Original Research Article

Assessment of Pull- and Push Technologies in Managing *Spodoptera frugiperda* in Maize and Multivariate Analysis of Associated Variables

ABSTRACT

Maize (Zea mays L.) is an important cereal in sub-Saharan Africa. Its production is however, affected by both biotic and abiotic factors. Among the biotic factors fall armyworm (*Spodoptera frugiperda*) is the pests of economic importance and causes high yield losses. The push and pull technology has been proved effective in controlling *Spodoptera frugiperda*. However the effect of push and pull technology in controlling *Spodoptera frugiperda* in maize may vary depending on environment understudy and the cereal- legume combination treatment employed. The objectives of this study were therefore, to; i) assess the effectiveness of push-pull technologies in controlling *Spodoptera frugiperda* infestation in maize ii) cluster the technologies into distinct sets, and iii) identify the variables with high discriminating influence among clustered push-pull technology sets. The experiment was laid as a randomised complete block design (RCBD) with three replications and 6 treatments in Chilanga. This study revealed Pearl millet/ Marigold push-pull treatment as the best performing treatment with a mean maize test yield value of 7.2 tons per hactare. The principle component analysis (PCA) revealed four distinct sets. With set 3 comprising of desirable technologies, with Pearl millet/Marigold push- pull treatment inclusive. For variables: number of damaged leaves, injury score leaves, egg batch, biomass with cobs, shelling %, plant height and grain yield were identified as important at differentiating the performance of push pull technologies.

Key words: fall armyworm, Zea mays, Principal Component Analysis.

1. INTRODUCTION

Maize (Zea mays L.) is an important cereal in sub-Saharan Africa. It is grown mostly by smallholder farmers and is cultivated across a wide range of environments [1, 2]. It requires deep, medium textured, well-drained fertile soil with a high water holding capacity. It grows well at a pH range of 5.5 to 6.5 but if cultivated in acidic medium with low pH (below 5.0) productivity is affected [3, 4]. Maize is utilized in many ways as food for both humans and animals. For human consumption, it is mostly used in making maize meal for porridge, oil, corn flakes, dextrose, syrups, gelatin and lactic acid and eaten as fresh green maize. In addition, maize is a source of income to farmers among whom many are resource poor in developing countries [5].

Maize production is however, affected by both biotic and abiotic factors. Among the biotic factors fall armyworm (*Spodoptera frugiperda*) is the pests of economic importance. This pest is native to the tropical regions of the western hemisphere from the United States to Argentina. The pest is capable of laying hundreds of eggs, and the emerging larvae attacks the plants by feeding on the foliage making ragged holes and burrows through the husks. In late 2016, Zambia experienced an outbreak of the fall armyworm that affected fields in over 100 districts [6]. Since then, the fall armyworm has been a problem leading to serious yield losses [7]. It has been suggested that Integrated Pest Management (IPM) is a best approach of managing *Spodoptera frugiperda*. This builds on ecosystem services such as pest predation while protecting other useful organisms, such as pollinators. Among the IPM technologies 'Push and Pull' developed by International Centre for Insect Physiology and Ecology (ICIPE) has been used in managing army fall worm [8]. The push and pull technology is an intercropping technique for controlling agricultural pests by using repellent "push" plants and trap "pull" plants. This technique is a novel tool for integrated pest management programs which uses a combination of behaviour-modifying stimuli to manipulate the distribution and abundance of insect pests and/or natural enemies. Previous studies have combined edible cereals as pull crops with legumes as a push technology to evaluate for an effective combination [6, 8, 9]. However the effect of a push and pull technology in controlling *Spodoptera frugiperda* in maize may vary depending on environment understudy and the cereal- legume combination treatment employed. Multivariate analysis such as principle component analysis (PCA) have been used where factor assessment involves utilization of several associated measured variables [10, 11]. The objectives of this study were therefore, to; i) determine the effectiveness of push-pull technologies in controlling *Spodoptera frugiperda* infestation in maize ii) cluster the technologies into distinct sets, and iii) identify the variables with high discriminating influence among clustered push-pull technology sets.

2.0 MATERIALS AND METHODS

2.1 Location of Experiment

The research project was carried out in the open field at Seed Control and Certification Institute (SCCI) in Chilanga district (15^0 32.772’ S; 28^0 15.76’ E) of Lusaka province. This research site receives an average annual rainfall of between 800 mm and 1000 mm.

