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Economic evaluation of the insecticides used in the wheat crop for efficient management of wheat aphids

Rashid Ahmed Khan[1,2*] Muhammed Naveed[1,2]

[1] *Plant Protection Division, Nuclear Institute for Agriculture & Biology, Jhang Road, Faisalabad, Pakistan*
[2] *Nuclear Institute for Agriculture and Biology College, Pakistan Institute of Engineering and Applied Sciences (NIAB-C, PIEAS), Faisalabad, Pakistan*
[*]*Corresponding author:* rashidpp2004@yahoo.co.uk

Abstract

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Wheat aphid is a serious sap-sucking pest of wheat in Pakistan. In case of severe infestation, the crop yield declines significantly due to reduced grain size. A field experiment was planned to determine the economic injury level (EIL) and economic threshold level (ET). The aphid population was maintained at different levels by using insecticides of different efficacies. Finally, an economic analysis of the insecticide application was carried out by assessing the gain threshold (GT) and benefit-to-cost ratio (BCR). The results showed that unchecked aphid infestation caused 23 percent grain weight loss and 26 percent yield loss. The increasing control cost per hectare caused increased EIL and ETL values. The lowest EIL and ETL value of 2.78 and 2.08 aphids per tiller was calculated for λ-cyhalothrin, whereas the highest EIL and ETL values were 8.33 and 6.18 for chlorpyriphos. The highest benefit-to-cost ratio of 13.33 was obtained for λ-cyhalothrin application for the control of wheat aphids. The information regarding EIL, ETL, and BCR may help to devise integrated pest modules and maximize economic benefits.

Keywords: wheat aphid; Economic Injury Level (EIL); Economic Threshold Level (ETL); Benefit to Cost Ratio (BCR); insecticide

Introduction

In Pakistan, wheat is a staple source of food. It accounts for 9.6 percent of the value-added and 1.9 percent of GDP. In 2022–2023, the area under cultivation stood at 9043 thousand hectares, observing an increase of 0.7 percent during the same period last year. An increase of 5.4 percent was seen with the total production remained at 27.634 million tons. The increase in yield is attributed to the improvement in the supply of inputs (Anonymous, 2023). To meet the demand of the ever-growing population, there is a dire need to increase the sustainable productivity of wheat without compromising the health of humans and their surrounding environment (Senapati and Semenoc, 2020). The increased wheat productivity is owing to the development of high-yielding cultivars, increase in fertilizer use and availability of irrigation water. The semi-dwarf wheat cultivar was cultivated on most of the irrigated land (Aslam et al., 1989).

Various insect pests and diseases contribute to the yield decline in wheat. Among them, aphids infest the wheat crop by sucking cell saps at various growing stages (Xie et al., 2020). The bird cherry-oat aphid, *Rhopalosiphum padi* is a devastating pest of wheat, sorghum and small grain around the world (Aqueel and Leather, 2011; Caballero-Lopez et al., 2012; Savaris et al., 2013). It attacks the vegetative stage of plant growth (Wang et al., 2018), which results in stunted growth of the plant. In severe cases, it can cause quantitative loss of up to 60% (Pickett, 2013). Apart from that wheat aphids (*Shizaphis granarium*) and English grain aphid (*Sitobean avenae*) infest wheat crops at the flowering and spike-forming stage of

the crop (Drakulic et al., 2015). In quantitative terms, *S. granarium* cause 30% of quantitative loss upon severe infestation (Ahmad et al., 2016) and *S. avenae* is reported to damage 15–30% of the wheat yield (Wang et al., 2015). These aphids collectively form an aphid complex, which causes significant yield loss starting from the early vegetative growth stage up to the reproductive stage, both in qualitative and quantitative form. These species include English grain aphid, *Sitobean avenae* and green bug/wheat aphid, *Shizaphis graminum,* wheat aphid, *Microsiphum miscanthi*, barlay aphid, *Sipha maidis,* bristly olive grass aphid, *Sipha elegans* also infest wheat in the different ecological zones of Pakistan (Qayyum et al., 2021; Inayat et al., 2011; Mahmood et al., 2002; Khan, 2005; Aslam et al., 2004; Khan and Maqbool, 2002; Mohyuddin, 1981; Hamid, 1983; Hashmi et al., 1983; Aheer et al., 1993). The complex of aphids causes damage to cereals by depriving nutrient-rich sap resulting in a severely reduced yield by 40-60 percent (Khan et al., 2018). The other aspect of damage is the spread of cereal yellow dwarf virus by these aphids and its damage reaches 85 percent (Papp and Mesterházy, 1993; Brault et al., 2007; Riedell et al., 2003; Jiménez-Martínez et al., 2004; Fabre et al., 2006; Borer et al., 2009). Due to changing climatic scenarios, aphid populations have increased in the wheat crop during the last few years (Aheer et al., 1994; Zia et al., 1999).

