Research Paper

An Alternative Planting Geometry for Facilitating Chemical Control of Fall Armyworm (*Spodoptera frugiperda*) in Maize and Its Impact on Growth and Yield

M.A.P.W.K. Malaviarachchi[1]*, K.N.C. Gunawardana[1], S. Thrikawala[2], S.R.G.H.S.M. Jayarathna[1], H.G.P.B. Darshana[1]

[1] *Field Crops Research and Development Institute, Mahailluppallama, Sri Lanka*

[2] *The Open University of Sri Lanka, Nawala, Nugegoda, Sri Lanka*

**Corresponding Author: wmalavi@yahoo.com*

ARTICLE INFO

Article history:
Received: 05 July 2023
Revised version received: 03 August 2023
Accepted: 25 August 2023

Citation:
Malaviarachchi, M.A.P.W.K., Gunawardana, K.N.C., Thrikawala, S., Jayarathna, S.R.G.H.S.M., Darshana, H.G.P.B. (2023). An Alternative Planting Geometry for Facilitating Chemical Control of Fall Armyworm (*Spodoptera frugiperda*) in Maize and Its Impact on Growth and Yield. *Tropical Agriculturist,* 171 (3), 41-54.

Abstract

A potential threat from the recent Fall Armyworm (FAW) outbreak was recorded from maize cultivation in Sri Lanka. Though an integrated approach has been suggested for its management, chemical control is needed in a severe infestation. However, the present planting geometry does not facilitate chemical spraying as the plant height and canopy expand. An experiment was conducted during two consecutive seasons at Field Crops Research and Development Institute, Mahailluppallama (08.60° N, 80.27° E, 137 m AMSL) to explore an alternative row arrangement to facilitate pesticide spraying with minimum impacts on growth and yield. Treatments consisted of 3 new planting geometries (strip planting of maize at 45 × 30 cm spacing as 4 or 6 rows leaving 120 cm inter-strip area and strip planting at 45 × 30 cm spacing as 4 or 6 rows leaving 90 cm inter–strip area) combined with 3 inter cropping arrangements where the inter-strip area was kept either cultivated with groundnut (*Arachis hypogea* (L.) R. Wilczek) or without cultivating in respective treatments. The present plant geometry was the control. Results revealed that the modified planting geometry did not affect on growth and yield compared to the present practice. Thus, maize planted at 45 × 30 cm in 4 rows with 90 cm space between strips cultivated with groundnut was found to be an effective plant geometry to facilitate both chemical application on FAW with no yield disadvantages and at comparatively low cost of seeding.

Key words: **Chemical control, Fall armyworm, Maize, Plant geometry**

Introduction

Maize is currently the most extensively cultivated upland cereal in Sri Lanka (DoA 2020). It is primarily grown for both food and feed industries, with a small quantity consumed as green cobs. Until 2018, the Stem borer (*Chilo partellus* (Swinhoe)), identified as the most destructive pest in maize in Sri Lanka (Gunewardena and Madugalla, 2011; Gunewardena *et al.,* 2016), was also recognized as a significant concern in other countries (Khan *et al.*, 1999; Yonow *et al.,* 2017). The Fall Armyworm (*Spodoptera frugiperda*), another serious pest, was first reported in Sri Lanka in 2018 and caused significant damage to maize during the 2018/19 *Maha* season (Climate and Food Security Monitoring Bulletin, 2019; Perera, 2019; Perera *et al.*, 2019). Although the Fall Armyworm attacks various crops, it exhibits a strong preference for maize and inflicts damage on both vegetative and reproductive structures. Recent evidence from CABI (Abrahams *et al.*, 2017; Day *et al.*, 2017) suggests that maize production could suffer losses of 40% - 45% due to Fall Armyworm infestation. In its native range, this insect is widely regarded as the most significant maize pest because it can rapidly infest and damage a large area of maize fields overnight (Sarmento *et al.*, 2002).

In controlling Fall Armyworm (FAW), an integrated pest management approach is preferred (Day *et al.*, 2017). However, when farmers anticipate devastating losses due to FAW, they are compelled to apply chemical pesticides for its control (Bateman *et al.*, 2018). It has also been recommended that chemical application becomes necessary when the level of infestation exceeds 10-20%, depending on the crop's growth stage (Huis, 1981; Afonso-Rosa and Barcelos 2012; Ontario Crop IPM, 2017).

However, regular inspection to identify the severity level of infestation and the application of chemicals onto the crop become challenging as the plants increase in height under the recommended current plant geometry, with inter and intra-row spacing of 60 cm and 30 cm, respectively (Anon, 1998). Generally, manipulating plant geometry, such as reducing plant populations, widening plant or row spacing, and adopting skip-row configurations, is an important agronomic consideration for achieving higher yields through better utilization of available natural resources (Stewart and Peterson, 2015). In this experiment, this concept was applied to increase the efficiency and effectiveness of pesticide applications in case of severe FAW infestation, despite the implementation of IPM approaches. Moreover, pesticides applied to the growing crop are most effective when used at the right time and in the right manner. Therefore, to facilitate effective chemical application, there is a need to revisit the current planting geometry with minimal impacts on crop growth and yield.

