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Research Article

A Modified Climate-Smart Push-Pull Technology for the Management of Fall Armyworm (*Spodoptera frugiperda*) in the Semiarid Lands of Kenya

Catherine K. Mumo, Phyllis W. Muturi, and Bernard M. Gichimu

Department of Water and Agricultural Resource Management, University of Embu, P.O. Box 6 60100, Embu, Kenya

Correspondence should be addressed to Catherine K. Mumo; catherinekuthea@gmail.com

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Successful use of push-pull technology in the control of fall armyworm (*Spodoptera frugiperda* Smith) in maize has been limited to areas that receive optimal rainfall as opposed to the semiarid areas. This study sought to determine the viability of a modified push-pull technology designed for drier areas. The technology involved the use of the drought-tolerant *Brachiaria* grass as a potential replacer of Napier grass as a pull crop, alongside drought-tolerant green-leaf *Desmodium* (*Desmodium intortum*) and edible legumes as push crops. The study was conducted in Mbeere South Subcounty in Embu County, Kenya. The experiments were laid out in split plots arranged in a randomized complete block design with three replications. The main plots contained Napier and *Brachiaria* grasses as comparative pull crops while the subplots tested the performance of the drought-tolerant green-leaf *Desmodium* and edible legumes (cowpea, pigeon pea, and green gram) as push crops. A maize monocrop was used as the negative control. The pest dynamics were determined using the area under damage/pest curve (AUDPC). The highest pest incidence was observed in the maize monocrop treatments with AUDPC range of 64–65.5 as compared to the intercrop treatments with AUDPC range of 45–56. The AUDPC for damage severity ranged from 24 to 24.5 in the maize monocrop treatments and 15.5 to 18.7 in the intercrop treatments. These findings implied that the drought-tolerant green-leaf *Desmodium* and the edible legumes can be adopted as effective push crops in the modified push-pull technology. *Brachiaria* and Napier grasses portrayed similar suitability as pull crops implying that the two can be used interchangeably as pull crops based on farmers' preference. This study confirmed the viability of the modified climate-smart push-pull technology in the management of fall armyworm in dryland areas.

1. Introduction

Maize (*Zea mays* L.) is a staple food crop in Kenya and one of the principal food security crops in the sub-Saharan Africa [1]. Green maize forms an important part of food as a nutritious horticultural crop in the world [2]. It is consumed as whole kernels, thus giving more nutritional benefits than most maize-based products, which are prepared using flour from degerminated and decorticated kernels [3]. The green maize is usually the first crop to reach the market after the dry season in many sub-Saharan African countries, thus breaking the hunger gap [4]. Therefore, green maize has greater local economic value [3] and contributes significantly to income generation and food security of many rural households. The sweet taste, soft endosperm, large ears/cob, long shelf life, and good roasting qualities (nonpopping) are the most desirable attributes of green maize [4]. Unfortunately, the production of green maize is threatened by the widespread infestation of the fall armyworm, *Spodoptera frugiperda* Smith (Lepidoptera: *Noctuidae*) [5], a sporadic and long-distant migratory pest that attacks almost 100 plant species [6]. Fall armyworm (FAW) was first detected in Africa in 2016 and has since spread to many countries with devastating economic effects [5]. The larvae feed on young leaf whorls, ears, and tassels causing substantial damage and reduced productivity of the maize crop [7]. The extent of damage depends on the agroecological zone, planting season, cultivar, and agronomic practices [8] among other factors. Management of FAW has been mainly through the use of expensive synthetic insecticides [9] which offer unsatisfactory results and raise environmental and health concerns [10].

The push-pull technology is an integrated pest management technique developed by the International Centre of Insect Physiology (*icipe*) and its partners [11]. The technology involves the use of behaviour-modifying stimuli to manipulate the distribution and abundance of a pest and/or beneficial insects for the management of the pest [12]. In a push-pull strategy, pests are repelled or deterred away (push) from the target crop by stimuli that mask the host apparently and are simultaneously attracted (pull) to the trap crop, leaving the target crop protected [13]. The push plant releases volatile chemicals such as (E)-β-ocimene and (E)-4, 8-dimethyl-1, 3, 7-nonatriene that have repellent properties to the female moths. On the other hand, the pull plant releases chemicals that are more attractive to the moths, thus facilitating their concentration in the pull plant which does not support their reproduction. Several past studies have shown the effectiveness of the push-pull technology for the control of FAW [14, 15]. In the sub-Saharan Africa, the push-pull technology has been recognized among the pathways of sustainable maize intensification [14]. Apart from its effectiveness in managing insect pests in an ecologically friendly and sustainable manner, the push-pull crops provide some high-value livestock fodder [14], thus facilitating milk production and diversifying farmers' income [15]. In addition, the leguminous push crops contribute to soil fertility improvement through nitrogen fixation and also act as cover crops, thus helping in soil moisture conservation, soil erosion control, and weed management [16].

