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Efficacy and profitability of insecticides and crop management practices in the integrated management of *Leucinodes orbonalis* Guenée (Lepidoptera: Crambidae) on garden eggs

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ABSTRACT

Leucinodes orbonalis is a key insect pest of garden eggs (*Solanum aethiopicum*) in Ghana. Generally, *L. orbonalis* is managed by the use of harmful pesticides, necessitating the development of strategies which are more environmentally benign. This study compared the effectiveness and profitability of using black plastic mulch (PM) to manage *L. orbonalis* incidence with chlorpyrifos-ethyl (C-ethyl) and emamectin benzoate (EB). The PM was laid before transplanting whilst C-ethyl and EB were applied fortnightly up to the fruiting stage. The incidence of *L. orbonalis* on shoots and fruits, the percentage of infested fruits, yield and gross margins of the treatments were determined. The incidence of plants with newly infested shoots between treatments across all treatment dates were not significant ($p > 0.05$). Between 30.41% (PM+EB) and 94.49% (PM+C-ethyl) of fruits harvested showed signs of *L. orbonalis* infestation. Significant differences in the percentage of infested fruits between treatments were respectively observed at 12 ($p = 0.021$) and 16 ($p = 0.035$) weeks after transplanting. Plants from plots with EB as mixture (PM+EB) or sole (EB) treatment produced the highest yield advantage over the Control of 33.6% and 30.3%, respectively. Gross margin analysis indicated that the treatment of plants with EB was most profitable at peak price. At the least price obtainable, the use of all treatments particularly, PM was not profitable. Due to the possibility that movement of larvae between fields reduced the ability of PM to effectively suppress *L. orbonalis* populations, future work should evaluate the effect of PM using whole fields.

Keywords: Plastic mulch; insecticides; damage; gross margin analysis; garden eggs

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Introduction

Leucinodes orbonalis (Guenée) (Lepidoptera: Crambidae), the eggplant fruit and shoot borer is a major insect pest of garden eggs (*Solanum aethiopicum*) in Ghana (Youdeowei, 2002; MoFA, 2011). Severe infestation by this pest can reduce garden eggs yield by up to 70% (Srinivasan, 2009). Recommended non-pesticide management strategies for *L. orbonalis* include use of resistant cultivars or varieties, avoiding cultivation of garden eggs on the same field for more than two consecutive years, conservation of natural enemies, and frequent removal and destruction of infested shoots and fruits (Srinivasan, 2009; MoFA, 2011). The implementation of these non-chemical management practices however poses challenges to farmers. For instance, frequent removal and destruction of garden egg shoots and fruits is labour intensive and may increase cost of production. Farmers' ability to practice crop rotation and fallowing in Ghana is constrained by limited availability of suitable land in the peri-urban areas where garden egg is cultivated.

Moreover, in Ghana, there is no garden egg variety or cultivar resistant to *L. orbonalis*. In other major production areas, notably South Asia, conventional breeding efforts spanning a period of over 40 years did not result in the development of any commercial variety with appreciable levels of resistance to the pest (Alam *et al*., 2003; Hanur, 2008; Srinivasan, 2008; IIVR, 2013). Due to lack of success in breeding *L. orbonalis* resistant varieties, the focus has shifted to genetically modified (GM) insect resistant varieties (Hautea *et al*., 2016: Prodhan *et al*., 2018). In view of the limited availability of effective alternate management strategies, farmers continue to perceive chemical pesticides as the most effective means of controlling pests (Hardy, 1995; Gerken *et al*., 2001; Yeboah, 2013), relying almost exclusively on these pesticides for the management of *L. orbonalis* on garden eggs.

A recent study in Ghana indicated that garden eggs farmers in the Volta Region sprayed insecticides on their crop between 16–20 times per growing season to control *L. orbonalis* (Boamah *et al*., 2017). In areas of Asia where eggplants are intensively cultivated, between 20–140 insecticide applications per growing season have been reported (BARI, 1994; Alam *et al*., 2003; Hautea *et al*., 2016). The repeated use of insecticide poses several challenges such as development of resistance by the targeted pests to commonly used insecticide active ingredients, contamination of the pesticide applicator, the produce as well as the environment. Adverse effects resulting from the abuse of insecticides on crop production, human and environmental health costs necessitate the development of strategies that are less damaging in outcome or have a more benign effect on the environment. Ghimire & Khattiwada (2001) have suggested that manipulating the crop environment to make it unfavourable to insect pests may present an opportunity to reduce pest incidence.

