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Effect of integrating night-time light traps and push-pull method on monitoring and deterring adult fall armyworm (*Spodoptera Frugiperda*)

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Abstract
The fall armyworm, *Spodoptera frugiperda* (J.E. Smith; Lepidoptera: Noctuidae), native to tropical and sub-tropical America, has become one of the most devastating pests in terms of crop loss and economic impact in Ethiopia and Africa. In Ethiopia, *S. frugiperda* infestations are reported in the Southern Nations, Nationalities and Peoples` State on March 2017 and spread fast to other states to become an epidemic pest in June 2017. Therefore, devising affordable and effective alternative options for control of *S. frugiperda* is paramount important. Therefore, a study was carried to evaluate the effect of integrating night-time light traps and push pull method on monitoring and deterring of *S. frugiperda*. Significantly greater number of *S. frugiperda* moths were captured in traps placed outside maize plots treated with light-push pull than traps placed outside control, light-trap or push pull treated maize plots ($P < 0.001$) during the period of July to end of October 2019 except in November. This resulted in lower number of moths inside maize plots treated with the integration of light-push pull method. This study depicted that integrating night-time light trap and push pull plants led to the capture of greater number of *S. frugiperda* moths than using light traps or push pull plants alone. Further study is needed to investigate whether the effect of integrating night-time light trap and push pull method can consequently reduce the population of other life stages of the insect involving the eggs, larvae and pupae.

Keywords: Fall armyworm (*Spodoptera Frugiperda*); Push pull method; Silver leaf desmodium, Sudan grass; Night-time light trap

1. Introduction
In Ethiopia, maize (*Zea mays* L.) is one of the major cereal crops grown for its food and feed values, being major stable food and feed sources for millions of Ethiopians [1, 2, 3, 4]. Insect pest problem is one of the major challenges of maize production in the country [1, 4]. Recently, the maize production in different states of the country have been threatened by an exotic pest called Fall army worm (*Spodoptera frugiperda* J.E. Smith [5]. The Fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae), believed to be originated in the tropics and subtropics of the America, is a devastative insect pest that causes damage to almost 100 plant species including maize, rice, sorghum, wheat and sugarcane but also vegetable crops and cotton [6,7]. *S. frugiperda* is a highly mobile insect pest [8,9,10]. It reproduces during the rainy season, during which the moths lay their eggs on crops. Their hatched larvae march in groups, devouring food sources they come across. They subsequently pupate to form moths, each of which can fly up to 1,000 km and lay 1,000 - 2,000 eggs in its 10-day lifetime [9]. Long-distance migration of *S. frugiperda* moths benefit from strong and persistent wind patterns [10]. *S. frugiperda* is one of the most devastating pests in terms of crop loss and economic impact, l*et al*one developing countries, even in high income countries such as United States, yearly losses to *S. frugiperda* ranges between USD 39 million and 297 million [5]. In case of Africa, outbreaks of *S. frugiperda* has been reported in Botswana, Democratic Republic of Congo, Ghana, Kenya, Malawi, Namibia, South Africa, Swaziland, and Zambia since 2016 [5,6]. Further spread of Fall Armyworm was observed in Ethiopia, Tanzania, and Zimbabwe [6]. What makes this pest sever is that forecasts show for high possibility of *S. frugiperda* spread to other African countries and might sustain and become regular pest in the continent [6]. In Ethiopia, the fall armyworm infestations are reported in the Southern Nations, Nationalities and Peoples` State on March 2017 and spread fast to other states to become an epidemic pest in June 2017 damaging maize crops [11]. Therefore, devising long-term and sustainable monitoring strategies for the control of this insect pest is vital. In other countries, management of *S. frugiperda* is mainly monitoring-based Integrated Pest Management. Monitoring methods for *S. frugiperda* in various countries such as USA, mainly involve use of specific pheromone traps (involving [(Z)-7-dodecenyl acetate (Z7-12: Ac), (Z)-9-dodecenyl acetate (Z9-12: Ac), (Z)-9-tetradecenyl acetate (Z9-14: Ac), and (Z)-11-hexadecenyl acetate (Z11-) and push-pull method [8,7,12]. Pheromone-based monitoring has been proven effective in controlling adult stage of many lepidopteran species [8,9,12] including *S. frugiperda* [9,12, 13]. Based on monitoring results, different management approaches are applied depending on the status of the pest. For instance, in the Americas, following monitoring, pesticides, biological control, and/or genetically modified (GM) crops are used for the control of *S. frugiperda* [6]. Other climate-smart method of management includes the 'push-pull' strategy, a novel tool for integrated pest management programs, uses a combination of behavior-modifying stimuli to manipulate the distribution and abundance of insect pests and/or natural enemies [14,15,16,17,18]. In this strategy, the pests are repelled or deterred away from the main crop (push) by using stimuli that mask host apparency or are repellent or deterrent. For example, desmodium plant (*Desmodium* sp.) or molasses