Although the push-pull technology has been effective in management of FAW in maize [10], it has been limited to the use of the silverleaf *Desmodium* (*Desmodium incanum*) as the push crop and Napier grass as the pull crop which is the original or conventional form. To popularize the technology especially in the dry and semiarid areas that are prone to food insecurity, there is a need to test the effectiveness of the technology using more beneficial and climate-smart crops. This study sought to evaluate the viability of a modified climate-smart push-pull technology in dryland areas. The study was guided by the hypothesis that the drought-tolerant Greenleaf *Desmodium* (*Desmodium intortum*) and edible legumes are potentially effective as alternative push crops in the modified climate-smart push-pull technology. Similarly, it was hypothesized that *Brachiaria* grass could be an alternative pull crop. The drought-tolerant edible legumes included cowpea (*Vigna unguiculata*), pigeon pea (*Cajanus cajan*), and green gram (*Vigna radiate*), which constitute the most popular legumes mainly grown and consumed in the semiarid areas in Kenya.

2. Materials and Methods

2.1. Description of the Study Area. The study was conducted in the Catholic Diocesan Farm in Mashamba, Makima Ward, Mbeere South Subcounty, Embu County (Figure 1). The site lies in the lower midland 4 (LM 4) agroecological zone within the coordinates 0° 45′ 19″S and 37° 30′ 36″E at an elevation of 1,048 m above sea level [17]. The area is characterized by semiarid conditions with a mean annual temperature ranging from 21.7°C to 22.5°C and annual rainfall between 780 and 900 mm. The soils are predominantly ferralsols and acrisols [18]. The experiment was conducted in two seasons; the short rain season (mid-October to December) and the long rain season (March to May).

2.2. Experimental Design and Layout. The experiment was laid out in split plots arranged in a randomized complete block design (RCBD) with three replicates. The main plot had *Brachiaria hibrido* cv. Mulato II and Napier grass planted at the borders as pull crops. The subplots comprised of maize crop (DH43 variety) intercropped with climate-smart greenleaf *Desmodium* (*Desmodium intortum*) and drought-tolerant edible legumes, namely, cowpea (*Vigna unguiculata*), pigeon pea (*Cajanus cajan*), and green gram (*Vigna radiata*) as push crops. A monocrop of maize plants was included as a control. The border plants (pull crops), i.e., Napier and *Brachiaria* grasses were planted six weeks before the start of the experiment to ensure that they were fully established by the time the subplots were being established [19]. The subplots measured 5.25 m by 5.25 m with a 1 m alley between the plots. Two maize seeds were planted per hole and thinning was done one week after germination. Weeding was done on the 3rd and 7th week and supplemental irrigation was done after every three weeks after sowing. The experiment relied on natural infestation [20] since the study site lies in the hotspot areas of FAW.

2.3. Data Collection. At crop emergence, plant stand count was determined following the Biologische Bundesanstalt, Bundessortenamt and Chemical Industry (BBCH) scales for each crop [21]. Twelve plants per plot were sampled from the two middle rows and tagged for data collection. Data were collected on maize plant growth, yield, and quality aspects of green maize, as well as the pest dynamics. The maize crop growth data collected included plant height, stem girth, number of leaves per plant, and internode length. Maize yield and quality data included plant ear aspect, cob weight, maize stover weight, cob diameter, number of rows of kernels per cob, and crop harvest index. Plant height was measured from the base to the tip of the plant using a meter rule. Stem diameter was measured at the 4th internode using Vernier callipers [22]. The number of functional leaves per plant was determined by physically counting the green leaves from the sampled plants [23]. The plant ear aspect was assessed on a scale of 1–5, where 1 = clean, uniform, large, and well-filled ears and 5 = ears with undesirable features [24]. The cob diameter was measured at the middle of the maize cob using Vernier callipers [25]. The crop harvest index was calculated as a ratio of cob weight to total maize stover weight [26]. Fall armyworm incidence was calculated as a ratio of the number of infested plants per plot to the total number of infested plants per plot [27]. Fall armyworm severity was determined as visual observation of the foliar

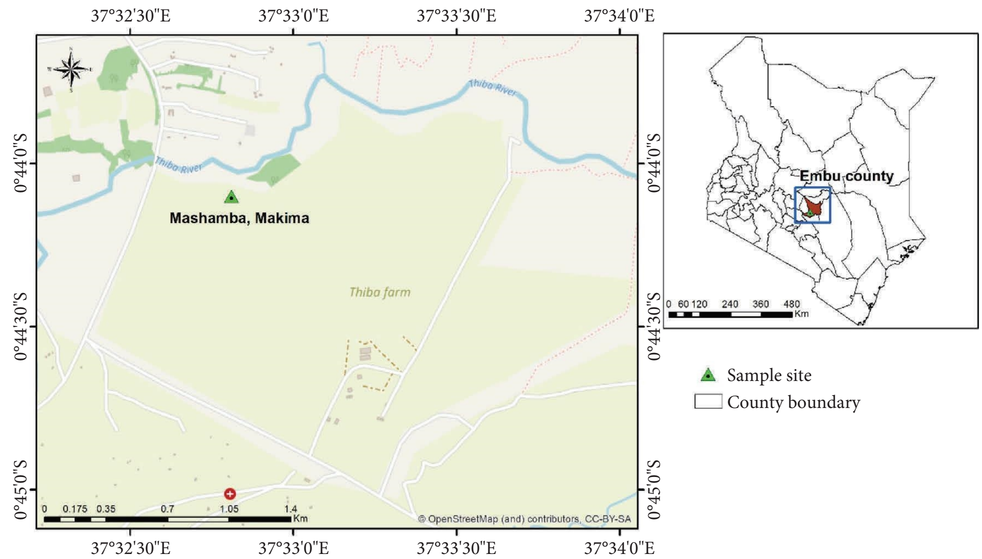

Figure 1: The map of the study site.