On the other hand, safety may be compromised when applying pesticides in densely populated plant populations, while ineffective pest control due to inefficient application might lead farmers to apply more and more pesticides, posing a threat to environmental sustainability. Therefore, this experiment aimed to introduce a new planting geometry (strip planting), where the plant density in a unit area (ha) was increased by 2,000-6,000 compared to the currently recommended density, with the expectation of achieving the same or higher productivity while facilitating effective chemical applications whenever necessary. In order to utilize the space between maize strips effectively, possibility of introducing a groundnut crop between strips was also tested in this study.

Materials and Methods

Experimental site

The field experiment was conducted during two consecutive seasons, 2020/2021 *Maha* (November -February), and 2021 *Maha* (May-August) at Field Crops Research and Development Institute, Mahailluppallama (08.60° N, 80.27° E, 137 m amsl). The location represented DL1b agro-ecological region of Sri Lanka characterized by an annual average rainfall of 900-1,100 mm (Punyawardana, 2008). The soil type at the site was identified as Rhodustalfs, with a moderately well-drained sandy clay loam texture (Panabokke, 1996).

Experimental treatments and design

The experiment was conducted using a Randomized Complete Block Design with three replicates. The study tested new planting geometries for maize, which included strip planting at a spacing of 45 × 30 cm with either 4 rows (Figure 1a) or 6 rows (Figure 1b), while maintaining a 120 cm inter-strip area. Further, strip planting at a spacing of 45 × 30 cm with either 4 rows (Figure 1c) or 6 rows (Figure 1d) was tested, leaving a 90 cm inter-strip area. In each respective treatment, the inter-strip area was either cultivated with Groundnut (*Arachis hypogaea*) or left uncultivated. The control treatment followed the present planting geometry (Figure 1e).

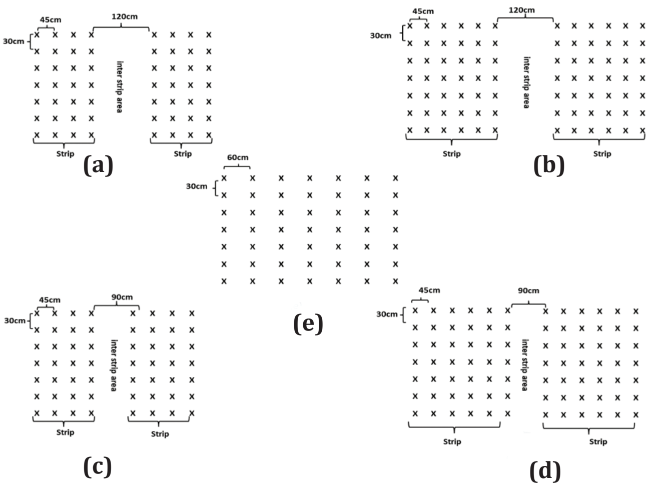


Figure 1. Planting geometry of maize tested in the experiment. Strip planting of maize at 45 × 30 cm spacing as 4 rows leaving 120 cm inter-strip area (Figure 1a), strip planting of maize at 45 × 30 cm spacing as 6 rows leaving 120 cm inter-strip area (Figure 1b) and planting of maize at 45 × 30 cm spacing as 4 rows leaving 90 cm inter-strip area (Figure 1c), planting of maize at 45 × 30 cm spacing as 6 rows leaving 90 cm inter-strip area (Figure 1d). The present planting geometry was taken as the control treatment (Figure 1e)

The treatment set up is further elaborated in Table 1. The first treatment (T_1) included planting maize at 45 × 30 cm with 4 rows and a 120 cm space left uncultivated between the strips. T_2 consisted of maize planted at 45 × 30 cm with 6 rows and a 120 cm space left uncultivated between the strips. In T_3, maize was planted at 45 × 30 cm with 4 rows, and a 120 cm space between the strips was cultivated with groundnut. For T_4, maize was planted at 45 × 30 cm with 6 rows, and a 120 cm space between the strips was cultivated with groundnut. T_5 represented maize planted at 45 × 30 cm with 4 rows, while maintaining a 90 cm space left uncultivated between the strips. T_6 denoted maize planted at 45 × 30 cm with a 90 cm space left uncultivated between the strips. In T_7, maize was planted at 45 × 30 cm with 4 rows, and a 90 cm space between the strips was cultivated with groundnut. For T_8, maize was planted at 45 × 30 cm with 6 rows, and a 90 cm space between the strips was cultivated with groundnut. The control treatment (T_9) included the regular maize crop planted at 60 × 30 cm.

Crop establishment and maintenance

Maize (variety MI MZ Hy 2) was established by direct seeding after disc-ploughing and harrowing the experimental field in both seasons. Plots (12 × 3 m) were prepared with shallow drains around them to drain excess water from high-intensity rains especially during *Maha*. The planting was done on 20th October 2020, for the *maha* season and 12th May 2021, for the *Yala* season.