grass are used as repellent to various lepidopteran pests [18, 20]. The pests are simultaneously attracted (pull), using highly apparent and attractive stimuli to other areas such as traps or trap crops like Napier grass (*Pennisetum purpureum*) or Sudan grass (*Sorghum sudanense*), where can be concentrated, facilitating their control [15,17,19,20]. Integrating monitoring and push-pull system could be an effective control method for *S. frugiperda*. In developing countries such as Ethiopia, there is a problem of accessing pheromone traps-based monitoring and is not affordable in farmers` capacity. Therefore, devising affordable and effective alternative options for monitoring of the *S. frugiperda* and other invasive insect pests and integrating with the push-pull method which has shown promising result in different Eastern countries such as Kenya and Uganda are vital [17, 20]. It is known that, adults (both male and female) of many lepidopteran species including *S. frugiperda* are characterized by their rapid positive response to light during night-time [21, 22, 23]. Thus, we hypothesized that night-time light-trapping system could be effective way of monitoring and mass trapping of adult *S. frugiperda*. Reports in Kenya shows that push-pull method has resulted in promising results in reducing the devastating effect of *S. frugiperda* [7, 20]. Therefore, the aim of this research was to devise integrated monitoring and deterrent system using night-time light trapping and push-pull system to greatly reduce the next generation of *S. frugiperda*.

2. Methodology

2.1. Study Area

Field experiment was carried out in Hawzien Woreda, Hatset Kebele (Kebele: a small administrative area), Northern Ethiopia. The district is located at elevation from 1800 – 2105 m.a.s.l and receives an annual rainfall of up to 500 mm year^{-1} and temperature range of 18-28^{o}C. The communities in the kebele, like the other districts of the Northern Ethiopia, are dependent on mixed Agriculture involving production such as wheat, maize, sorghum, and barley and livestock production being the main livelihood. The administrative area was selected because it has been greatly affected by *S. frugiperda* since 2017, damaging maize crops. The experimental site was maize crop fields. The study was conducted from July to November 2019.

2.2. Materials

2.2.1. Light trap

Solar-charged light (d.light, S2 Lamp: 3.2V, 72-93mA) was used as night-time light source for the light trap. The light trap was designed in a way involving d.light in a cylindrical transparent plastic container covered with white Abujedid (trap size: 15 cm diameter, 30 cm height) applied with molasses (as adhesive material) and hanged at 1.5 m height in a wooden robe above ground.

2.2.2. Planting materials for push-pull

In the push-pull system, silver leaf desmodium (*Desmodium uncinatum*) as repellent plant (push-plant) Sudan grass (*Sorghum sudanense*) as trap plant (pull-plant) were used. The seeds of silver leaf desmodium were obtained from Aksum Agriculture Research Center and Sudan grasses were obtained from Wukro Agriculture College. Maize (*Zea mays* L.; Variety: Melkassa-1Q)) seeds were obtained from Hawzien Woreda Seed Distribution Office.

2.3. Treatments and experimental design

2.3.1. Experiment 1: Adult S. frugiperda captured on traps placed outside maize plots under different treatments

The experiment had four treatments involving untreated (control that is maize crop), light traps-treated (maize plant with night-time light traps at edges), push-pull treated (silver leaf desmodium intercropped with maize and Sudan grass planted at all edges of maize plot), and night-time light-trap plus push-pull treated maize crop fields (See detailed description of treatments in Table 1) each replicated five times. The treatments were laid out using Completely Randomized Design (CRD).

Table 1. Description of treatments

Treatment	Description
Control	Maize crops (four rows of maize crops with 6 plants per row = 24 plants), 0.5m: 0.5m inter-row: intra-row spacing, without light trap and push-pull treatment but treated with lightless trap
Night-time light trap treated maize plants (Light trap)	Maize crops (four rows of maize crops with 6 plants per row (24 plants), with the same spacing as described above, surrounded by six light traps at 2m interval between traps and 1m away from the plot in all sides.
Push-pull treated maize crop (Push-pull)	Maize crops intercropped with silver leaf desmodium, with the same spacing as described above (three rows of maize + silver leaf desmodium with 0.5m intra-row spacing) surrounded by two rows of pull-plant (Sudan grass), treated with lightless trap.
Push-pull + light trap-treated maize crops (Light-push pull)	Maize crops intercropped with silver leaf desmodium, (four rows of maize + desmodium with the same spacing as described above) surrounded by two rows of pull-plant (Sudan grass). The field is then surrounded by six light traps at 2m interval between traps and 1m away from the plot in all sides.