damage attributed to the pest using a scale of 1 to 5, where 1 = clean with no visual infestation symptoms, 2 = very little damage, 3 = high level of damage where plants showed the presence of FAW larvae feeding and most of the young leaves show infestation symptom, 4 = severe damage where almost 75% of the leaves are severely affected and excrement was visible on the infested areas and the maize whorls, and 5 = very severe damage where plant damage due to FAW was beyond control.

2.4. Data Analysis. The average pest incidence and damage severity were estimated by plotting progress curves showing the trends of pest incidence and damage score over time (weeks) across different treatments and seasons. From the plotted curves, the cumulative area under damage/pest curve (AUDPC) for each graph was calculated in Microsoft Excel using the following calculus theorem formula [28].

$$\text{AUDPC} = \sum_{i=1}^{n-1} \left(\frac{y_i + y_{i+1}}{2} \right) \left(t_{i+1} - t_i \right), \quad (1)$$

where AUDPC is the area under damage/pest curve, n is the total number of observations, y_i is the percent pest incidence/damage score on the crop at the i^{th} observation, and t is time (in weeks) at the i^{th} observation beginning 4 weeks to 14 weeks after maize germination.

The calculated AUDPC datasets were taken as the average pest incidence and damage severity. The area under curve discretizes the time when calculating the average disease or pest intensity between each pair of adjacent time points which are then summed over time intervals [29]. The use of AUDPC was also adopted by Kasoma et al. [30] to analyse the damage of fall armyworm infestation in screening resistant maize genotypes.

Data were also taken on the growth and yield data components including plant height, internode length, stem girth, cob length, cob girth, plant ear aspect, and crop harvest index. The entire pest and crop data were subjected to ANOVA using XLSTAT software version 2023, and significant means were separated using Tukey's honestly significant difference (HSD) at 95% level of confidence. The Pearson correlation analysis was used to assess the relationship between pest infestation levels, plant growth, and yield parameters.

3. Results

3.1. Weather Data. The daily temperature and precipitation were recorded at the experimental site during the study period. The temperature range was 15–27°C and 16–29°C in the first and second seasons, respectively (Figure 2). High daily average temperatures were consistently observed in the second (short rain) season as compared to the first (long rain) season. The rainfall in the first season increased from 2.5 mm/day in April to 3.6 mm/day in May followed by precipitous decrease in June (0.2 mm/day) signifying the end of long rains. The short rain season, commenced in October with 1.3 mm/day continuing in November (2.3 mm/day) with an abrupt increase in December (4.9 mm/day) towards the end of the vegetative period of maize, before subsiding to the minimum in January (1 mm/day).

3.2. Fall Armyworm Incidence and Damage Severity. Both the pest incidence and damage severity varied significantly ($P < 0.05$) among the cropping systems in both seasons and were highest in the maize monocrop (control) plots and lowest in the plots where *Desmodium* was used as a push crop (Figure 3). *Desmodium* was significantly ($P < 0.05$) more effective as a push crop in reducing the pest incidence than all the other push crops regardless of the pull crop used. However, there was no significant effect on the performance of *Desmodium*, green gram, and pigeon pea in reducing the pest damage severity. The effect of the three push crops in reducing the severity of the pest damage was

