) compared to the rest. The reduction in striga number can be attributed to the enhanced effectiveness of the intensified system over the seasons and also management practices that were applied by the farmers.

Effectiveness of agro-ecological practices increases over time, because of slow nutrient mining in the soil (Milheiras et al., 2022). Other factors affecting crop performance in intercrops include; farm elevation, management practices such as weeding, fertilizer application and

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fallowing) (Mugi-Ngenga et al., 2021). A previous study showed that striga density was highest during the short rains compared to long rain seasons (Makete et al., 2018). The results are similar to our study showing that the striga population density was higher in season 3SR short rain season and least in season 4LR which is long rain season. During the long rain season the plants are more competitive while during the short rain the drought stress may make the plants vulnerable to weed stress including striga. Interaction effects for striga between site, season and treatment have been reported when comparing climate smart push-pull, 3rd generation push-pull and maize monocrop; in Bondo, Siaya county. Striga population in maize monocrop was not significantly different from the 3rd generation push-pull during long rain seasons (Cheruiyot et al., 2021). Generally, Striga effects on growth of maize can potentially suppress yield.

Major limitation of any intercropping strategy or introduction of companion crops is the reduction of yield. In general willingness to practice intercropping comes at a cost that some farmers may or may not be willing to bear including the costs of reduced yield and labor intensity for striga weed suppression (Silberg et al., 2020). Generally, maize grain yield was not compromised as a result of intensification in all three sites. This implies that farmers of the three counties can employ intensification as (push-pull +pigeon pea) or (maize +pigeon pea) depending on the farmer's preference. This also is an indication that on the same portion of land, the farmer can maintain the yield at the same time increase the productivity in term of reduced striga population and soil fertility improvement by the presence of pigeon pea in the farm which can be utilized for food fodder and firewood. Push-pull is reported to produce 0.3–1.1 t ha^{-1} more maize compared to non-push-pull creating need for adoption of push-pull technology to reduce shock in farming systems (Ndayisaba et al., 2020). Productivity for this study ranged from 1.8 to 2.6 t ha^{-1} which was not significantly different in all treatments but was significantly different for some treatments in specific counties for example maize+desmodium in Kisumu and maize mono-crop in Siaya at p=0.05 (Figure 7). The lack of significant differences could be attributed to reduced planting density as a result of pigeon pea introduction at the same time enhanced growth and improved soil fertility by the pigeon pea. Variation for individual treatment performance was noted for grain yield in maize+desmodium was highest in Kisumu, push-pull +pigeon pea, and maize mono-crop in Siaya and maize + pigeon pea in Siaya and Kisumu counties. This strategy holds promise for increased land equivalent ratio among smallholder farming systems and also an alternative striga management strategy.

5.0 Conclusion

Pigeon pea intercrops with maize can reduce striga populations to below critical levels. Besides the pigeon pea will help to improve the soil fertility and provide alternative services such as fodder and firewood. Pigeon pea is a promising crop with potential as an alternative crop in weed management. Farmers who only have a need for managing striga and less need for fodder can explore this option. The intensification maintains grain yield thus increasing farm utility potential.

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6.1 Conflict of interest

The authors report there are no competing interests to declare

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