For the effective management of aphid population, pesticides are regarded as the major tool of protection. (Dinu et al., 2022; Stoicea et al., 2022; Popescu et al., 2021; Iordan et al., 2022). The annual wheat productivity increased to 11.17% in studied European countries by the use of pesticides (Tudor et al., 2023), but these chemicals pose great concerns to non-target creatures and also deteriorate the environment through greenhouse gas emission (Geiger et al., 2010; Heimpel et al., 2013; Wyckhuys et al., 2022). Biocontrol agents in wheat also help suppress the pest population in a natural way, which helps to reduce the pesticide application, and action threshold levels rise, which reduces the cost of protection (Ramsden et al., 2017). The optimized use of pesticides in the food production system can significantly limit the cost of protection, moreover, the judicious application of these pesticides will help in minimizing the environmental residual risk and its remedial cost along with getting good production (Guo, et al. 2021).

Numerous studies have been conducted during the last two decades to establish the Economic Injury Level (EIL) for a wide range of pests (Mahmoud, 2014). The usefulness of any pest management plan is based on the Economic Threshold Level (ETL) (Maleki and Damavandian, 2015). ETL by definition is a point where benefits from pest management actions are equal to the cost associated with it (Stern et al., 1959). The pest control actions, where the pest is below the ETL are not justified, whereas economic damage to the crop may occur in case the pest population exceeds the EIL (Pedigo et al., 1986). Pest management plans, devised to help farmers make decisions to control pests based on economic thresholds, are a rational approach to pest management (Way et al., 1991). The Economic threshold levels of *Diuraphis noxia* are well documented in wheat, barley and durum wheat (Helden et al., 2022). Action threshold is also devised for sugarcane aphids on sorghum, for developing an integrated approach for its management, by collecting data from different growing conditions, while keeping in view their grain value and management cost (Gordy et al., 2019).

The use of insecticides to control insect pests, such as aphids is critical owing to their economic and environmental damage. The economic threshold depends on factors such as pest prevalence and its economic damage and the cost involved to manage the pest population. (Dachbrodt-Saaydeh et al., 2018). So, this study was planned to investigate the economics of the frequency of insecticides used to control aphids, to establish ETL and Benefit to Cost ratios (Obopile, 2006).

Material and Methods

Experimental site

The experiment was conducted at the Nuclear Institute for Agriculture & Biology (NIAB) experimental farm, situated at terrestrial coordinates 73°1′49″ E, 30°24′0″ N, with a height of 469.16 ft above sea level.

Experimental design

The experiment was laid out under Randomized Complete Block Design (RCBD) with five treatments having replicated thrice. For assessing the impact of treatments one positive and one negative control were cultivated with three replications. Each replicate was plotted on an area of 35×25 ft^2 area. The experimental plot is separated by a 5 ft buffer zone from adjacent fields. Each treatment along with its replicate was separated by a 7.5 ft inter-replicate/treatment path. All the experimental replicates received the recommended agronomic practices.

Treatment methodology

Five different chemistries viz. fipronil, imidacloprid, λ-cyhalothrin, chlorpyriphos and emamectin benzoate were used at recommended doses using a knapsack sprayer 60 days after sowing. Pretreatment data of the aphid population were taken a day before the scheduled treatment. The same treatments were repeated after a fifteen days interval. All the insecticide treatments were arranged in Randomized Com-

plete Block Design (RCBD) having three replicates per treatment and three replicates without the treatments as control.

Data acquisition

The data of collective aphids' complex population was calculated from each tiller by counting the number of aphids to determine the infestation on wheat before insecticide application. Five random plants were selected from each replicate. After the insecticide application, the data was recorded for the next three consecutive days. The same protocol was followed after 2nd application of insecticide treatment.