The plant densities in the new planting geometry were 51,948, 57,742 58, 608 and 61, 938 per hectare while it was 55, 555 ha^{-1} in the control treatment (Present recommended plant geometry) (Table 1).

Table 1. Spacing, strip and row arrangement with respective plant densities in different treatments

Treatment	Plant spacing (cm)	Plant density ha^{-1}	Number of rows per strip	Inter- strip distance (cm)	Inter-strip space
T_1	45 × 30	51,948	4	120	Uncultivated
T_2	45 × 30	57,742	6	120	Uncultivated
T_3	45 × 30	51,948	4	120	Cultivated with Groundnut
T_4	45 × 30	57,742	6	120	Cultivated with Groundnut
T_5	45 × 30	58,608	4	90	Uncultivated
T_6	45 × 30	61,938	6	90	Uncultivated
T_7	45 × 30	58,608	4	90	Cultivated with Groundnut
T_8	45 × 30	61,938	6	90	Cultivated with Groundnut
T_9	60 × 30	55,555	No strips	0	No space

Fertilizers applied for the control treatment at sowing were 75 kg ha^{-1} of Urea, 100 kg ha^{-1} of Triple Super Phosphate and 50 kg ha-1 of Muriate of Potash and at 4 weeks after planting 250 kg ha^{-1} of Urea. The amount of fertilizers applied for the new planting geometries increased proportionately depending upon the plant density as outlined in (Table 2). Weed control was done manually. Pests and diseases were controlled by an integrated pest management (IPM) approach recommended by the Department of Agriculture with periodic spraying of recommended chemicals where necessary. The crops were harvested on 05th February 2021 and 23rd August 2021 in *Maha* and *Yala* seasons, respectively.

Measurements and data analysis

Daily weather data were collected from the nearest meteorological station (500 m away from the experimental site). A destructive sampling of four randomly-selected plants per plot was taken to measure the total leaf area per plant at 50% flowering (TLA) and total biomass at 50% flowering (TBM) while the net plot area (20 m^2) was used for measuring seed yield. TLA was measured using an automatic leaf area meter (LI 202, CID, Inc.). Dry weights of roots, stems, leaves and pods were measured by oven drying at 80 ^{o}C to a constant weight. Light interception was measured using the Canopy Analysis System Type SS1 (Delta-T Devices). Occurrence of FAW was recorded by counting larvae and pupae within the net plot area (20 m^2) and the level of damage was estimated by calculating the severity index at 6 weeks after planting (WAP). The time spent on spraying chemicals with a knapsack sprayer was measured using a stop watch. The data were analyzed using the General Linear Model (PROCGLM) using the software, Statistical Analysis System (SAS), Version 9.0. Duncan's New Multiple Range Test (DNMRT) was used to examine the significance of differences among treatments at *P*= 0.05.

Table 2. Amount of fertilizers applied for respective plant densities in different treatments

Treatment	Plant density ha^{-1}	Fertilizer application (kg ha^{-1})			
		Basal dressing		Top dressing	
		Urea	TSP	MOP	Urea
T_1	51,948	75	93.5	47	234
T_2	57,742	82	104	52	260
T_3	51,948	75	93.5	47	234
T_4	57,742	82	104	52	260
T_5	58,608	80	105.5	53	264
T_6	61,938	86	111.5	56	279
T_7	58,608	80	105.5	53	264
T_8	61,938	86	111.5	56	279
T_9	55,555	75	100	50	250

Results and Discussion

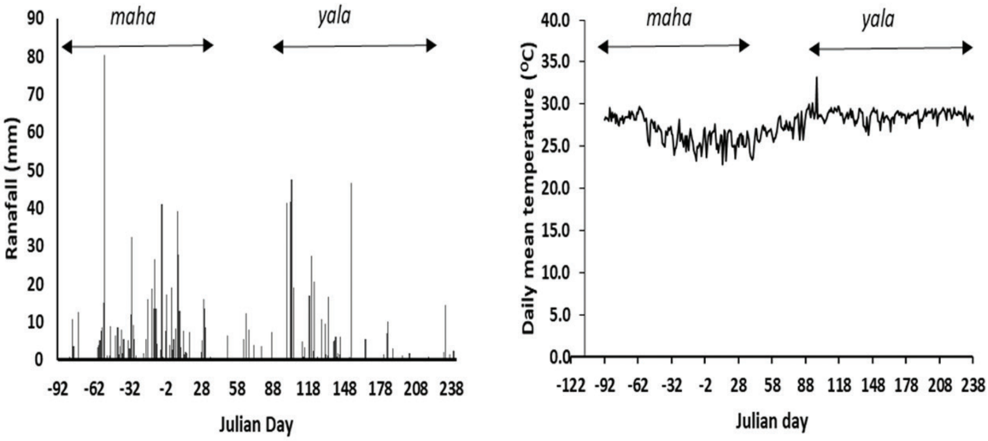
Weather during the experimental period

Total rainfall received during *Maha* and *Yala* seasons were 635 and 436 mm, respectively (Figure 2a). Rainfall received during the vegetative growth (249 mm) period was relatively low compared to the reproductive phase (358 mm) in *Maha* whereas in *Yala* a significantly higher rainfall was received during vegetative period (110.3 mm) than the reproductive period (41.2 mm) (Figure 2a). However, supplementary irrigation ensured that the crops were grown without any moisture limitation.