Newly hatched larvae of *L. orbonalis* larvae are reported to use plant parts or debris deposited on the soil beneath the plant canopy as a breeding/maturation ground (Srinivasan 2009). Manipulating this plant environment to deny mature larvae or pupae, the ability to successfully utilise plant debris below the crop canopy may present an opportunity for mitigating intensive insecticide use on plant foliage and fruits. This study compared the effect and profitability of using black plastic mulch to manage *L. orbonalis* by limiting contact between life stages and soil surface with application of chlorpyrifos-ethyl, the most commonly used insecticide on garden eggs in Ghana (Asiedu, 2013; Donkor *et al*., 2016) and emamectin benzoate, a biorational insecticide which is reported to be effective against *L. orbonalis* and increase yield in the native range of the pest (Kumar & Devappa, 2006; Anil & Sharma, 2010; Anwar *et al*., 2015).

Materials and Methods

The experiment was conducted at the CSIR-Plant Genetic Resources Research Institute (PGRRI), Bunso, Ghana, in the year 2019. The set-up was under rain-fed conditions and watering was undertaken as and when necessary. The experimental design was split plot with three replications. Mulch was maintained as main plot while insecticide treatment was the sub-plot. Three 23 m × 10 m blocks were marked and cleared after which six 2 m × 10 m plots were demarcated in each block. One set of three plots in each block were randomly selected and covered with 2 × 10 m black plastic mulch. The other set of three plots were left uncovered. Seedlings of the garden egg cultivar, 'Dwomo' were transplanted into the prepared (covered and uncovered) plots at five weeks after germination.

Transplanting on plastic mulch covered plots was done by first using pegs to mark points for planting holes in each of the three rows. A sharp blade was used to cut a 5 cm diameter ring around each peg after which a sharp cutlass was used to create a planting hole for the transplanting of seedlings. There were three rows of 10 plants per treatment plot. A space of one metre was maintained between plants in a row and between adjacent rows. The distance between adjacent plots was 1.5 m. Two weeks after transplanting, all the set of black plastic mulch covered plots in the three blocks were assigned numbers. Using the numbers, one plastic-mulched plot in each block was randomly selected and left unsprayed whilst the other two were either sprayed with a biorational insecticide (emamectin benzoate) at the rate of 250 ml/ha or a synthetic insecticide (chlorpyrifos-ethyl) at the rate of 1.4 l/ha. The same procedure was used to select bare ground plots (plots without plastic mulch) for insecticide application using the same regime above. The experimental treatments were thus: Control, Plastic mulch (PM) only, Emamectin benzoate (EB), Chlorpyrifos-ethyl (C-ethyl), PM+EB, PM+C-ethyl. Treatments (spraying) were repeated every fortnight from two weeks after transplanting until 11 weeks after transplanting. After the first application of insecticides, each plot was clearly labelled with the treatment imposed on it. All other recommended agronomic practices for garden egg production were adhered to.

Data on the incidence of *L. orbonalis* on 10 plants in the middle rows of each plot commenced two weeks after transplanting. The incidence of new infestation on shoots of garden egg plants was collected before the first insecticide application. Thereafter, the incidence was recorded a week after each insecticide application. After each data collection, all infested shoots were excised with a sharp blade and destroyed. Garden egg fruits were ready for harvesting nine weeks after transplanting (WAT). Due to the low number of fruits available, the fruits harvested between 9 and 11 WAT were pooled together. This also enabled the fruits harvested in between insecticide applications to be separated from those harvested after insecticide application was stopped (11 WAT). At each weekly harvest, the total number of fruits harvested per treatment was counted and weighed. The number and weight of damaged fruits was also recorded and expressed as a percentage of the total number and weight of the fruits assessed. Yield (tonnes/hectare) was estimated using the total weight of fruits harvested per treatment plot.

Data analysis

Data on the incidence and damage of *L. orbonalis* on garden egg fruits and shoots were transformed (count data = square root, percentage data arcsin, weight data = log) to normalise variances (Gomez & Gomez, 1984) before being subjected to analysis of variance (ANOVA) using SPSS (version 24) statistics software (IBM Corporation, U.S.A.). Untransformed means are however presented in Tables and in Figures. Treatment means that were significant were compared and separated using Tukey's multiple comparison test (p = 0.05).