2.3.2. Experiment 2: Adult S. frugiperda captured on traps placed inside maize plots under different treatments

The number of adult *S. frugiperda* inside maize plots exposed to the four different treatments (control, light traps-treated, push-pull treated, and light trap-push pull treated maize crop fields) (See detailed description of treatments in Table 1) were also considered as separate treatment. This is aimed to determine the effect of the different treatments in deterring *S. frugiperda* from interring into the maize plots.

2.4. Data collection

The number of adult *S. frugiperda* captured in traps of the different treatments, outside and inside the maize plot, were counted biweekly.

2.5. Data analysis

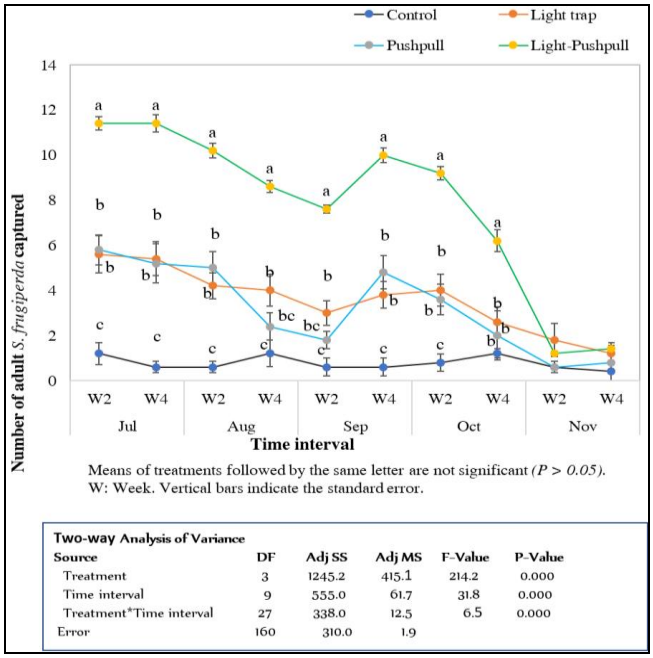
Collected data were analyzed using MINITAB 17 software package. The number of adults caught in traps, inside and outside maize plots exposed to different treatments and interaction effect have been subjected to Analysis of

Variance (ANOVA) after the data normality was checked. Any significant difference among treatment means were compared using Tukey-Kramer Multiple Range Test (at 5% alpha level) or Least Significant Difference (LSD 5%).

3. Results and discussion

3.1. Adult S. frugiperda captured on traps placed outside of maize field plots under different treatments

The result shows that the number of *S. frugiperda* moths captured in traps were significantly differed among the different treatments (Fig. 1; $P < 0.001$) throughout the experiment period except in November in which there was no significant difference among the treatments ($P > 0.100$). Significantly greater number of *S. frugiperda* moths were captured in traps placed outside maize plots treated with light-push pull than the remaining treatments (Fig. 1; $P < 0.001$) during the period of July to end of October except in November in which there was no significant difference among the four treatments. *S. frugiperda* Moths captured on traps placed outside maize field plots treated with light-trap and push pull treatments were significantly greater than the control treatment (Fig. 1). However, *S. frugiperda* Moths captured on traps placed outside maize field plots treated with light traps were statistically similar with push pull treatments in majority of the experiment period. As shown in Fig. 1, the population of the *S. frugiperda* moths varied among the time interval which was higher from July to October with lowest capture of the insect in November (Fig 1. Anova; $P < 0.001$). The interaction of treatments and time interval during the study period also significantly affected the capture of adult *S. frugiperda* (Fig 1. Anova; $P < 0.001$). In November, the population of the *S. frugiperda* moths greatly reduced. This might be because of the reason that majority of the crops have been whether under harvest or dried which does not support the survival of the insect. Besides, as the weather gets colder, the insect has less survival probability. The current result indicates that combining night-time light traps and push pull plants can significantly reduce the entrance of *S. frugiperda* moths to maize fields. The higher number of moths captured on traps outside the light-push pull treated maize plots indicates that putting light traps at the edges of push pull treated maize fields has an additive effect in reducing the entrance of the insect into the maize field. This is because, during the night, the light trap attracts the moths resulting in their capture and during the day the push plant deters them from the entering the maize field by releasing repellent volatiles. As previous findings indicated, push pull uses a combination of behavior-modifying stimuli to manipulate the distribution and abundance of insect pests and/or natural enemies [14,15,17,18,19]. In a push pull technology, pests are repelled or deterred away from the main crop by using stimuli that mask host apparency or are repellent or deterrent (push) [17,20], in the current study is the silver desmodium plant. The pests are simultaneously attracted (pull), using highly apparent and attractive stimuli to edges by trap crops [15,16,17,18,20], in the current study case is the Sudan grass, where *S. frugiperda* moths are concentrated, facilitating their capture by light trap during the night time.