Mean seasonal temperatures experienced during two seasons were 29.1 °C and 27.9 °C in *Yala* and *Maha* respectively (Figure 2b). Thus, the crop has been undergone nearly optimum temperature ranges (Belfield and Brown, 2008) during the cropping period. In *Yala*, a slightly decreasing trend in temperature was observed towards the end of the season while an increasing trend was observed in *Maha* towards the end of the season.

Variation of crop growth of maize with the new planting geometry

Leaf area and biomass at 50% flowering ranged between 3,960-5,940 cm^2 $plant^{-1}$ and 4,016 -5,438 kg ha^{-1} in *Maha* 2020/21. In *Yala* 2021, they were 4,235-5,285 cm^2 $plant^{-1}$ and 3,813-5,430 kg ha^{-1} respectively. However, no statistical significant differences were observed among the treatments except for the biomass in *Yala* season where T_1 and T_3 recorded a significantly lower biomass compared to T_2, T_4 and T_8. However, in general, the measured growth parameters had not varied with the number of rows in a strip (T_2, T_4, T_6, T_8 vs T_1, T_3, T_5, or T_7), inter-strip distance (T_1, T_2, T_3, T_4 vs T_5, T_6, T_7 or T_8) or presence or absence of strips (T_9 vs rest of the treatments) (Table 3).



(a) (b)

Figure 2. Rainfall distribution (a) and daily mean temperature (b) during the two cropping seasons at Mahailluppallama

Table 3. Growth parameters and light penetration into canopy as affected by different row arrangements

Treatment	Leaf area (cm^2 plant^{-1})	Biomass (kg ha^{-1})	Leaf area (cm^2 plant^{-1})	Biomass (kg ha^{-1})	Total light penetrated through the canopy (W m^{-2})	
	2020/21 *Maha*		2021 *Yala*		2020/21 *Maha*	2020 *Yala*
T_1	4,180^{a}	4,287^{a}	4,966^{a}	3,840^{b}	959.9^{ab}	1,169.5^{a}
T_2	4,840^{a}	4,830^{a}	5,285^{a}	5,430^{a}	838.3^{ab}	1,128.1^{a}
T_3	5,060^{a}	5,189^{a}	4,573^{a}	3,813^{b}	704.6^{b}	1,098.6^{a}
T_4	4,400^{a}	4,483^{a}	5,178^{a}	5,073^{a}	801.1^{b}	990.0^{a}
T_5	5,060^{a}	5,058^{a}	4,869^{a}	4,755^{ab}	890.1^{ab}	1,075.1^{a}
T_6	3,960^{a}	4,016^{a}	5,169^{a}	4,681^{ab}	866.6^{ab}	1,077.9^{a}
T_7	5,940^{a}	5,438^{a}	4,451^{a}	4,613^{ab}	1,000.4^{a}	976.9^{a}
T_8	4,400^{a}	4,515^{a}	4,235^{a}	5,302^{a}	1,007.0^{a}	1,199.1^{a}
T_9	5,060^{a}	4,112^{a}	4,585^{a}	4,441^{ab}	756.8^{ab}	1,081.7
CV (%)	12.9	14.5	15.2	11.7	11.7	15.4

T_1 - Maize planted at 45 × 30 cm (4 rows) with 120 cm space (uncultivated) between strips; T_2 - Maize planted at 45 × 30 cm (6 rows) with 120 cm space (uncultivated) between strips; T_3 - Maize planted at 45 ×30 cm (4 rows) with 120 cm space (cultivated with groundnut) between strips; T_4 - Maize planted at 45 × 30 cm (6 rows) with 120 cm space (cultivated with groundnut) between strips. T_5 - Maize planted at 45 × 30 cm (4 rows) with 90 cm space (uncultivated) between strips; T_6 - Maize planted at 45 × 30 cm (4 rows) with 90 cm space (uncultivated) between strips; T_7 - Maize planted at 45 × 30 cm (4 rows) with 90 cm space (cultivated with groundnut) between strips; T_8 - Maize planted at 45 × 30 cm (6 rows) with 90 cm space (cultivated with groundnut) between strips T_9- Maize planted at 60 × 30 cm (control)

The per plant nutrient supply was same for all plant densities and water was supplied adequately without causing any moisture stress in all treatments. Thus, light availability could be the only possible limiting factor that might have an impact on crop growth. Whereas the amount of light penetrated through the canopy remained unchanged irrespective of the planting geometry (Table 4). Although the plant density is highly sensitive to nutrient supply (Monneveux *et al.,* 2005), the modified planting arrangement did not influence an inter-plant competition due to a resource limitation probably due to the proportionate increase in fertilizer application under each density. The objective of the new planting geometry was to keep either an approximately as same plant density as current recommendation or a higher plant density ensuring that external resources such as nutrients, water and light are utilized with minimum limitations. To achieve this the maximum allowable number of rows per strip was selected as 4 or 6 expecting maximum light penetration from either side of the strip. Thus, the absence of statistical differences among treatments in the measured growth parameters indicated that an inter-strip distance of 90 or 120 cm with either 4 or 6 maize rows had not negatively influenced the growth of the plants. However, it seemed that maintaining a 90 cm distance was much easier in practical terms since the famer could simply leave a single row unplanted to create this 90 cm gap between strips (T_5, T_6, T_7 and T_8). In contrast, for

T_1, T_2, T_3 and T_4 the farmer would have to determine the distance of 120 cm while planting the remaining rows at the spacing of 45 cm (Table 1).