Gross margin analysis

The gross margin for a crop is the difference between the revenue obtained from selling the crop and the direct costs incurred in producing the crop (Buckett, 1988). Gross margins can be a quick means through which farmers can determine which technology among several alternatives should be adopted (Karen, 2006). The gross margins for each treatment evaluated were calculated under two scenarios reflecting the marketing of garden egg fruits in the southern part of Ghana. The first, Scenario A, is the sale of fruits at peak price (GH¢ 0.5 per fruit) with the second, Scenario B, being the sale of fruits at the least price (GH¢ 0.07 per fruit). The cost of the treatments was computed on a per hectare basis: emamectin benzoate GH¢ 140.00, chlorpyrifos-ethyl (mid-dose) GH¢ 100.00, plastic mulch GH¢ 140.00.

Results and Discussion

With the exception of the control treatment, the incidence of new plants with infested shoots decreased after the first insecticide application. The incidence of plants with newly infested shoots recorded between the third and fifth applications were all higher than that recorded before and after the first insecticide application. Differences in the incidence of plants with newly infested shoots between treatments across all treatment dates were not significant ($p > 0.05$) (Table 1).

TABLE 1

Incidence of fresh garden egg shoots infested by Leucinodes orbonalis larvae under the different pest/crop management treatments at Bunso

Treatment	Mean (SEM) percentage of garden egg shoots with new infestation on different spray days					
	Before Spray	Spray 1	Spray 2	Spray 3	Spray 4	Spray 5
Control	26.67 (4.02)	28.33 (5.20)	58.33 (3.21)	70.00 (3.94)	58.33 (2.81)	75.00 (5.34)
PM	33.33 (6.36)	10.00 (8.22)	40.00 (5.08)	65.00 (6.22)	56.67 (4.45)	63.33 (8.45)
C-Ethyl	26.67 (3.67)	21.67 (4.74)	51.67 (2.93)	63.33 (3.60)	50.00 (2.57)	70.00 (4.88)
EB	20.00 (4.50)	11.67 (5.81)	46.67 (3.59)	66.67 (4.40)	61.67 (3.15)	66.67 (5.97)
PM+EB	23.33 (9.00)	8.34 (11.62)	45.00 (7.18)	50.00 (8.80)	55.00 (6.29)	60.00 (11.94)
PM+C-ethyl	20.00 (5.19)	13.33 (6.71)	46.67 4.14)	76.67 (5.08)	65.00 (3.63)	68.33 (6.90)
F	0.389	1.123	0.929	0.643	1.032	0.203
P	0.847	0.399	0.496	0.672	0.442	0.955

Figures in brackets are standard error of means (SEM)

More fruits were harvested from EB only, PM+EB, and PM+C-ethyl treated plots than from Control plots on all harvest dates (weeks) (Figure 1). Differences in the number of fruits harvested among treatments on all harvest dates were not significant ($p > 0.05$).

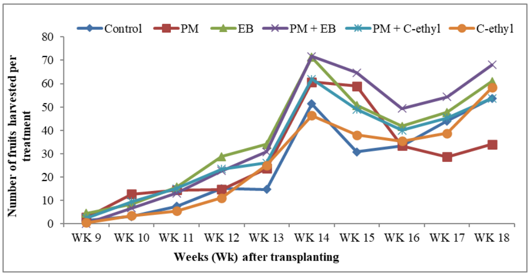

Fig. 1: Number of garden egg fruits harvested from plots with different pest/crop management treatments at Bunso

Fruits harvested between 30.41% (PM+EB) and 94.49% (PM+C-ethyl) showed signs of *L. orbonalis* infestation. The least proportion of infested fruits was harvested in between insecticide applications whilst the highest proportion of infested fruits was harvested five weeks after the last insecticide application was made (11 WAT) (Table 2). Significant differences in the percentage of fruits infested among treatments were observed 12 WAT ($F_{(5,12)} = 4.115$; $p = 0.021$) and 16 WAT ($F_{(5,12)} = 3.55$; $p = 0.035$). Differences on all other dates, including 17 and 18 WAT were not significant ($p > 0.05$).

