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

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aims: 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.

Place and Duration of Study: The research was undertaken in Chilanga district, Zambia during the 2021/ 22 cropping season.

Methodology: The experiment was laid as a randomised complete block design (RCBD) with three replications and 6 treatments. Four push –pull combinations and the two controls (Negative and Positive). Maize was used as a test crop. Data on *Spodoptera frugiperda* incidence was collected at weekly intervals for a period of 5 weeks and at harvest from maize crop. Analysis on measured variables was computed using analysis of variance (ANOVA) and principle component analysis (PCA), a multivariate tool.

Results: Significant differences were obtained on all measured variables except harvest index with regards to push- pull treatments main effects (P =0.05). The evaluation of treatments using principal component analysis showed that push - pull treatments clustered into four sets, arising from a phenotypic variation explained of 89.1%.

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Conclusion: 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 hectare. 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.

Keywords: Fall armyworm; Zea mays; principal component analysis; yield; integrated pest management.

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. 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 behavior-modifying stimuli to manipulate the distribution and abundance of insect-pests and natural enemies. Previous studies have combined edible cereals as pull crops with legumes as a push technology to evaluate for an effective combination [6,8,9,10]. However the effect of a push and pull technology in controlling *Spodoptera frugiperda* in maize may vary with environmental under study 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 [11,12]. In evaluating push-pull technologies, several variables such as, number of damaged leaves, injury score leaves, egg batch, plant height and grain yield have been used to measure the severity and intensity of *Spodoptera frugiperda* infestation. However, studies to determine the relevance of these variables in discriminating the technologies (push and pull combinations) are limited. Therefore, the present study was carried out with following objectives:

- Determine the effectiveness of push-pull technologies against *Spodoptera frugiperda* incidence in maize.
- Cluster the technologies into distinct sets.
- Identify the variables with high discriminating influence among clustered push-pull technology sets.

2. MATERIALS AND METHODS

2.1 Location of Experiment

The study was carried out in the open field in sandy loam soils during the 2020/ 21 cropping season, at Seed Control and Certification Institute (SCCI) in Chilanga district (15^0 32.772’ S; 28^0 15.76’ E). The area 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 genotype, ZamSeed 301, obtained from the Zambia Seed Company (ZamSeed) was used as a test crop. The crop was raised by following all recommended practices except plant protection measures. Basal fertilizer (D compound; NPK 10:20:10) was applied at planting at the rate of 200kg per hectare.The experiment was laid out with three replication and six treatments in a randomized complete block design (RCBD) making a total of 18 experimental units. The plot size of each treatment was kept 5.0 X 4.8 m and buffers were maintained by 2.0m and 90.0 cm between replication and treatment plots, respectively. The crop was planted in four-row with spacing of 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. The main treatments were: four cereal and legume push - pull combinations. The other two control treatments being Maize with chemical spray (positive) and Maize without chemical spray (negative) (Table 1). The plants belonging to the family poaceae (Grass) were used as “pull” plants those planted along the borders of the plots, whereas, marigold and legumes were used as the “push” plants which intercropped with maize. For the positive control, the chemical trade name DeminFit was applied at 5g in 16 lt sprayer. The first spray was given at two weeks after maize emerged the second and last spray at 4 and 6 weeks after emergency, respectively.

2.3 Data Collection and Analysis

Data on *Spodoptera frugiperda* incidence was collected at weekly intervals for a period of 5 weeks from maize 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. [13]. 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.

The data recorded during the course of investigation were subjected to statistical analysis by using analysis of variance technique after square root transformations Sheoran et al. [14]. Further, performance assessment on scatter groupings for push- pull treatments and discriminating capability of measured variables was computed by performing a multivariate approach tool, principle component analysis, using XLSTAT in excel.

3. RESULTS

3.1 Analytical Assessment of Push-Pull Treatment Combinations

Significant differences were obtained on all measured variables 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.

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 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 denim Fit at a rate of 5g/ 16 lt. of water

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

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 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*

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

SOV	DF	BC	BWC	CH	% S	PH	GY	HI
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, ns- non significant. BC: Biomass with Cob, BWC: Biomass without Cob, CH: Number of uninfested cobs at harvest, PH- Plant Height, GY- Grain Yield, Harvest Index- HI; % S- Shelling percentage*

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

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

3.2.1 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% (Fig. 1). With PC1 and PC2 contributing 47.8 and 41.3 % respectively.