Variation of grain yield and yield components of maize with the new planting geometry

The average cob number per square meter varied between 5.2-6.3 in *Maha* and 5.4-6.3 in *Yala* (Table 4). The cob number increased significantly obviously with the increasing plant densities (T_2, T_4, T_5, T_6, T_7 and T_8) in both seasons. Hundred seed weight (HSW) did not show significant differences in both seasons except between T_5 and T_6 in *Yala*. However, the observed values (28.3-31.1 g in *Maha* and 28.0-30.0 g in *Yala*) (Table 4) fell within the values recorded from many hybrid maize varieties (Deivasigamani and Swaminathan, 2018; Rathnayaka *et al.,* 2010). There were no significant differences among treatments in the number of seeds per cob. Grain yield ranged between 5.48-6.53 in *Maha* and 6.19-8.10 t ha^{-1} in *Yala* (Table 5) but did not show statistically significant differences in alternative plant geometries in compared with the control (T_9) in both seasons indicating new planting geometry did not have negative impacts on the overall crop productivity. However, few differences were observed between some treatments (T_3 and T_7 vs T_6 in *Maha* and T_1 vs T_2, T_4, T_5, T_6 in *Yala*) which could be attributed to variations in plant densities. Maize yield is largely dependent on the number of plants per unit area which is one of the important yield components (Malaviarachchi *et al.*, 2007). Although yield increases would be expected in T_2, T_4, T_5, T_6, T_7 and T_8 due to 4%, 5.5% and 11.5 % greater plant densities (57,742, 58,608 and 61,938 plants/ha) in comparison to the control (55,555 plants ha^{-1}), it was not achieved in both seasons. However, it was shown in this study that all the modified planting geometries ultimately achieved similar yields compared to the control (current practice). This was further supported by the analysis of orthogonal contrasts (Table 6) where significant yield differences were observed only in the contrast "Control treatment (T_9) vs others". Moreover, maize yield was not influenced by groundnut when cultivated in between the strips (T_3, T_4, T_7 & T_8) in comparison to the treatments where the space in between strips was kept uncultivated (Table 6).

Thus, the absence of significant yield differences among treatments indicated that planting geometry could be rearranged without any negative impacts on yield in order to facilitate pesticide applications even at matured stages of the crop against FAW. Further, seed yield obtained from groundnut within the inter-strip area were 29. 76. 15.6, 26.55 and 13.78 kg ha^{-1} in *Maha* while they were 71.90, 40.97, 66.56 and 36.48 kg ha^{-1} in *Yala* in T_3, T_4, T_7, and T_8 respectively (Table 5). *Maha* yields were lower than Mala probably due to comparatively lower light availability in Maha and heavy rainfall experienced during the pod maturity stage. Considering the cost of cultivation (Rs 123.00/kg) and farm gate price (Rs 405.00/kg) of groundnut (DoA. 2020), the additional profit a farmer could earn from groundnut per hectare was marginal in *Maha* (Rs 3,885.96 – 8,392.80) whereas it was considerable in *Yala* (Rs 10,287.36 -20,275.80).

Table 4. Yield parameters as affected by different row arrangements in 2020/21 *Maha* and 2021 *Yala* seasons

Treatment	Cob number/m^2		Number of seeds/ cobs		Hundred seed weight at 14% moisture (g)	
	2020/21 *Maha*	2021 *Yala*	2020/21 *Maha*	2021 *Yala*	2020/21 *Maha*	2021 *Yala*
T_1	5.2^c	5.5^c	489^a	503.5^a	30.1^a	29.5^{ab}
T_2	6.0^{ab}	6.0^b	456^a	509.5^a	29.2^a	29.0^{ab}
T_3	5.5^c	5.5^c	492^a	540.0^a	30.4^a	30.0^{ab}
T_4	5.9^b	6.0^b	452^a	532.0^a	30.1^a	28.5^{ab}
T_5	5.9^b	5.9^b	493^a	543.0^a	29.5^a	28.0^b
T_6	6.1^b	6.3^a	499^a	525.5^a	28.3^a	30.5^a
T_7	5.9^b	5.9^b	459^a	522.0^a	31.1^a	29.5^{ab}
T_8	6.3^a	6.3^a	476^a	534.0^a	28.8^a	29.0^{ab}
T_9	5.4^c	5.4^c	472^a	534.0^a	29.9^a	29.5^{ab}
CV (%)	2.3	1.2	7.0	5.2	3.7	3.6