Computational analysis

The data were subjected to analysis of variance (ANOVA) to determine the significance of yield within the treatments. The number of aphids in a plant and respective yield data were subjected to linear regression analysis

$$Y = a + bx \quad (1)$$

where Y = yield potential, a = expected yield loss at zero levels of aphid infestation, b = regression coefficient/yield loss in tons per hectare caused by aphid per plant and x = number of aphids per plant.

Economic injury level (EIL) was calculated following the procedure adopted by Stone and Pedigo, 1972. The calculation of EIL needs an estimate of the Gain Threshold (GT). It is the yield increase in tons per hectare required to compensate for the control cost of the pest for each treatment using the following formula.

$$GT = CP/MV \quad (2)$$

where CP = cost of protection (US $/hectare) and MV = market value (US $/ton) of the grain yield per hectare.

According to the formula, the GT is directly proportional to the cost of protection and inversely proportional to the market price of the produce. The wheat market support price fixed by the Govt. of Pakistan at PKR 100,000.00 per ton, which is equal to USD 350.87 in 2023 at 285 PKR per US $. The cost of insecticide application is 3.50 US $ in 2023 per hectare.

EIL for each treatment was determined following the procedure adopted by Stone and Pedigo (1972). The economic threshold (ET) levels were calculated at 75% of EIL (Pedigo, 1991).

$$EIL = GT/b \quad (3)$$

where b = regression coefficient calculated by (1).

Percent yield loss under the direct influence of aphids was calculated following the procedure of Walker, 1990.

$$P\,(\%) = r_m - y_i / r_m \times 100 \quad (4)$$

where P = percent grain yield loss, r_m = yield potential of the uninfested plant, y_i = yield of the i^{th} treatment i.e. levels of aphid infestation.

The EIL determined as the number of aphids per wheat tiller causing economic yield loss was determined by the regression coefficient in the equation in Fig. 1.

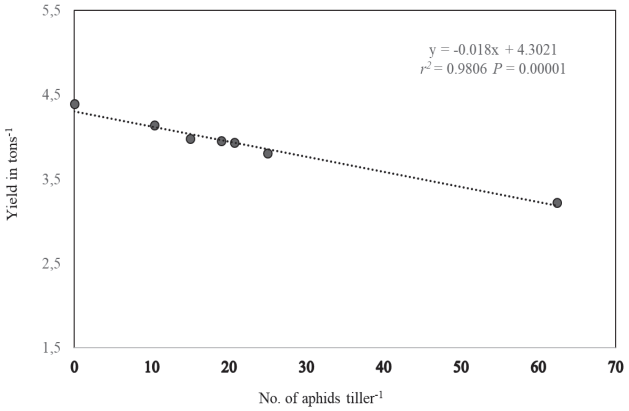


Fig. 1. Impact of aphid complex infestation on yield maintained at different levels in wheat

Source: Authors' own elaboration

The benefit-cost ratio (BCR) was calculated using the following formula:

$$BCR = \frac{\text{Total cost of plant protection (US \$ h}^{-1})}{\text{Value of yield loss saved (US \$ h}^{-1})} \quad (5)$$

Results and Discussion

The aphid infestation started during the 1st week of February. The first application of all the five insecticides viz., fipronil, imidacloprid, λ-cyhalothrin, chlorpyriphos and emamectin benzoate in recommended doses (Table 1) was carried out in the 2nd week of February, whereas the second application was carried after fifteen days. The aphid infestation remained significantly different among treatments (Table 2). A significant increase in 1000-grain weight was observed in all the treatments compared with the untreated control. The total percent loss reached 23.49 percent compared to zero aphid control (Table 2).

A significant yield reduction was observed with the increasing aphid population. The maximum yield of 4.13 tons ha^{-1} was observed in fipronil treatment, followed by imidacloprid, λ-cyhalothrin, chlorpyriphos and emamectin treatments. The maximum yield loss of 26.32 percent was observed in non-treated control, whereas the minimum

Table 1. Details of insecticides used to maintain the different levels of aphids population

Trt.	Trade name	Active ingredients	Formulation	Manufacturer	Dosage h^{-1}	Price US $ h^{-1}
T_1	Regent®	Fipronil	80 WG	Bayer	74.1 gm	16.96
T_2	Confidor®	Imidacloprid	20SL	Bayer	617.5 ml	9.88
T_3	Karate®	λ-cyhalothrin	2.5 EC	Syngenta	815.1 ml	5.97
T_4	Chlorpyrifos®	Chlorpyriphos	40 EC	Bayer	2470 ml	23.05
T_5	Proclaim®	Emamectin Benzoate	19 EC	Syngenta	494 ml	11.19