2.2 Push- Pull Technology Combination used and Conduct of Experiment

The maize monocrop ZamSeed 301, obtained from the Zambia Seed Company (ZamSeed) was used as a test crop. It was chosen on the basis of being a popular variety in the country. It matures within 90-120 days and was planted during the 2020/ 2021 cropping season. Land measuring approximately 30m by 20m was ploughed and harrowed to a fine tilth. Eighteen plots were demarcated each measuring 5m by 4.8m. The maize plants in each plot was laid as a four-row plot spaced at 75 cm x 30 cm as inter by intra row respectively. The “pull” plants were drilled around each plot and the “push” plants were planted in-between maize rows. Basal fertilizer (D’ compound) was applied at planting at the rate of 200 kg per hactare.

The experiment was laid as a randomised complete block design (RCBD) with three replications and 6 treatments making a total of 18 experimental units. The main treatments were: four cereal and legume push- pull combinations. The other two control treatments being Maize monocrop with chemical spray (positive) and Maize monocrop without chemical spray (negative) (Table 1). In this experiment, the plants belonging to the family poaceae (Grass) were used as “pull” plants and were planted along the borders of the plots, whereas, the marigold and legumes were used as the “push” plants and were intercropped with maize. For the positive control, the chemical trade name DeminFit was applied at a late 5g in 16 L sprayer. The first spray was at two weeks after emergency, with the second and last spray at 2 weeks and 4 weeks respectively after emergency.

Table 1. Push-pull combinations used in the study

Treatment	Grass	Legume
Brachiaria/ Desmodium	Brachiaria	Desmodium
Finger millet/ Sunn hemp	Finger millet	Sunn hemp
Pearl millet/ Marigold	Pearl millet	Marigold
Sweet Sorghum/ Cowpea	Sweet sorghum	Cowpea
^{X}Negative Control	none	none
^{Y}Positive Control	none	none

X- No chemical was applied; Y- Chemical trade name denimFit at a rate of 5g/ 16 l of water

2.3 Data Collection

Data associated with *Spodoptera frugiperda* infection was collected weekly for a period of 5 weeks on maize test crop. It was collected on damaged/windowed leaves (DL), number of egg batches (EB) Number of Larva (NL) and injury score leaves (ISL). The presence of larva was assessed by visually checking the presence of the larva on young leaves, leaf whorls, young tassel and cobs. Injury score leaves (ISL) was assessed as by Davis *et.al* [12].The other variables measured at harvest were number of cobs per plot (CH), shelling percentage (S%), grain yield (GY), biomass with cobs (BC), biomass without cobs (BWC) plant height (PH) and harvest index (HI). The harvest index was determined= GY/BC where GY- grain yield and BC was biomass with cobs.

2.4 Data Analysis

Data was analysed using analysis of variance (ANOVA). Treatment means for all measured parameters were separated using least significant difference (LSD) at alpha level of 0.05. All data was performed using GenStat statistical software. Further, performance assessment on scatter groupings for push- pull treatments and discriminating capability of measured variables was computed by performing a multivariate approach too, principle component analysis, using XLSTAT in excel. Visual qualitative assessment of the salient push-pull treatments effect on maize test crop was also undertaken.

3. RESULTS

3.1 Analytical Assessment of Push-Pull Treatment Combinations

Significant differences were obtained on all measured parameters with regards to push- pull treatments main effects (P= 0.05). Similarly significant differences were also obtained on all measured parameters with regards to the week main effect. The interaction effect (Push- pull treatment x week) was also significant (P = 0.001) (Table 2). Qualitative analysis revealed that with the Pearl millet/ Sunn hump push pull treatment, sunn hemp outgrew the maize test crop leading to etiolated maize plants.

Table 2. Analysis of Variance (ANOVA) exhibiting mean squares for measured variables evaluated weekly for a five-week period

SOV	DF	DL	ISL	NEB	NL
Replication	2	0.078	0.011	1.2333	16.178
Push-Pull	5	25.351***	11.424***	9.0933***	117.344***
Week	4	133.461***	17.833***	13.350***	80.678***
Tre. x Week	20	3.934***	1.247**	1.977***	13.344***

			*		
Error	58	0.262	0.115	0.578	2.844
Total	89				

SOV- Source of variance, Tre- treatment, ***,* Significant at P= 0.001 and P= 0.05 respectively. DL- Number of damaged leaves, ISL- Injury Score Leaves, NEB- Number of egg batches, NL- Number of larva

Significant differences were also obtained on push-pull treatment main effects with regards to yield and selected yield components except for harvest index (Table 3).