Note: Please refer to table 3 for treatment caption

Table 5. Seed yield of maize and groundnut as affected by different row arrangements in 2020/21 *Maha* and 2021 *Yala* seasons

Treatment	Maize (t ha^{-1})		Groundnut (kg ha^{-1})	
	2020/21 *Maha*	2021 *Yala*	2020/21 *Maha*	2021 *Yala*
T_1	5.54^{ab}	6.19^b	-	-
T_2	5.72^{ab}	8.04^a	-	-
T_3	5.48^b	7.28^{ab}	29.76^a	71.90^a
T_4	5.58^{ab}	7.73^a	15.60^{bc}	40.97^b
T_5	5.73^{ab}	7.70^a	-	-
T_6	6.53^a	8.10^a	-	-
T_7	5.45^b	6.88^{ab}	26.55^{ab}	66.56^a
T_8	5.59^{ab}	6.76^{ab}	13.78^c	36.48^b
T_9	5.57^{ab}	6.76^{ab}	-	-
CV (%)	7.1	12.2	16.3	3.7

Note: Please refer to table 3 for treatment caption

Table 6. Orthogonal contrasts for seed yield of maize planted under different planting geometries

C ontrast	DF	Contrast SS	Mean Square	Probability
Control (T_9) vs Others	1	2,878,664.71	2,878,664.71	0.0118
Inter-strip distance 120 vs Inter-strip distance 90	1	746,772.51	746,772.51	0.1057
6 rows per strip vs 4 rows per strip	1	671,832.56	671,832.56	0.1204
Strip uncultivated vs Cultivated with Groundnut	1	54,121.36	54,121.36	0.6183

Fall armyworm infestation during two seasons

FAW infestation was comparatively lower in 2020/21 *Maha* than that of 2021 *Yala* at 6 weeks after seeding. Furthermore, the infestation level during the two seasons was generally lower in comparison to the previous seasons at the experimental site. The number of larvae observed within the plot area (20 m^2) did not show significant differences in all modified planting geometries compared to the control treatment in *Mah*a season (Table 7). This could be attributed to the lower pest infestation during that season. However, significant statistical differences were observed among some of the treatments (T_6 vs T_1, T_3, T_5 & T_7) in *Yala* season. Moreover, the level of damage was similar to the control (T_9) in T_2, T_4, T_6 and T_8 where a maize strip consisted of 6 rows while it was lower in other treatments which consisted of 4 rows in a strip (T_1, T_3, T_5 and T_7) in *Yala*. These results suggests that under a comparatively higher pest infestation level (in *Yala* compared to *Maha*), the planting geometries with a broader strip width (6 rows per strip) may have reduced the effectiveness of applying insecticides, perhaps, into the middle rows potentially resulting in a higher severity index in T_2, T_4, T_6 and T_8. A similar inefficiency in spraying chemicals could be expected in the control treatment too due to the difficulty in moving within the crop in the current planting geometry. Thus, the pest severity index showed more or less similar values in the control too compared to the treatments with 6 row strips.

Table 7. Abundance of larvae and severity of FAW infestation at 6 weeks after establishment

Treatment	Number of caterpillars/20 m^2	Number of caterpillars/20 m^2	Severity index	Severity index
	2020/21 *Maha*	2021 *Yala*	2020/21 *Maha*	2021 *Yala*
T_1	19.5^a	27.4^b	19.7^b	20.1^b
T_2	18.5^a	38.5^{ab}	23.5^{ab}	33.6^a
T_3	21.0^a	29.0^b	23.1^{ab}	23.1^b
T_4	17.0^a	31.5^{ab}	23.5^{ab}	36.5^a
T_5	18.0^a	26.0^b	25.1^{ab}	21.7^b
T_6	24.0^a	45.3^a	25.1^{ab}	36.1^a
T_7	17.2^a	28.7^b	22.6^{ab}	21.6^b
T_8	21.3^a	33.0^{ab}	23.9^{ab}	33.9^a
T_9	27.0^a	40.5^{ab}	27.5^a	31.6^a
CV%	18.9	14.2	11.80	12.2

Note: Please refer to table 3 for treatment caption

Time saving and practical feasibility in applying agro - chemicals

The time spent on spraying a pesticide to the experimental plots of maize crop with different row arrangements varied between 1.65 - 3.08 minutes in *Maha* season and between 1.69 - 3.20 minutes in *Yala* seasons. The differences in time spent on spraying between two seasons were mainly due to the difference in application efficiency of the person responsible. Alternative planting geometries where maize was planted as strips with (T_3, T_4, T_7, T_8) or without (T_1, T_2, T_5, T_6) any crop in between significantly reduced the time required for insecticide spraying in comparison to the control (T_9) during both seasons (Table 8). It seemed that cultivation of a crop in between strips did not disrupt the movements of the sprayer. The time difference observed between strip planting and the regular planting (On average 1.2 minutes in *Yala* and 1.0 minutes in *Maha*) corresponded to an estimated saving of 5.6 and 4.6 hours per hectare respectively. Whereas this extrapolation would be even higher in larger-scale farming where maneuvering the knapsack sprayer within the entire cropping area is more challenging compared to a research plot. Moreover, considering the fact that most farmers own larger extents of land in the main maize growing areas, this time-saving aspect is particularly significant amid severe labor shortages during the cultivation season. Therefore, our observation suggests that handling the sprayer is much easier when planted in strips on a larger scale.