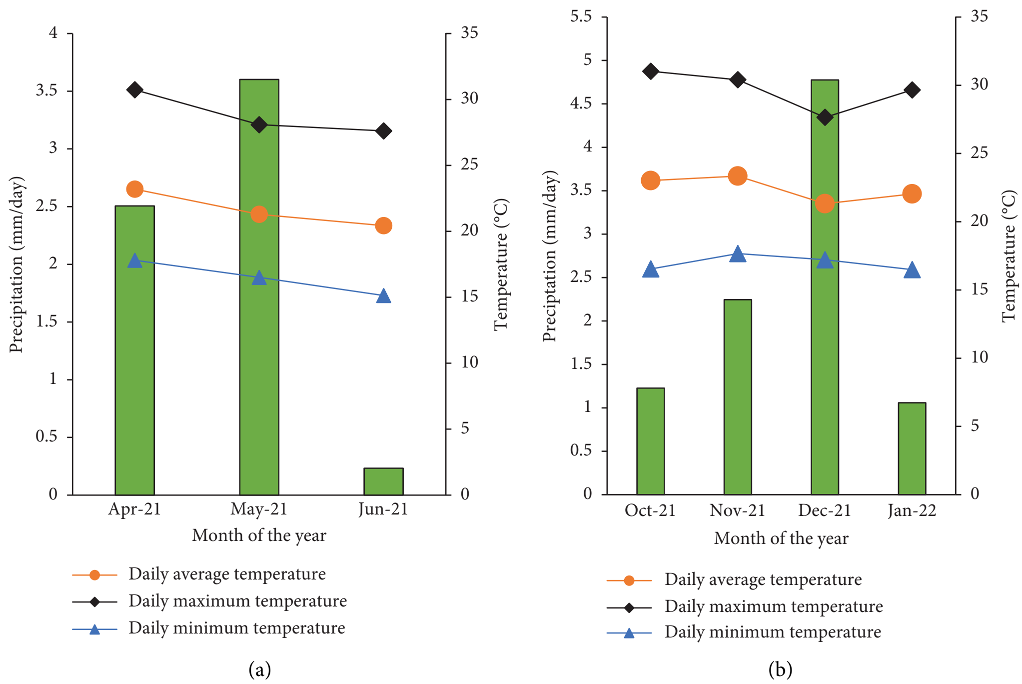

Figure 2: Average rainfall and temperature recorded at the experimental site during the 1st (a) and 2nd (b) seasons.

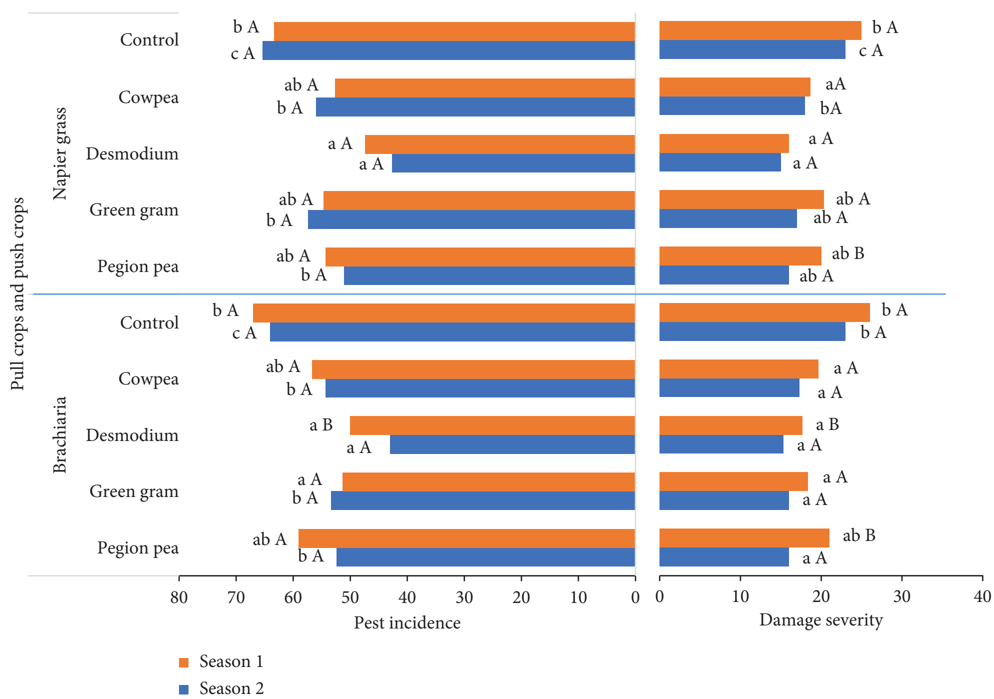

Figure 3: Incidence and damage severity of FAW on maize planted in a push-pull cropping system. Different lower-case letters indicate significant effects of the push crops while different upper-case letters indicate seasonal variations.

significantly ($P < 0.05$) higher than that of cowpea, and this observation was consistent where both Napier grass and *Brachiaria* were used as pull crops.

The effect of the pull crops on both the incidence and damage severity of FAW on maize was not significant as shown by the small letters in Figure 4. Significant ($P < 0.05$) seasonal variations in pest incidence were observed where *Brachiaria* was used as the pull crop with season 1 recording higher pest incidences than season 2. On the contrary, the effect of Napier grass on pest incidence did not vary between the two cropping seasons. On the other hand, there were significant ($P < 0.05$) seasonal variations in FAW damage