Table 3. Analysis of Variance (ANOVA) exhibiting mean squares for measured variables evaluated at harvest

SOV	DF	BC	BWC	CH	% S	PH	GY	H I
Replication	2	0.475	0.336	4.67	15.30	163.50	0.002	0.001
Treatment	5	27.196***	6.995***	41.97***	290.93***	139.07^{ns}	7.116***	0.001^{ns}
Error	58	0.502	0.338	11.13	10.05	36.77	0.014	0.001
Total	89							

SOV- Source of variation, ***,* Significant at P=0.001 and 0.05 respectively 0.001). BC- Biomass with Cob, BWC- Biomass without Cob, CH- Number of uninfected cobs at harvest, PH- Plant Height, GY- Grain Yield, Harvest Index- HI; % S- Shelling percentage

Further analysis revealed that push pull combinations performed better than the controls (positive and negative) exhibiting lower mean values across weeks (Table 4).

Table 4. Mean performance of the push- pull treatments for measured variables across weeks

Treatment	DL	ISL	NEB	NL
Brachiaria/Desmodium	3.200	1.667	0.867	2.60
Finger millet/Sunn hemp	3.667	0.933	0.267	1.13
Pearl millet/Marigold	3.533	1.067	0.400	1.40
Sweet Sorghum/Cowpea	3.467	1.200	0.333	2.07
^{X}Negative Control	6.533	3.200	2.333	8.67
^{Y}Positive Control	5.067	2.267	1.000	2.87

LSD (α= 0.05)	0.3739	0.2474	0.5558	1.233

LSD: Least significant differences of means (α= 5%), DL- Number of damaged leaves, ISL- Injury Score Leaves, NE- Number of egg batches, NE- Number of egg batches, NL- Number of larva

Furthermore, analysis on measured variables at harvest showed that Pearl millet/ Marigold was the highest performer with mean maize yield of 7.2 tons /ha (Table 5).

Table 5. Mean performance of the treatments for measured variables at harvest

Treatment	**BC**	**BWC**	**CH**	**% S**	**PH**	**GY**	**HI**
Brachiaria/ Desmodium	12.51	6.09	40.00	93.24	184.3	6.68	0.54
Finger millet/Sunn hemp	5.61	2.52	37.67	69.44	204.0	2.91	0.52
Pearl millet /Marigold	14.33	6.64	44.00	95.30	192.3	7.17	0.50
Sweet Sorghum/Cowpea	12.73	6.13	42.67	95.64	199.7	6.70	0.53
Negative Control	10.90	4.45	34.33	86.98	192.0	5.99	0.55
Positive Control	10.79	4.68	36.33	88.51	193.7	6.16	0.57
LSD (α= 0.05)	1.29	1.06	6.07	5.77	11.03	0.22	0.058

LSD: Least significant differences of means (α= 5%). BC- Biomass with Cob, BWC- Biomass without Cob, CH- Number of uninfected cobs at harvest, % S- Shelling percentage, PH- Plant Height, GY- Grain Yield (tons/ hectare), Harvest Index- HI

3.2 Multivariate Evaluation of Push- Pull Treatment and Parameters

3.2.2 Evaluation of Push Pull Treatment Combinations

The evaluation of genotypes using principal component analysis showed that push- pull treatments clustered into four sets, arising from a phenotypic variation explained of 89.1% (Figure. 1). With PC1 and PC2 contributing 47.8 and 41.3 % respectively.

3.2.1 Evaluation of Measured Variables

The variables, number of damaged leaves (DL), injury score leaves (ISL), egg batch (NEB) and number of cobs at harvest (CH) were identified as important at differentiating genotypes with regards to PC1, attaining absolute factor loading values 0.88, 0.82, 0.81 and 0.91 respectively. On the other hand, biomass with cobs (BC), shelling % (%S), Plant height (PH) and grain yield (GY) were important with regards to PC2 attaining 0.85, 0.86, 0.80 and 0.91 respectively (Table 6).