Table 8. Time required to spray plants in each plot with different row arrangements

Treatment	Time (minutes/plot)	
	2020/21 *Maha*	2021 *Yala*
T_1	1.65^{b}	1.69^{c}
T_2	1.92^{b}	2.24^{bc}
T_3	1.85^{b}	2.03^{bc}
T_4	1.91^{b}	1.84^{bc}
T_5	1.93^{b}	2.15^{bc}
T_6	1.90^{b}	2.21^{bc}
T_7	2.05^{b}	2.44^{b}
T_8	2.03^{b}	2.19^{bc}
T_9	3.08^{a}	3.20^{a}
CV (%)	9.1	11.8

The recommended approach for controlling FAW is an integrated pest management approach (IPM) which should be implemented from seeding to harvesting (Day *et al.*, 2017). IPM does not imply that the crop is maintained under completely chemical free conditions but rather involves spraying chemicals as needed based on the threshold infestation level determined at different stages of plant growth, as FAW can attack at any stage (Bateman *et al.*, 2018). It is crucial to apply pesticides to the growing crop at the right time and in the correct manner, such as directing the spray into the funnel when using knapsack sprayers. (Abrahams *et al.*, 2017). However, the height and the canopy characteristics of maize make it difficult for individuals to spray chemicals effectively in a larger cropping area by moving among the plants in the current planting geometry. Therefore, this study explored the practicality of spraying pesticides using strip planting. This is particularly important for pest control because the smaller larvae remain inside the funnel of older plants while the larger larvae can bore into the developing reproductive structures such as maize cobs. The traditional way of spraying may have helped protect pests within these structures especially because the efficacy of pesticides depends upon contact. (Bateman *et al.*, 2018). Few chemicals have been tested and identified as effective against FAW under Sri Lankan conditions (Gunewardena *et al.,* 2019) and they could be applied effectively once the new planting geometry is adopted.

One of the secondary objectives of the experiment was to test whether planting another crop in between maize strips could reduce the FAW infestation by creating a diversified plant environment. It has been reported that companion plants can control insect pests either directly by deterring pest establishment or indirectly by attracting natural enemies that kill the pest (Parker *et al.*, 2013; Vandermeer, 1989). However, due to the low pest infestation during both seasons, the effect of this approach could not be practically demonstrated in this experiment. Therefore, further experiments are suggested under conditions of a significant FAW population.

Conclusions

Maize planted at 45 × 30 cm in 4 rows strips with a space of 90 cm between strips cultivated with groundnut could be recommended as an effective plant geometry which facilitates both chemical application on FAW with no yield disadvantages and seeding at comparatively low cost. The fertilizer level that should be applied at this planting geometry would be 347, 107 and 53.5 kg ha^{-1} of Urea, Triple Super Phosphate and Muriate of Potash respectively. However, further studies are suggested to assess the potential economic benefits and repellent effects on FAW of incorporating a companion crop within the inter-strip area.

References

Abrahams, P., Bateman, M., Beale, T., Clottey, V., Cock, M., Colmenarez, Y., Corniani, N., Day, R., Early, R., Godwin, J. L., Gomez, J., Gonzalez-Moreno, P., Murphy, S. T., Oppong-Mensah, B., Phiri, N., Pratt, C., Richards, G., Silvestri, S., Witt, A. (2017). Fall armyworm: impacts and implications for Africa. Evidence Note (2), September 2017. Wallingford, UK: CABI

Afonso-Rosa, A. P. S. & Barcelos. H.T. (2012). Bioecologia e controle de Spodoptera frugiperda em milho. Pelotas: Embrapa Clima Temperado; *Embrapa Informação Tecnológica*, 2012, 9-10.

Anonymous. (1998). *Saubhagyamath Sri LankawakSandaha*. Crop recommendations. Department of Agriculture, Sri Lanka. pp. 7-9.

Bateman, M. L., Day, R. K., Luke, B., Edgington, S., Kuhlmann, U., Cock. M. J. W. (2018). Assessment of potential bio-pesticide options for managing fall armyworm (*Spodoptera frugiperda*) in *Africa*. *Journal of Applied Entomology*, 142, 805–819.

Belfield, S. & Brown, C. (2008). Field Crop Manual: Maize. A Guide to Upland Production in Cambodia. New South Wales Department of Primary Industries. New South Wales, Australia.

Climate & Food Security Monitoring Bulletin. (2019). World Food Programme, No 2, Jawatte Avenue, Colombo 05. Issue. January - March 2019.