TABLE 2

Weekly incidence of Leucinodes orbonalis damage on garden egg fruits under the different pest/crop management treatments at Bunso

Treatment	**Mean (± SEM) percentage of harvested garden egg fruits with *L. orbonalis* damage**					
	11 WAT*	12 WAT	13 WAT	14 WAT	15 WAT	16 WAT
Control	72.96 (8.54)	41.71 (3.04)^{ab}	52.08 (4.60)	86.64 (5.91)	82.72 (4.65)	79.65 (2.05)^{b}
PM	41.48 (13.50)	74.58 (4.81)^{a}	44.59 (7.28)	81.63 (9.35)	86.58 (7.35)	88.75 (3.24)^{a}
C-Ethyl	65.87 (7.79)	38.83 (2.78)^{b}	51.23 (4.20)	72.69 (5.40)	91.28 (4.24)	86.86 (1.87)^{b}
EB	55.00 (9.54)	58.44 (3.40)^{ab}	69.89 (5.15)	76.02 (6.61)	80.31 (5.20)	82.45 (2.29)^{b}
PM+EB	30.41 (19.09)	49.11 (6.80)^{ab}	56.69 (10.29)	75.69 (13.22)	76.84 (10.39)	86.40 (4.58)^{a}
PM+C-ethyl	50.83 (11.02)	56.63 (3.93)^{ab}	56.21 (5.94)	77.08 (7.63)	84.22 (6.00)	94.49 (2.65)^{a}
F	0.866	4.115	0.834	0.835	0.948	3.55
P	0.531	0.021	0.550	0.550	0.485	0.034

*Harvest made during insecticide application; Means within the same column followed by different letter(s) are significantly different at the 0.05 level; Figures in brackets are standard error of means

The mean number of exit holes per infested fruit ranged from 1.3 (Control) to 2.32 (C-ethyl). Differences in the number of exit holes per fruit among treatments was not significant ($F_{(5,12)} = 1.664$; $p = 0.218$) (Table 3). There was weak negative correlation ($R = –0.36$; $p = 0.135$) between weight per fruit and number of exit holes per fruit.

TABLE 3

Mean fruit weight, mean percentage by weight of infested fruits and mean number of exit holes per harvested garden egg fruit under the different pest/crop management treatments

Treatment	Mean (±SEM) weight per fruit (g)	Mean (±SEM) percentage by weight of infested fruits	Mean (±SEM) number of exit holes per fruit
Control	40.00 (0.02)^{a}	66.52 (6.11)	1.32 (0.04)
PM	40.00 (0.04)^{a}	67.51 (9.67)	1.93 (0.06)
C-Ethyl	30.00 (0.02)^{b}	66.72 (5.58)	2.32 (0.04)
EB	40.00 (0.03)^{a}	64.29 (6.84)	1.87 (0.05)
PM+EB	36.96 (0.05)^{ab}	53.78 (13.67)	1.83 (0.09)
PM+C-ethyl	37.00 (0.03)^{ab}	66.64 (7.89)	1.95 (0.05)
F	4.713	0.181	1.664
P	0.013	0.965	0.218

Means within the same column followed by different letter(s) are significantly different at the 0.05 level; Figures in brackets are standard error of means

Yield obtained from treatment plots were not significantly different (p = 0.643) but ranged from 1.52 t/ha to 2.29 t/ha. The yield obtained from plots treated with EB only, PM+EB and PM+C-ethyl were higher than that obtained from Control plots and plots treated with PM only or C-ethyl only (Figure 2).

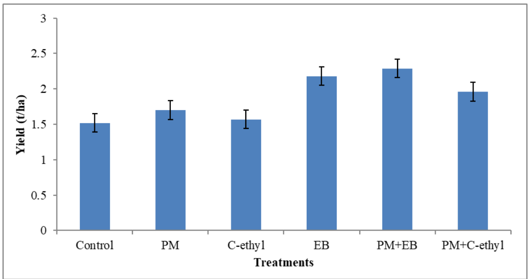

Fig. 2: Yield of garden egg plants cultivated under different pest/crop management treatments at Bunso

Table 4 indicates the gross margins associated with the cultivation of garden eggs using the different treatments evaluated in this study. Using scenario A, the cultivation of garden eggs using all the treatments was profitable. Although the highest yield was obtained from PM+EB plots, the highest benefit cost ratio (BCR) of 2.48 was obtained for Control plots with bare ground. The least BCR of 1.54 was obtained in PM+C-ethyl treated plots (Table 4). Under scenario B, the cultivation of garden eggs using all the treatments was associated with negative returns. The highest negative returns were obtained from plots with plastic mulch either as a sole or a co-treatment (Table 4).