Further exploration indicated CH and PH as the most linked variables associated with PC1 and PC2 as evident by the smallest acute angles on the respective axis respectively. Interestingly PH didn't not positively correlate with any other variables as observed by created obtuse angles with it and others (Figure 1)

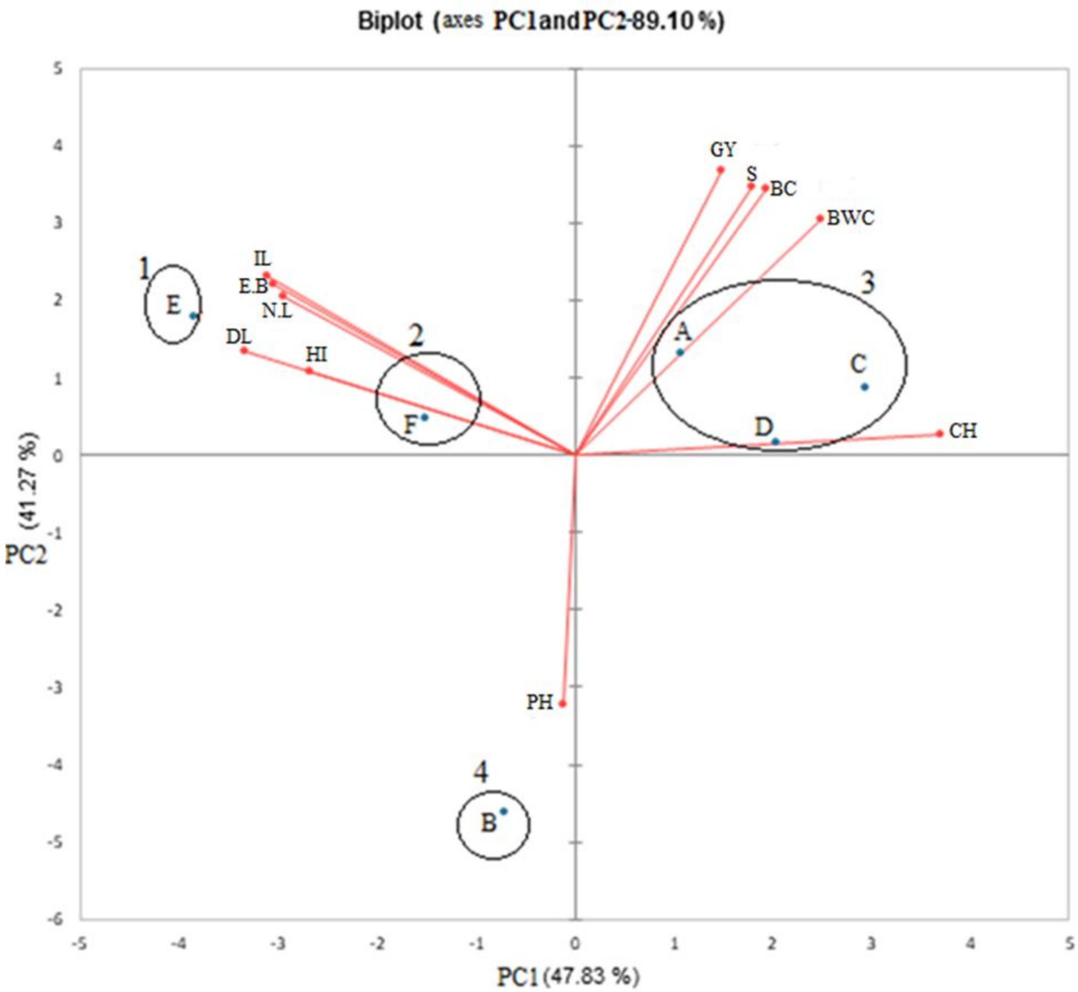

Figure 1. Scatter plot for Principal Component analysis

With a total percentage variation explained of 89.1. Four sets were generated **1**, **2** and **3** were singletons and **4**, a cluster with C, D and A treatments. A-Brachiaria/ Desmodium, B- Finger millet/ Sunn hemp, C-Pearl millet/Marigold, D- Sweet Sorghum/ Cowpea, E- Negative Control, F- Positive Control. Variable: DL- Number of damaged leaves, ISL- Injury Score Leaves, NEB- Number of egg batches, NL- Number of larva. BC- Biomass with Cob, BWC- Biomass without Cob, CH- Number of cobs at harvest, % S-Shelling percentage, PH- Plant Height, GY- Grain Yield, Harvest Index- HI

Table 6. Factor loadings of the measured variables corresponding for computed principle components 1 to 3

Variable	PC	PC2	PC3
DL	-0.88	0.33	-0.20
IL	-0.82	0.57	-0.001
NEB	-0.81	0.55	-0.19
NL	-0.78	0.51	-0.34
BC	0.51	0.85	-0.08
BWC	0.66	0.75	-0.02
CH	0.98	0.07	-0.16
% S	0.48	0.86	0.035
PH	-0.03	-0.80	-0.27
GY	0.39	0.91	0.03
HI	-0.71	0.27	0.60