Two-way Analysis of Variance

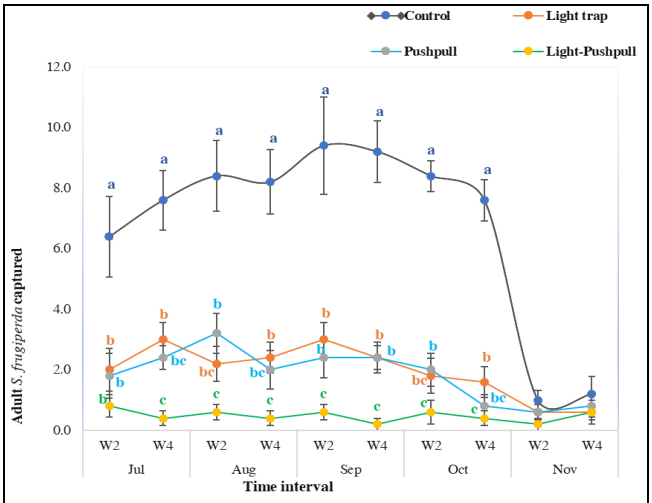
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	3	1245.2	415.1	214.2	0.000
Time interval	9	555.0	61.7	31.8	0.000
Treatment*Time interval	27	338.0	12.5	6.5	0.000
Error	160	310.0	1.9		

Fig 1: Adult s. frugiperda captured in traps outside maize field plot as exposed to different treatments

3.2. Adult *S. frugiperda* captured on traps placed inside maize field plots under different treatments

The number of *S. frugiperda* moths captured on traps inside maize plots exposed to different treatments were significantly different throughout the experiment period (Fig. 2; $P < 0.001$) except on November in which there was no significant difference among the treatments (Fig. 2; $P > 0.10$). Significantly greater number of *S. frugiperda* moths were captured on control traps placed inside plots than the remaining three treatments followed by light trap treated or push pull treated maize field plots. In majority of the study period, the number of *S. frugiperda* moths captured on light trap treated and push pull treated maize field plots are significantly greater than the light-push pull treatment (Fig. 2; $P > 0.10$). This depicts the light-push pull treatment effectively deterred the entrance of adult *S. frugiperda* to inside the maize field plot. The interaction of treatments and time interval during the study period significantly affected the capture of adult *S. frugiperda* (Fig 2. Anova; $P < 0.001$). The number of adult *S. frugiperda* captured varied among the time interval with November with lowest capture of the insect (Fig 2. Anova; $P < 0.001$). The greater number of moths captured on control maize plots indicates that maize fields with no light trap or push pull methods are prone to the insect. On the contrary, using push pull, night-time light trap and in the best way integrating night-time light trap and push pull greatly reduce the entrance of the insect to maize fields/plots as explained in 3.2 of this study. In the principle of push-pull system the repellent/deterrent plant, i.e. the silver leaf desmodium produces volatile chemicals, such as (*E*)-ß-ocimene and (*E*)-4,8-dimethyl-1,3,7-nonatriene, which repel the *S. frugiperda* moths from the maize ('push') [20]. The trap crop, i.e. the Sudan grass releases volatile chemicals like octanal, nonanal, naphthalene, 4-allylanisole, eugenol and linalool,

which attract female moths ('pull') to lay eggs on it rather than on maize [20] or can be captured by night-time light trap as found on the current study which enhances (additive effect) the control of the insect. Therefore, the current study confirms that by monitoring and deterring *S. frugiperda* moth population away from the maize fields and capturing by night-time light traps, it is possible to significantly reduce and control the entrance of the pest into the field with the target crop (maize). Consequently, by deterring the female moth from laying eggs on the target crops and capturing on night-time light traps, it is expected that the other life stages (eggs and larvae) can be reduced significantly from becoming a problem, though needs further investigation.



Analysis of Variance					
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	3	1093.1	364.4	188.30	0.000
Time Interval	9	223.5	24.8	12.83	0.000
Treatment*Time Interval	27	250.1	9.3	4.79	0.000
Error	160	309.6	1.9		
Total	199	1876.3			

Figure 2. Adult *S. frugiperda* captured inside maize field plots as exposed to different treatments

Fig 2: Adult s. frugiperda captured in side maize field plot as exposed to different treatments

4. Conclusion

Considering the importance of maize for Ethiopians, being major stable food and feed sources for millions in the country, controlling the devastating insect pest of the crop, *S. frugiperda*, is paramount important. This study depicted that integrating night-time light trap and push pull plants led to the capture of greater number of *S. frugiperda* moths than using light traps or push pull plants alone. This resulted in deterrence of *S. frugiperda* moths from entering to maize plots. Thus, the current study is the first to report the importance of integrating night-time light trap with push pull method to control *S. frugiperda* in maize fields. However, whether the other life stages involving the eggs, larvae and pupae population can be significantly reduced as a result of integrating night-time light traps and push pull plants, needs further investigation.

5. Acknowledgment

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