Source: Authors' own elaboration

Table 2. Impact of aphid complex on 1000 grain weight at different levels of aphid complex maintained with insecticide applications

Trt.	Mean no. of aphids $tiller^{-1}$ [a]	1000 grains weight (gm)	Mean weight of grain (gm)	Percent grain weight loss (gm)
T_0	0 ^{D}	42.61	0.041	–
T_1	10.33 ^{CD}	40.52	0.040	4.90
T_2	15 ^{BC}	39.46	0.039	7.39
T_3	19 ^{BC}	36.34	0.036	14.71
T_4	20.66 ^{BC}	36.22	0.036	14.99
T_5	25 ^{B}	36.11	0.036	15.25
T_C	62.66 ^{A}	32.6	0.033	23.49

[a] Means followed by the same letter in rows are not statistically different at alpha level 0.05.
Critical Value for Comparison of aphid population among treatments is 12.21.
Source: Authors' own elaboration

Table 3. Loss in yield in the wheat crop in response to wheat aphid complex infestation maintained with insecticide applications

Trt.	Mean no. of aphids $tiller^{-1}$ [a]	Mean weight of grains plant (gm)	Mean grain yield (tons ha^{-1})	Yield loss over control (tons ha^{-1})	Percent yield loss $plant^{-1}$
T_0	0 ^{D}	18.23	4.38 ^{A}	–	–
T_1	10.33 ^{CD}	16.73	4.13 ^{B}	0.24	5.49
T_2	15 ^{BC}	16.1	3.98 ^{C}	0.4	9.15
T_3	19 ^{BC}	15.97	3.95 ^{C}	0.43	9.84
T_4	20.66 ^{BC}	15.90	3.93 ^{CD}	0.44	10.07
T_5	25 ^{B}	15.36	3.79 ^{D}	0.58	13.27
T_C	62.66 ^{A}	13.04	3.22 ^{E}	1.15	26.32

[a] Means followed by the same letter in rows are not statistically different at alpha level 0.05.
Critical Value for Comparison of aphid population among treatments is 12.21.
Source: Authors' own elaboration

yield loss of 5.49 percent compared to no aphid control (Table 3).

Economic Injury Level (EIL) based on Gain Threshold (GT) for aphid infestation level and yield reduction was used for the determination of EIL and ETL. A significant reduction in yield was observed with increasing aphid infestation per tiller (Fig. 1). The maximum yield was obtained when wheat was treated with two applications of fipronil. The EIL values for fipronil, imidacloprid, λ-cyhalothrin, chlorpyriphos, and emamectin remained at 6.66, 4.44, 2.78, 8.33 and 4.44, respectively (Table 4).

The maximum cost-to-benefit ratio was observed when the wheat plant was kept free of aphids, however, it is not practically possible under field conditions. Two applications of λ-cyhalothrin recorded the highest cost-to-benefit ratio of 13.33, followed by imidacloprid, fipronil, emamectin and chlorpyriphos with cost-to-benefit ratios of 9.96, 7.80, 6.80, and 4.69, respectively (Table 5). These

results coincide with the findings of Yousafi et al. (2020), who tested and calculated on *Bravicorny brassicae* on brassica reported imidacloprid with good BCR of 2.57, but showed lower BCR of 2.37 for emamectin benzoate. This may be due to differences in aphid species under investigation. The effectiveness of pyrethroids and neonicotinoid on aphids was also reported by Singh and Kumar (2022), which resulted in a 7.5 Benefit to cost ratio to 1 for pyrethroid (cypermethrin) + neonicotinoid (imidacloprid) application. Our results contradict with results of Pal et al. (2023), which show a 15.4:1 benefit-to-cost ratio of Dimethoate an organophosphate insecticide as compared to neonicotinoid insecticides. This may be due to the low recommended dose rate of pesticide against aphid population in mustard, as compared to chlorpyrifos recommended dose against sucking pest population, which may result in reduced cost of insecticide. Pyrethroid and neonicotinoid insecticides are the main groups of pesticides for managing the aphid population in wheat (Foster et al., 2014; Miao et al., 2014) due to their effectiveness against infesting aphid population and reduced cost of insecticidal management. The effectiveness of λ-cyhalothrin and imidacloprid was also reported by Shafique et al. (2016), against the wheat aphid population in wheat.