PC1, PC2 and PC3- Principal component 1, 2 and 3 contributing 47.8%, 43.3% and 5.9% of the percentage variation explained respectively. DL- Number of damaged leaves, ISL- Injury Score Leaves, NEB- Number of egg batches, NL- Number of larva. BC- Biomass with Cob, BWC- Biomass without Cob, CH- Number of cobs at harvest, % S- Shelling percentage, PH- Plant Height, GY- Grain Yield, Harvest Index- HI;

4. DISCUSSION

4.1 Assessment of Push-Pull treatment Combinations

Maize (Zea mays L.) production in Zambia is usually constrained by both biotic and abiotic factors and infestation by fall armyworm is one of the biotic factors limiting maize production. This study hypothesized that adoption of the push-pull technologies as a farming practice would reduce infestation and damage of maize by fall armyworm. In this study, lower infestation or damage were observed on all measured variables on the pull and push treatments than the controls (positive or negative) (Table 5). The enhanced test performance of maize in these push-pull treatment is in line with Gurr et al. [13] suggestion that manipulation of habitats and plant diversification are important tools to utilize in a sustainable insect pest management approach. Pearl millet/ marigold push pull treatment was the best performer with regards to yield response on maize test crop exhibiting mean yield of 7.2 tons/ ha. The relative highest performance could be attributed to lowest levels of damaged and injured leaves as a result of lower numbers of larva infestation compared to other push pull treatments (Table 5). It was found that leaf damage, injury or defoliation affects evapotranspiration and photosynthesis, thereby reducing the plants' productivity [14]. However, the poor performance (3 ton/ ha maize) of Finger millet/ Sunn hemp push- pull treatment despite low infestation levels of *Spodoptera frugiperda* could be due to vigorous growth of sunn-hemp which over shadowed the maize plants leading to slow growth rate and ultimately low maize yield.

4.2 Multivariate Assessment of Push Pull Treatments

Principle component has been used as vital analytical multivariate tool to assess the performance of various crop combinations with regards to a test crop [11]. In this study, the first two-dimensional PCA scatter diagram generated four sets explaining 89.1 % of total percentage variation explained (PVE).

The higher the combined total phenotypic percentage variation of the two PC scores, the more reliable the information from the two-dimensional scatter plot [10]. In our case PC1 and PC2 gave a combined approximate higher value of 89.1% implying that technologies cluster set are likely to perform in the similar manner when replicated and exposed to *Spodoptera frugiperda* infested environment. From this study we can deduce that push-pull cluster set 3 consisting Brachiaria/ desmodium (A), Pearl millet/Marigold (C) and Sweet Sorghum/ Cowpea (D) was the best performer. Set 1 was the least being a non-chemical control treatment followed by set 2 consisting fertilizer treatment and maize test crop only. Implying that chemicals to some extent enhance crop performance though sole dependence on chemicals is discouraged as it is not environmentally friendly. Set 4 consisting of Pearl millet/ Sunn hump performed similarly with regards to set 2 on PC1 but opposing responses where evident with regards to PC2.

4.3 Multivariate Evaluation of Measured Variables

From 11 variables utilized, number of damaged leaves, injury score leaves, egg batch biomass with cobs, shelling %, plant height and grain yield were identified as important at differentiating genotypes (Table 6). The discrimination capability of variables (traits) is an important aspect to agronomist because it helps to cut down on number of traits to utilize in screening for appropriate technologies, in our case push-pull combinations [15]. Being that the percentage variation explained by the 2 principal components (47.7 for PC1 and 41.3% for PC2), are almost equal, all important variables associated with each principal component were taken as important. In this research a variable with a minimum factor loading score of 0.8 was taken as important. Generally screening for an appropriate technology is costly and identification of important traits with a higher discrimination capability helps to narrow down to only few essential variables to utilize and it saves cost [16]. However it's important to note that the high factor loading value associated with PH could be due to enhanced height as a result of etiolation of the maize in Pearl millet/ Sunn hump push-pull treatment. This entails that further research should be undertaken to ascertain its reliability

5. CONCLUSION

This study revealed that Pearl millet/Marigold push-pull treatment was the best performing push-pull treatment with a mean maize test yield value of 7.2 tons per hectare. The Principle component analysis revealed four distinct sets. With set 3 comprising of desirable technologies. For variables: number of damaged leaves, injury score leaves, egg batch, biomass with cobs, shelling %, plant height and grain yield were identified as important at differentiating push pull technologies.

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