TABLE 4

Gross margins associated with the cultivation of garden eggs under different pest/crop management treatments at Bunso

Activity/item	Cost (GH¢) per hectare of treatment					
	Control (Bare ground)	Plastic mulch (PM)	Chlorpy-rifos-ethyl (C-ethyl)	Emamectin Benzoate (EB)	PM + C-ethyl	PM + EB
Yield (t/ha)	1.52	1.70	1.57	2.18	1.96	2.29
Gross income A[1]	21,708.90	24,279.69	22,423.01	31,135.13	27,993.05	32,706.17
Gross income B [2]	3,040.00	3,400.00	3,140.00	4,360.00	3,290.00	4,580.00
Variable costs						
Land preparation[3]	260.38	3,655.20	260.38	260.38	3,655.20	3,655.20
Field establishment[4]	251.43	251.43	251.43	251.43	251.43	251.43
Insecticide costs[5]	0.00	0.00	968.57	1,008.57	968.57	1,008.57
Fertilizer costs[6]	2,916.52	2,916.52	2,916.52	2,916.52	2,916.52	2,916.52
Weeding (4x)	1,215.24	0.00	1,215.24	1,215.24	0.00	0.00
Harvesting (8x)	1,453.33	1,620.95	1,495.24	2,076.19	1,862.86	2,177.14
Total variable costs (TVC)	6,096.95	8,444.10	7,107.38	7,728.33	9,654.58	10,008.86
Gross margin A	15,611.95	15,835.54	15,315.59	23,406.75	18,338.42	22,697.26
Gross margin B	-3,056.95	-5,044.15	-3967.43	-3,368.33	-6,364.63	-5,428.91
Fixed costs						
Cutlass	45.00	45.00	45.00	45.00	45.00	45.00
Knapsack sprayer	0.00	0.00	1200.00	1200.00	1200.00	1200.00
Wellington boot	50.00	50.00	50.00	50.00	50.00	50.00
Harvesting sacks	50.00	50.00	50.00	50.00	50.00	50.00
Total fixed costs	145.00	145.00	1345.00	1345.00	1345.00	1345.00
Total cost	6,241.95	8,589.10	8,452.38	9,073.33	10,999.58	11,353.86
Net Return A	15,466.95	15,690.54	13,970.59	22,061.75	16,993.42	21,352.26
Net Return B	-3,201.95	-5,189.15	-5,312.43	-4,713.33	-7,709.63	-6,773.91
Benefit Cost Ratio (BCR) A	2.48	1.83	1.65	2.43	1.54	1.88

[1]Based on an estimate of the value of harvest at peak price of GH¢ 14,282.17 x yield obtained; [2]Based on an estimate of the value of harvest at least price of GH¢ 2,000.00 x yield obtained; [3]Land clearing + leveling + cost of plastic mulch + cost of laying mulch; [4]Cost of seeds + transplanting; [5]Insecticide product + cost of application (applied 5x); [6]NPK + foliar fertilizer + application costs (applied 5x)

The infestation of the shoots of garden egg plants by *Leucinodes orbonalis* in this study did not reflect any clear pattern. A similar observation was made by Shukla & Khatri (2010) who reported that the population of *L. orbonalis* fluctuated to a very high degree from one month to the other. None of the treatments evaluated was effective in significantly reducing *L. orbonalis* damage to garden egg shoots and fruits on all the sampling weeks. Relative to fruits harvested during insecticide application, the percentage of infested fruits that were harvested two weeks after the cessation of insecticide application in all treatments was markedly higher, exceeding 75% of harvested fruits. Duodu (1986) reported that infestation of fruit by *L. orbonalis* is comparatively high in local cultivars of eggplant than improved varieties.