3.2.2 Evaluation of measured variables

The variables, number of damaged leaves (DL), injury score leaves (ISL), egg batch (EB) 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 (%), 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 positively correlate with any other variables as observed by created obtuse angles with it and others (Fig. 1).

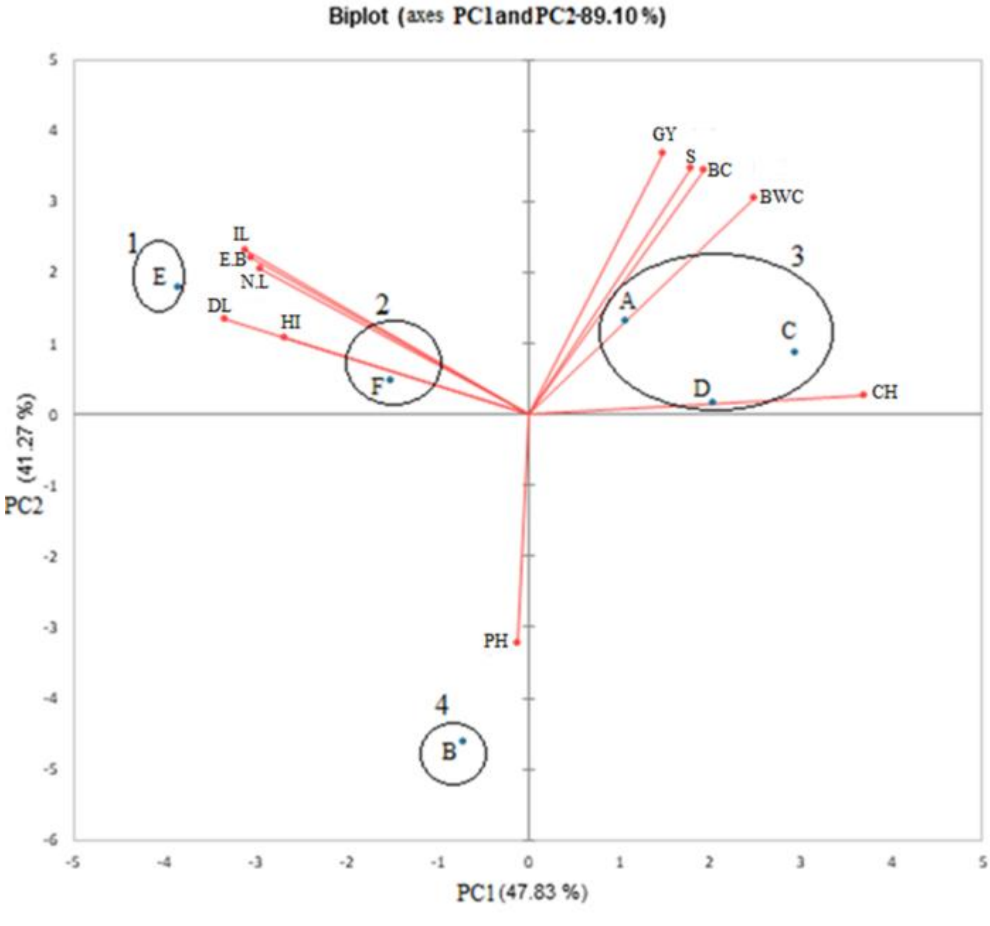

Fig. 1. Scatter plot for Principal Component analysis

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, EB- 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
ISL	-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 production in Zambia is usually constrained by both biotic and abiotic factors. The infestation by fall armyworm is one of the biotic constraint [10]. This study hypothesized that adoption of the push-pull technologies as a farming practice would reduce infestation of army worm in maize crop. In this study, lower insect infestation was observed on all measured variables on the *pull* and *push* treatments than control (positive or negative) (Table 5). The enhanced test performance of maize in these push-pull treatments are in line with Gurr et al. [15] 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 maize yield (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 [16]. However, the poor performance (3 ton/ha maize) of Finger millet/Sunn hemp *push- pull* treatment despite low infestation levels of *S. 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 [12]. 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 [11]. 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 *S. 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 [17]. 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 [18]. 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

It was concluded that Pearl millet/Marigold was the best performing push-pull treatment with a mean yield value of 7.2 tons/ha. 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.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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