Day, R., Abrahams, P., Bateman, M., Beale, T., Clottey, V., Cock, M., Colmenarez, Y., Corniani, N., Early, R., Godwin, J., Gomez, J., Moreno, P. G., Murphy, S. T., Oppong-Mensah, B., Phiri, N., Pratt, C., Silvestri, S. & Witt, A. (2017). Fall armyworm: Impacts and implications for Africa. *Outlooks on Pest Management* 28, 196-201.

Deivasigamani, S. & Swaminathan, C. (2018). Evaluation of Seed Test Weight on Major Field Crops. *International Journal of Research Studies in Agricultural Sciences* (IJRSAS), 4 (1), 8-11.

DoA. (2020). *Agriculture Statistics.* Socio Economic and Planning Centre, Department of Agriculture, Peradeniya, Sri Lanka.

Gunewardena, K. N. C. &. Madugalla, S. R. K. (2011). Efficacy of selected granular insecticides for the control of maize-stem borer (*Chilo partellus*) (lepidoptera: pyralidae). *Tropical Agricultural Research & Extension*, 14(1), 12-15.

Gunewardena, K. N. C., Nadeeshani, S. M. A. O., & Sandaruwani, P. A. I. (2019). Strategies for sustainable management of Fall Armyworm in Sri Lanka. *Annals of Sri Lanka Department of Agriculture*, 21, 169p.

Gunewardena, K. N. C., Wickramasooriya, I. P. S. D. & Jayanthi. K. P. (2016). Management of maize stem borer *Chilo partellus* swinhoe (lepidoptera: pyralidae) using selected plant powders with insecticidal properties. *Annals of Sri Lanka Department of Agriculture*, 18, 118-120.

Huis, A. V. (1981). Integrated pest management in the small farmer's maize crop in Nicaragua. *Mededelingen Landbouwhogeschool Wageningen*, 81(6), 221p.

Khan, M. A., Khan, A. H., Ahmad, K., & Baloch, M. S. (1999). Control of stem borer by different insecticides in corn hybrid 4208. *Pakistan Journal of Biological Sciences*, 2(3), 612-613.

Malaviarachchi, M. A. P. W. K., Karunarathne, K. M., & Jayawardane, S. N. (2007). Influence of plant density on yield of hybrid maize (*Zea mays* L.) under supplementary irrigation. Journal of Agricultural Sciences - Sri Lanka, 3(2), 58-66.DOI: https://doi.org/10.4038/jas.v3i2.8100

Monneveux, P., Zaidi, P. H., & Sanchez, C. (2005). Population density and low nitrogen affects yield-associated traits in tropical maize. *Crop Science*, 45(2), 535-545.

Ontario Crop IPM. (2017). Fall Armyworm. Available at: http://www.omafra.gov.on.ca/IPM/english/sweet-corn/insects/fall armyworm.html#advanced. (Accessed on: 05 December 2020).

Panabokke, C. R. (1996). Soils and agro-ecological environments of Sri Lanka. *Natural Resources*, 35-101.

Parker, J. E., Snyder, W. E., Hamilton, G. C., & Rodriguez-Saona, C. (2013). Companion planting and insect pest control. *Weed and pest control-conventional and new challenges*, 10, 55044.

Perera, M. T. M. D. R. (2019). Occurrence, taxonomic identification and life cycle of Fall Army Warm in Sri Lanka. *Annals of the Department of Agriculture*, 21, 4p.

Perera, R. N. N., Magamage, M. P. S., & Siriwardhana, C. (2019). Implications of Fall Armyworm epidemic in Sri Lanka: A case study in Rathnapura district. 4th International Research Symposium on Pure and Applied Sciences. (p. 41). Faculty of Science, University of Kelaniya, Sri Lanka.

Punyawardana, B. V. R. (2008). Evolution of climatic zones in Sri Lanka. *Agro-climatological Zones and Rainfall Pattern in Sri Lanka* (in Sinhala medium). (pp. 44-113). Department of Agriculture, Sri Lanka.

Rathnayaka, A. E., Malaviarachchi, M. A. P. W. K. and Senanayake N. (2010). Growth and yield of commercial hybrid maize (*Zea mays* L.) varieties under dry zone rainfed conditions. *Proceedings of the second Annual Research Symposium*, (p 21.). Rajarata University of Sri Lanka.

Sarmento, R. A., Aguiar, R.W. S. A., Aguiar, R. A. S. S., Vieira, S. A. M., Oliveira, H., & Holtz, A. M. (2002). Revisão da biologia, ocorrência e controle de Spodoptera frugiperda (Lepidoptera, Noctuidae) em milho no Brasil. *Bioscience Journal*, 18, 41–48.

Stewart B.A. & Peterson, G.A. (2015). Managing green water in dry land agriculture. *Agronomy Journal*, 107, 1544–1553.

Vandermeer J. H. (1989). The Ecology of Intercropping. Cambridge University Press, New York, New York, USA.

Yonow, T., Darren, J. K. Ota, N. Berg, J. V. D. & Hutchiso, W. D. (2017). The potential global distribution of *Chilo partellus*, including consideration of irrigation and cropping patterns. *Journal of Pest Science*, 90, 459–477.