In a related study, Chakraborti & Sarkar (2011) observed that the application of effective pest management strategies at the initiation of *L. orbonalis* infestation prevents a build-up of heavy populations of the pest. In the current study, it appears that the high susceptibility of the local cultivar coupled with the frequency of application of two weeks, which was ineffective, may have resulted in a build-up of the population of *L. orbonalis* which was carried over to the fruiting stage. Results of previous studies suggest that extending insecticide application beyond the fruiting period is critical for achieving a significant reduction in shoot and fruit damage caused by *L. orbonalis* (Patel *et al*., 2001; Misra, 2008; Adiroubane & Raghuraman, 2008; Latif *et al*., 2009; Mochiah *et al*., 2011; Owusu, 2011).

Compared to the estimated 8.0 t/ha and 15.0 t/ha average yield and achievable yield, respectively of garden eggs in Ghana, the yields obtained in this experiment were significantly lower. A possible explanation for this could be the fact that the seeds used in the experiment were farmer-saved seeds (recycled). According to Schippers (2000), the yield of garden egg plants raised from certified or improved seeds is between 100–150% higher than that obtained using farmer-saved seeds. Additionally, the low yield could be the short period (9–18 WAT) that harvesting was done in this experiment. Harvesting of marketable fruits of eggplant has been reported to extend to beyond 30 WAT (Obodji *et al*., 2015). In contrast to the results obtained for shoot and fruit damage, all the treatments evaluated in the study had a yield advantage over the Control. Plants from plots with emamectin benzoate either as a mixture (PM+EB) or sole (EB) treatment produced the highest yield advantage over the Control of 33.6% and 30.3%, respectively.

Plants in plots with plastic mulch as a sole treatment also resulted in a 10.6% and 7.7% yield advantage over Control and C-ethyl treatment plots. The observed yield advantage obtained from EB treated plots is consistent with the results of previous studies (Sharma &Srivastava, 2010; Wankhede & Kale, 2010; Chatterjee & Mondal, 2012; Shah *et al*., 2012; Dey, 2019). The efficacy of EB was also observed by Chakraborti & Sarkar, (2011) who reported that the application of NSKE followed by the application of EB was effective in the management of *L. orbonalis.* Moreover, Dey (2019) reported that EB was most effective against *L. orbonalis* when it was applied as a co-treatment with Cartap hydrochloride at the rate of 1750 g/ha. With respect to plastic mulch-treated plots, AVRDC (2012) reported that the use of plastic mulch following seedbed preparation with organic manure resulted in more fruit production. This may account for the yield advantage of PM over the Control and the C-ethyl treatments.

One of the main determinants of the prices for garden egg fruits in Ghana is the season (GIDA *et al*., 2004). Fruit prices increase from November and reach a peak in April–May. In the study area, personal interaction with farmers reveals that the peak price is attained in December. The highest gross income in the current study was obtained through the application of EB to plants in plastic mulch plots during periods of peak market value. Due to high production costs associated with the use of the plastic mulch and the application of insecticides, the BCR of cultivating garden eggs on bare ground (Control) was higher than that obtained from all other treatment plots. The use of plastic mulch as a co-treatment significantly increased production cost. Thus, treatments with plastic mulch were the most unprofitable treatments at low price. This reflects the findings of Horna *et al*. (2007) which indicated that whilst gross margins for garden egg production in Ghana indicate that the cultivation of the crop can be a profitable activity, there is also the potential for negative returns.

According to Darst & Fixen (2000), high yields and low unit production costs, which enables farmers to make a profit when prices are low and make the most profits when prices are higher, are a farmer's best bet against price fluctuations. It is obvious that whilst the use of PM as a sole or co-treatment resulted in some yield advantage over the Control and C-ethyl, the saving on labour for weeding were not sufficiently high enough to off-set the high costs associated with the use of plastic mulch, making the use of PM very unprofitable at low price. The use of plastic mulch has been shown to facilitate plant growth and lead to early flowering and fruiting (Kotey *et al.*, 2018). This may be due to better soil moisture conservation during dry conditions as those that prevail during most of the minor or dry season in most parts of Ghana. It is therefore possible that in areas of high-water stress, the laying of plastic mulch may result in good plant growth and an increased yield. This together with higher savings on labour for frequent irrigation may increase income associated with plastic mulch use.