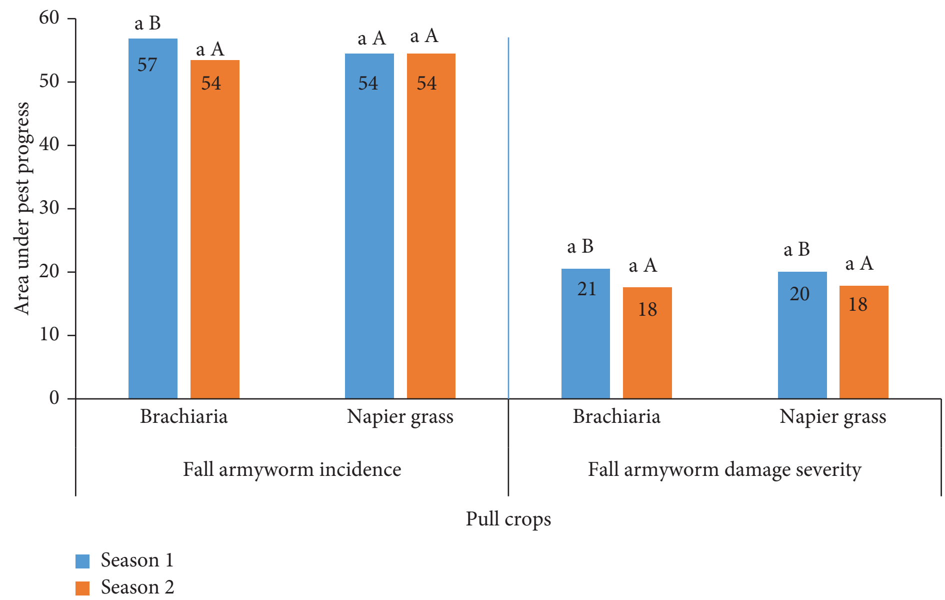

Figure 4: Effects of Napier and *Brachiaria* grasses as pull crops in management of FAW in maize using a push-pull cropping system. Different lower-case letters indicate significant differences between the pull crops in each season while different upper-case letters indicate significant seasonal variations on the effects of each pull crop.

severity regardless of the crop used as the pull crop with higher pest damage being observed in season 1 than in season 2 (Figure 4).

There were significantly ($P < 0.05$) lower incidences of FAW in the push-pull plots than in maize monocrop (control) plots across both cropping seasons (Figure 5). In the first season, Napier grass-*Desmodium*, *Brachiaria*-*Desmodium*, and *Brachiaria*-green gram were significantly the most effective push pull combinations in reducing the FAW incidences on the maize plants. The trend was similar in the second season where Napier grass-*Desmodium* and *Brachiaria*-*Desmodium* were significantly the most effective push-pull combinations. Similarly, damage severity was highest in the control plots and lowest in plots where *Desmodium* was used as a push crop in both cropping seasons (Figure 5). The most distinct results were obtained in season 2 where all the push-pull treatments were significantly different from the control treatments. There were no significant ($P > 0.05$) push crop × pull crop, pull crop × season, and push crop × season interactions in terms of pest incidence and damage severity.

A combined season analysis showed that the fall armyworm incidence and its damage severity varied significantly across cropping systems ($P < 0.05$). The pest incidence was highest in the control plots where no push crop was used and lowest in Napier grass-*Desmodium* and *Brachiaria*-*Desmodium* cropping systems. The other push-pull treatments portrayed moderate pest incidences (Figure 6). The FAW damage severity seemingly followed the same trend but portraying a more distinct significant effect of the push-pull treatments as compared to the control treatments (Figure 6).

3.3. Growth and Yield Components of Maize. The analysis of the growth and yield data across the two cropping seasons showed that there were no significant ($P > 0.05$) effect of the pull crops on most of the growth and yield components of maize except on the internode length ($P = 0.004$) and stem girth ($P < 0.0001$) where both of them recorded significantly higher growth in plots where Napier grass was used as the pull crop. On the other hand, there was no significant ($P > 0.05$) effect of the push crops on all the growth and yield components (Table 1). However, there were highly significant seasonal variations in all the growth and yield components except for the stem girth. There were significant interactions of both pull crop × season and push crop × season ($P < 0.05$) in terms of all growth components and yield and quality components except for the cob girth and the number of rows. However, there was no significant interaction of push crop × pull crop in both growth components and yield/quality components except for the stem girth (Table 1).

The combined treatment analysis showed that there was no significant ($P > 0.05$) influence of the push-pull cropping systems on the growth and yield parameters of maize except the stem girth. The highest stem girth (1.48 cm) was observed in the Napier-*Desmodium* cropping system (Table 2). There were significant seasonal variations in all growth and yield/quality components except for the cob girth, stem girth, and number of rows per cob.

3.4. Effects of FAW Infestation to the Growth and Yield of Maize. As expected, there was significant ($P < 0.05$) positive correlation between fall armyworm incidence and damage severity in both seasons (Table 3). However, no correlation was observed between both the pest incidence and damage severity and all the plant's growth and yield components except the internode length which recorded significant ($P < 0.05$) negative correlation with the pest dynamics in season 2 (Table 3).