It was observed that the reduction in grain yield of wheat increased with the increased aphid exposure. The benefit of using insecticides is evident as all the insecticides control the aphid population to different degrees. The reduced grain yield was attributed to the higher population of the aphids. The significant reduction in 1000 grain weight in control against the treatment vindicates the usefulness of insecticides used for aphid management. However, the benefits of

Table 4. Economics of aphid complex infestation on the wheat crop at different levels of infestation with insecticide application

Trt.	Mean no. of aphids tiller^{-1} [a]	Yield tons ha^{-1} [b]	Total control costs (UD $ ha^{-1})	Grain Threshold	Regression equation	EIL values (aphids tiller^{-1})	ETL
T_0	0 ^{D}	4.38 ^{A}	–		–	–	
T_1	10.33 ^{CD}	4.13 ^{B}	40.92	0.12	$Y = -0.018x + 4.3021$ $R^2 = 0.98$	6.66	4.99
T_2	15 ^{BC}	3.98 ^{C}	26.76	0.08		4.44	3.33
T_3	19 ^{BC}	3.95 ^{C}	18.94	0.05		2.78	2.08
T_4	20.66 ^{BC}	3.93 ^{CD}	53.10	0.15		8.33	6.18
T_5	25 ^{B}	3.79 ^{D}	29.38	0.08		4.44	3.33
T_C	62.66 ^{A}	3.22 ^{E}	–		–	–	

[a] Means followed by the same letter in rows are not statistically different at alpha level 0.05.
[b] Critical Value for Comparison of aphid population among treatments is 12.21.
Critical Value for Comparison of yield among treatments is 0.1433
Source: Authors' own elaboration

Table 5. Economics of plant protection measure and their economic benefits at different levels of infestation of aphid complex maintained with insecticide use

Trt.	Yield (tons ha^{-1})	Yield increase over control (tons ha^{-1})	Gross monitory profit (US $ ha^{-1})	Total control Cost (US $ ha^{-1})	Benefit to Cost Ratio (BCR)
T_0	4.38 ^{A}	1.16	407		
T_1	4.13 ^{B}	0.91	319.29	40.92	7.80:1
T_2	3.98 ^{C}	0.76	266.66	26.76	9.96:1
T_3	3.95 ^{C}	0.72	252.62	18.94	13.33:1
T_4	3.93 ^{CD}	0.71	249.11	53.10	4.69:1
T_5	3.79 ^{D}	0.57	199.99	29.38	6.80:1
T_C	3.22 ^{E}	–			

[a] Means followed by the same letter in rows are not statistically different at alpha level 0.05.
[b] Critical Value for Comparison of yield among treatments is 0.1433
The market value of the wheat grains = 350.87 US $ ton^{-1}
Source: Authors' own elaboration

using insecticides may differ owing to their market price, recommended dose, and efficacies.

The crop inspection for insect infestation is the most important aspect of an integrated pest management program for developing a rational framework of pest management with judicial use of pesticides (Barzman et al., 2015). Economic injury level based on market value (GT) is influenced by variations in the market value of crops, protection cost, and level of insect pest damage. The regression coefficient (b) for the damage per insect is considered comparatively constant, while both the market value of produce and control cost may fluctuate (Obopile, 2006). So, the more rational economic threshold encompasses the current price of insecticides and the value of the crop. Therefore, insect thresholds may differ for the type of insecticide and frequency of application. In general, lower control cost and higher market value of crop outcome in the lower threshold (Miles, 2016).

A general perception in any IPM program is the implementation of a benefit-to-cost ratio (BCR) of 2:1. It simply means that the action is necessary when the price of the damage prevented by the pest is twice the price of the control measure. This perception is more realistic for low-control cost-based thresholds (Miles, 2016). Pest economics helps in decision-making for the management of aphids. Pest economics will constantly change under the influence of the market price of wheat, cost of control, yield reduction by the pest, and inherent plant capability to counter the pest damage.

Conclusion

In our studies, λ-cyhalothrin being cheaper than other tested insecticides and effective as well gave the highest benefit-to-cost ratio of 13.33:1. The experiment not only helped to determine the comparative efficacies of the insecticides, but also determined the economy of their use for the control of wheat aphids depending upon their market price and efficacies. In addition, the experiment would also help the farmer in decision-making for the management of wheat aphids based on the ETL of the insecticides for better yield and attractive cost-benefit ratio.

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