The most important damage by *L. orbonalis* on garden eggs is the feeding activity of the larvae of the pest on fruits (Hautea *et al*., 2016) which renders them unmarketable and unfit for human consumption (Srinivasan, 2009). In this study, the application of C-ethyl up to the beginning of fruiting did not confer any significant advantage over the Control treatment in terms of yield or reducing the incidence and damage of *L. orbonalis*. Similarly, the use of C-ethyl was less profitable under all scenarios compared to the Control, EB and plastic mulch treatments. Similar results of the lack of efficacy of C-ethyl have been previously reported (Latif *et al*., 2010; Chatterjee & Mondal, 2012; Anwar *et al*., 2015; Niranjana *et al*., 2017*).* Srinivasan (2009) has noted that the best approach for the effective management of *L. orbonalis* is a strategy that combines several component tactics in an IPM programme. In Ghana, however, probably due to the perception that the application of C-ethyl will protect yield and the quality of fruits, the use of chlorpyrifos continues to be popular amongst garden egg and vegetable farmers (Amoah *et al*., 2006; Kotey *et al*., 2007; Asiedu, 2013; Donkor *et al*., 2016). To achieve a satisfactory level of control of *L. orbonalis*, farmers spray huge volumes from transplanting up to the fruiting stage amounting to as many as 16 to 20 insecticide applications per cropping season (Donkor *et al*., 2016; Boamah *et al*., 2017). The spraying is usually done in such a way as to leave sufficient residues on the sprayed plant part (AVRDC, 1999*)*.

A key factor heightening the risks posed by the use of chropyrifos is its persistence. Whilst the residues of biorational insecticides such as emamectin benzoate can degrade quickly, those of synthetic insecticide active ingredients such as chlorpyrifos can persist over a number of days. Angioni *et al.* (2011) have reported that repeated application of chlorpyrifos can result in accumulation leading to residue levels above Maximum Residue Levels (MRLs) even after the pre-harvest interval (PHI). The PHI of the chlorpyrifos product used in this study is 15 days. Farmers in Ghana however harvest garden egg fruits twice a week (Horna *et al*., 2007), which is more than 11 days before the recommended PHI. The non-observance of the recommendations on the pesticide product label has resulted in chlorpyrifos residues above FAO/WHO MRLs being recorded on harvested produce and food products in Ghana (Biney, 2001; Odhiambo, 2005; Amoah *et al*., 2006; Kotey, 2007).

Garden egg fruits may be eaten fresh or with little processing, the risks of exposure of consumers to toxic residues is therefore very high. Persistence of the insecticide in the environment also facilitates resistance development in target pests. *Leucinodes orbonalis* is reported to have a remarkable ability to develop resistance to many synthetic insecticides including chlorpyrifos (Dittrich *et al*., 1985; Prabhaker *et al*., 1995; Shirale *et al*., 2017). Whilst there is no report indicating that *L. orbonalis* is resistant to chlorpyrifos in Ghana, previous studies reported that the resistance status of populations of *Plutella xylostella*, a lepidopteran pest of cabbage, a vegetable crop that is also frequently sprayed with chlorpyrifos, changed from moderately resistant to highly resistant to chlorpyrifos within a five-year period (Kaiwa, 2000; Odhiambo 2005). According to Thompson (2004), when an insecticide loses its efficacy against an insect pest, farmers try to compensate for the loss of efficacy by increasing the application frequency and dosage, setting up a positive feed-back loop in which intensive pesticide use brings about increased resistance development and more pest situations and environmental contamination.

Conclusion and Recommendation

The application of chlorpyrifos ethyl and emamectin benzoate every two weeks did not result in any significant reduction to *Leucinodes orbonalis* damage to fruits and shoots of garden egg. The use of emamectin benzoate or plastic mulch as sole or co-treatments resulted in a yield advantage over Control and chlorpyrifos only treated plots. Whilst treatments with plastic mulch were amongst the most profitable at peak price of garden eggs, high production costs associated with the use of plastic mulch made them the least profitable at low prices. Given the results obtained with plastic mulch, future work should evaluate the effect of plastic mulch using whole fields. This will reduce the possibility for the movement of *L. orbonalis* larvae and adults between plots. The use of insecticide products with chlorpyrifos as an active ingredient is a common feature in all garden egg production areas of Ghana. Results of this study and that of others indicate that whilst the continued use of chlorpyrifos confers no advantage over Control plots, it poses significant risks to consumers and the environment. Increasing farmer and consumer awareness as well as research and policy formulation to promote more benign alternatives will improve the economic and environmental sustainability of garden egg production.

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