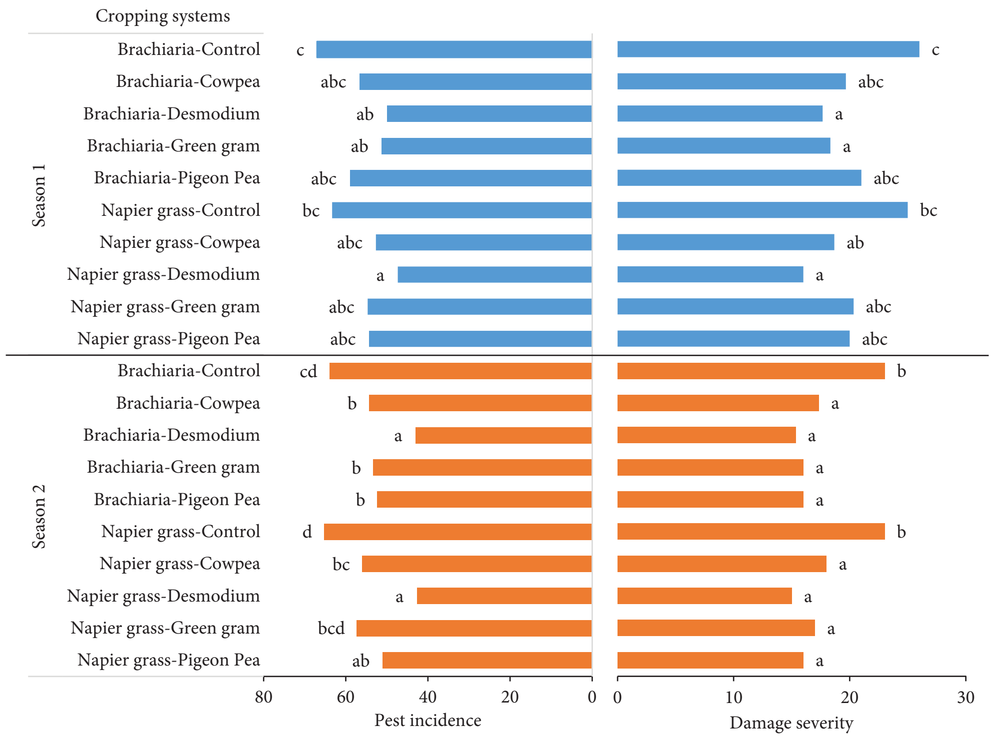

FIGURE 5: FAW incidence and damage severity across cropping systems (combined treatments). Different letters indicate significant differences between the different push-pull treatments.

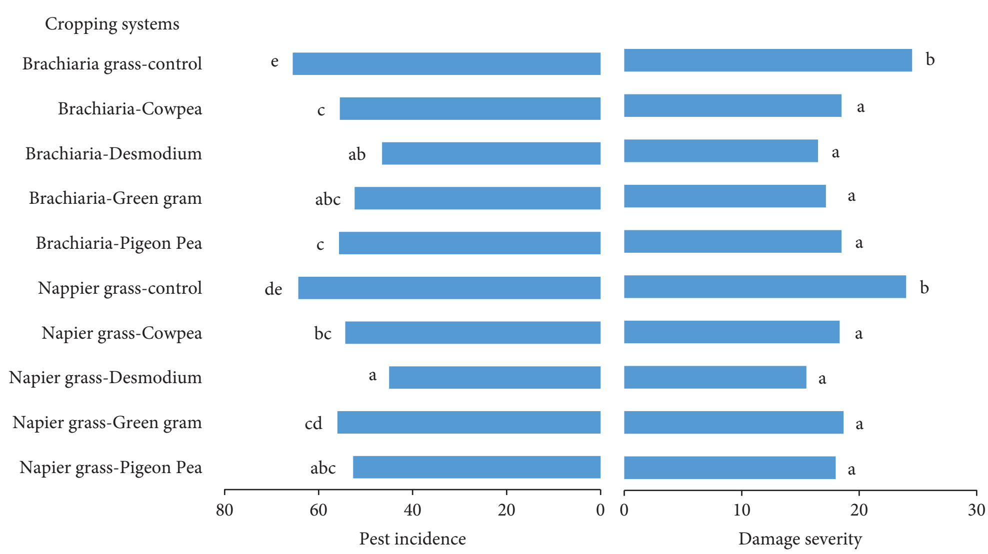

FIGURE 6: FAW incidence and damage severity across cropping systems for combined seasons. Different letters indicate significant differences between the different push-pull treatments.

4. Discussion

The current study evaluated the potential of the modified climate-smart push-pull technology in managing fall armyworm damage in green maize. To understand the intensity of FAW infestation and damage severity during the study period, the area under damage progress curve (AUDPC) was computed. The AUDPC have previously been used to estimate injury/damage of diseases [31] and pests [29, 32, 33] over time. The results showed significantly lower FAW infestation and damage severity in plots where drought-tolerant *Desmodium* and edible legumes were intercropped with maize compared to the maize monocrop plots. This was an indication that the modified climate-smart push-pull technology has a high potential of controlling FAW infestations in maize farming in the dryland areas. The results also coincide with those of Cheruiyot et al. [34] who recorded significantly lower FAW infestation levels in the

TABLE 1: Growth and yield components of maize in the main and subplots of the push-pull planting system.

Factors	Treatments	Growth components				Yield and quality components				
		Plant height (cm)	Internode length (cm)	Stem girth (cm)	Leaf number	Cob girth (cm)	Cob length (cm)	No. of cob rows	PEA	CHI
Main plots (pull crops)	*Brachiaria*	221.68	56.69b	1.36b	9.34	4.38	17.45	13.19	2.00	2.54
	Napier grass	220.13	59.49a	1.44a	9.58	4.43	16.89	13.21	1.90	2.73
	P value	0.638	**0.004**	**<0.0001**	0.111	0.304	0.362	0.906	0.568	0.279
	Standard error	2.309	0.656	0.013	0.107	0.032	0.433	0.147	0.123	0.120
Subplots (push crops)	Control	221.91	57.98	1.42	9.44	4.44	17.58	13.44	2.42	2.77
	Pigeon pea	222.68	58.94	1.39	9.32	4.31	17.48	12.84	1.83	2.55
	Cowpea	214.73	55.90	1.41	9.59	4.41	15.79	13.31	1.83	2.56
	Green gram	222.20	58.56	1.38	9.39	4.39	17.09	12.84	1.92	2.65
	Desmodium	223.01	59.09	1.41	9.55	4.47	17.91	13.56	1.75	2.65
	P value	0.467	0.197	0.710	0.781	0.219	0.231	0.096	0.127	0.924
	Standard error	3.651	1.037	0.021	0.169	0.050	0.684	0.233	0.195	0.189
Seasonal variations	Season 1	237.62a	65.90a	1.39	8.55b	4.52a	15.47b	13.65a	1.60b	3.34a
	Season 2	204.19b	50.29b	1.41	10.37a	4.29b	18.87a	12.75b	2.30a	1.30b
	P value	**<0.0001**	**<0.0001**	0.340	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
	Standard error	2.309	0.656	0.013	0.107	0.032	0.433	0.147	0.123	0.120
Interactions	Push crop × pull crop	0.993	0.978	**0.001**	0.998	0.439	0.529	0.592	0.688	0.955
	Pull crop × season	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	0.291	**<0.0001**	0.249	**0.001**	**<0.0001**
	Push crop × season	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	0.539	**<0.0001**	0.599	**<0.0001**	**<0.0001**

The *P* values in bold are significant at alpha = 0.05 and values with different letters within the column are significantly different at $\alpha = 0.05$; PEA: plant ear aspect—assessed based on the physical features of the maize plant ears; CHI: crop harvest index—the ratio of cob weight to total maize stover weight.

Table 2: Growth and yield components of maize in the push-pull planting system.

Cropping systems		Growth components: Plant height (cm)	Internode length (cm)	Stem girth (cm)	Leaf number	Yield and quality components: Cob girth (cm)	Cob length (cm)	No. of cob rows	PEA	CHI
Brachiaria-control		222.71	56.64	1.40ab	9.33	4.44	17.28	13.83	2.33	2.56
Brachiaria-cowpea		218.26	55.56	1.38ab	9.67	3.68	14.20	11.50	2.00	2.03
Brachiaria-Desmodium		222.55	56.80	1.34ab	9.50	4.43	17.43	13.33	1.83	2.75
Brachiaria-green gram		225.62	57.46	1.32b	9.17	4.25	17.35	12.50	2.00	2.60
Brachiaria-pigeon pea		219.25	57.01	1.35ab	9.33	4.38	18.16	13.33	1.83	2.34
Napier grass-control		221.11	59.31	1.43ab	9.50	4.45	17.89	13.33	2.50	2.98
Napier grass-Cowpea		211.20	56.25	1.44ab	9.67	4.40	14.53	13.17	1.67	2.64
Napier grass-*Desmodium*		223.48	61.38	1.48a	9.83	4.52	18.40	14.00	1.67	2.54
Napier grass-green gram		218.77	59.67	1.45ab	9.50	4.52	16.84	13.00	1.83	2.70
Napier grass-pigeon pea		226.11	60.87	1.43ab	9.67	4.25	16.81	12.67	1.83	2.76
P value		0.754	0.130	**0.008**	0.857	0.454	0.262	0.610	0.527	0.802
Standard error		5.430	1.584	0.030	0.279	0.247	1.246	0.796	0.286	0.339
Seasonal variations	Season 1	237.62a	65.90a	1.39	8.53b	4.37	14.90b	13.20	1.60	3.25
	Season 2	204.19b	50.29b	1.41	10.50a	4.29	18.87a	12.93	2.30	1.93
	P value	**<0.0001**	**<0.0001**	0.282	**<0.0001**	0.634	**<0.0001**	0.600	**0.001**	**<0.0001**

The *P* values in bold are significant at alpha = 0.05 and values with different letters within the column are significantly different at $\alpha = 0.05$. PEA: plant ear aspect—assessed based on the physical features of the maize plant ears; CHI: crop harvest index—the ratio of cob weight to total maize stover weight.

Table 3: Correlation between fall armyworm infestation levels and the maize growth and yield parameters.

Variables	Season 1: Pest incidence	Season 1: Damage severity	Season 2: Pest incidence	Season 2: Damage severity
Plant height	0.257	0.215	−0.234	−0.145
Internode length	−0.083	−0.055	**−0.363**	**−0.393**
Stem girth	−0.092	0.008	−0.046	0.013
Leaf number	−0.166	−0.208	−0.209	−0.158
Cob girth	0.193	0.070	0.267	0.355
Cob length	0.244	0.114	0.129	0.196
Rows per cob	0.183	0.072	0.080	0.112
Crop harvest index	0.161	0.201	−0.059	−0.003
Damage severity	**0.916**	—	**0.869**	—

Values in bold are different from 0 with a significance level at alpha = 0.05.

climate-smart push-pull plots compared to the maize monocrop fields. These results also concur with those of Guera et al. [35] who reported that push-pull systems presented lower incidence and severity of fall armyworm, compared to monocultures. Hailu et al. [36] also recorded significantly lower FAW infestation in fields where maize was intercropped with leguminous crops as compared to the monocropped fields.

The study further demonstrated that the edible drought-tolerant legumes were either equally effective or comparable to the greenleaf *Desmodium* in controlling the FAW infestation when intercropped with maize. This implies that intercropping maize with edible drought-tolerant legumes could be an alternative and possibly a more sustainable pest management option in the dry areas. Apart from their primary role of repelling insect pests, the drought-tolerant legumes would act as cover crops thus helping to conserve moisture and controlling weed growth as reported by Khan et al. [16]. In addition, Ndayisaba et al. [14] reported that the ability of legumes to fix atmospheric nitrogen in the soil improves the soil fertility during their growth, and their residues may also be incorporated back into the soil as green manure. Besides, these edible legumes are used as vegetables and eventually, their grains are utilized as high sources of plant protein [16]. Some farmers also utilize their residues as fodder after threshing off the grains. Therefore, it has been a practice for most smallholder farmers to intercrop maize and food grain legumes to diversify their farm products and diets [15]. This practice will facilitate faster adoption of the climate-smart push-pull technology with the drought-tolerant legumes since the farmers are already familiar with these crops.

This study also established that there was no significant variation between the pull crops (Napier grass and *Brachiaria*) in terms of FAW incidence and damage severity. The two pull crops did not also significantly modify the growth and yield of maize. This was an indication that the two fodder grasses are suitable candidates as pull crops in the push-pull technology and can be used interchangeably depending on farmer's preferences or prevailing environmental conditions. According to Njeru et al. [37], Napier or *Brachiaria* grass act as trap plants in the push-pull technology in the management of FAW by emitting attractive volatile organic compounds. However, these crops do not support the survival of the emerging larvae, thus eliminating them before they cause any destruction to the grasses [10, 37]. Therefore, the push-pull technology offers additional benefits to the farmers since the Napier and *Brachiaria* grasses are nutritious fodder crops for livestock [14]. The technology also lowers the cost of production since the farmers do not use synthetic pesticides to control FAW [37].

The current study found that there were no significant differences in the growth and yield of maize between the modified climate-smart push-pull plots and the maize monocrop plots despite the high pest infestation recorded in the monocrop plots. This contradicts the findings by Midega et al. [10] who reported higher maize yields in climate-adapted push-pull plots than in the maize monocrop plots. These results also contradict those of Ndayisaba et al. [14] who reported that push-pull plots outperformed the maize monocrop plots in terms of maize grain yield. This observation was attributed to the favourable environmental factors that may have enhanced the maize tolerance to pest infestations. In addition, the study site was presumably fertile because it had been previously used to grow tomatoes under intensive high fertilization programme, thus the residual fertility masked the nutritional contribution of legumes. In addition, the rainfall and temperature levels that prevailed during the study period were favourable for the growth of maize [38]. The significant interactions between push crops and seasons as well as between pull crops and seasons indicated that the effect of the push and the pull crops on modifying the growth and yields of maize in the climate-smart push-pull system was different in different seasons. This was also attributed to the different temperature and rainfall levels experienced in different seasons.

The study showed that FAW incidence and damage severity were positively and significantly correlated. This was an indication that as FAW infestation increased, damage severity also increased, while lower FAW infestation resulted in lower damage severity. These results corroborate the findings of Singh et al. [39] who found a significant and positive correlation of FAW damage rating with severity and insect intensity or incidence. The results also coincide with those of Guera et al. [40] who observed a significant positive correlation between FAW incidences and FAW severity in the early weeks of maize growth.

5. Conclusion

This study appraised the potential of drought-tolerant edible legumes and *Brachiaria* grass as alternative push-pull crops for the modified climate-smart push-pull technology in drought-prone areas. The findings portrayed the drought-tolerant greenleaf *Desmodium* and the edible legumes as effective push crops in the modified push-pull technology. On the other hand, the study established that *Brachiaria* and Napier grasses can be used interchangeably as pull crops based on farmers' preference. Consequently, this study confirmed the viability of the modified climate-smart push-pull technology in the management of fall armyworm in dryland areas. This technology would be useful for smallholder farmers who practice mixed cropping under rainfed systems in drought-prone areas. The improvement of the conventional push-pull technology to the modified climate-smart form will facilitate its faster adoption among farmers in dryland areas due to the additional benefits of the push-pull crops.

Data Availability

Most of the data used to support the findings of this study are included within the article. Additional data are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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