Journal of Entomology and Zoology Studies

Available online at www.entomoljournal.com

E-ISSN: 2320-7078
P-ISSN: 2349-6800
JEZS 2018; 6(2): 795-799

Received: 07-01-2018
Accepted: 08-02-2018

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Control efficacy of different seed dressing insecticides against sorghum shoot fly, *Atherigona soccata* (Rondani) in forage sorghum, *Sorghum bicolor* (L.) Moench

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Abstract
Attack of sorghum shoot fly in sorghum causes considerable yield losses at initial growth stage of plant. Delay in insecticide application for control adds to high yield losses. Seed treatment is the easiest and economical method for timely management of shoot flies. Different seed dressing insecticide treatments *viz*. thiamethoxam 30 FS, imidacloprid 600FS and fipronil 2.8 EC at varying doses, were imposed on sorghum variety SL 44 during *kharif* 2015-16. The pooled efficacy data in terms of deadhearts (DH) obtained over two years showed significant reduction in damage across different treatments as compared with untreated control and standard check. Number of eggs laid per five plants within each treatment plots revealed no difference irrespective of treated and untreated seed. Mean data on per cent deadheart count at all the observations revealed the superiority of seed treatment with thiamethoxam 30 FS @ 10 ml per kg seed and closely followed by fipronil @ 10 ml per kg seed and gaucho @ 7ml per kg seed (7.71, 8.79 & 9.47% DH, respectively) in comparison to standard (11.53) and untreated control (17.08). The green fodder yield (q/ha) also revealed the same pattern with 612 q/ha green fodder yield in the seed treatment with thiamethoxam (10ml/kg seed). Economic analysis of different treatments revealed that protection against shoot fly damage lead to yield advantage of 93-153 q/ha and promising treatment yielded net return of Rs. 19370/ha.

Keywords: sorghum shoot fly, deadhearts, seed treatment, thiamethoxam, gaucho, fipronil

Introduction
Sorghum (*Sorghum bicolor* [L.] Moench) is the fifth most important cereal crop by area after wheat, rice, maize and barley in the world [20]. In North Indian states, it is chiefly used as a forage crop for feeding dairy animals and also a principle feed ingredient in poultry and dairy industry [4]. Sorghum is reported to be attacked by nearly 150 insect pest species, of which sorghum shoot fly, *Atherigona soccata* is one of the major pest [18]. The early season attack of shoot fly may result in 75.6 per cent grain yield and 68.6 per cent in fodder yield. [16]. In sorghum cultivars CSH 5 and M 35-1 increase in one per cent level of shoot fly infestation from Economic threshold level may lead to grain loss of 89.1 and 30.5 kg ha^{-1}, respectively [15]. The attack of this pest starts immediately after germination from 1-4 weeks after seedling emergence. Maggots attack the growing point of the plant resulting in withering of central shoot referred as deadheart symptoms. The damaged seedling is generally killed and plant grows side tillers which are further attacked under high pest population leading to considerable loss [19]. In rainy season crop, severe attack of the dipteran pest may even require re-sowing. The consolidated strategy to manage this pest is combination of cultural practices, natural enemies, insecticides and host plant resistance. Chemical control alone proves expensive as it requires repeated applications against target pest which is not affordable for marginal farmers as well as safety concern to dairy animals [6]. Therefore, the seed treatment seems to be a viable option for pest management system in terms of cost effectiveness and compatibility with other components of IPM [3, 4] and also protection of early stage growth of the plants which is most susceptible to shoot fly devastation [2]. Seed treatments, especially those with systemic activity (imidacloprid, thiamethoxam, clothianidin and fipronil), show great promise for corn, infested with a variety of soil inhabiting and early-season foliar-feeding insect pests. Because of the convenience of seed treatments, it may help in areas where one or more early-season pests are chronic problems [7]. The effectiveness of different chemicals to this pest has also been promising for the control of dipteran shoot flies [6, 9]. Therefore, the study was

planned to evaluate different seed treatment insecticides and their cost effective dose for the protection of most susceptible stage of the crop against attack of sorghum shoot fly.

Materials and Methods

The present study was conducted for two consecutive years during *kharif* 2015 and 2016 with three test insecticides at different doses in comparison to standard check and untreated control. The experimentation site was Forage Research Farm, Punjab Agricultural University, Ludhiana. The different insecticides treatments were imposed on sorghum variety SL 44 sown in plots of size 4 X 5 m^2 in three replications. The treatments thus included in the study were broad spectrum systemic seed dressing chemicals at varying doses, *viz* Gaucho 600 FS (imidacloprid 600 FS) M/S Bayer Crop Science Ltd, Mumbai @ 3,5,7 ml per kg seed; Slair (thiamethoxam 30 FS) M/S GSP Crop Science Pvt Ltd, Ahemdabad @ 5,7 & 10 ml per kg seed and Regent (fipronil 5 SC) M/S Bayer Crop Science Ltd, Mumbai @ 5,7, 10 ml per kg seed. Foliar spray of Malathion 50 EC @ 625 ml/ha on 2-3 weeks old crop was kept as standard check and untreated control for comparing the efficacy data. The seed coating with insecticides was done one day prior to sowing and treated seeds were shade dried. The crop was raised as per recommended package of technology for forage sorghum except insecticide sprays for shoot fly control. However, blanket application of Malathion 50 EC @ 750 ml/ha was given after 25 days of germination to prevent the attack of stem borer, *Chilo partellus* and cotton grey weevil, *Myllocerus* sp and other pests. The observations like number of eggs laid per 5 plants and damage in terms of per cent deadheart incidence was recorded 7, 14, 21 & 28 days after germination (DAG) from respective treatment plots and its replications. Other agronomic parameters like seedling length and primary and secondary root length were also recorded on 10 day old seedlings to ascertain treatment effect on seedling growth (if any).

Statistical Analysis

The data on egg counts, infestation parameters (DH%) and yield from individual trials year wise were pooled and analyzed using two-way ANOVA as per Gomez and Gomez [8]. The economic analysis of different treatments was done by taking into account the prevailing prices of green fodder, cost of treatments and net returns.

Results and Discussions

The efficacy data in terms of deadhearts (DH) obtained over two years and pooled, reflected treatment effect in reduction of damage across various treatments as compared standard and untreated control.

Seedling Characteristics: The seedling characteristics such as seedling length and root length were studied to ascertain any adverse effect of seed treatment on seedling germination and its growth. The perusal of data in Table 1 indicated that seedling height significantly varied from 12.5-14.0 cm across different treatments, whereas length of primary and secondary roots varied from 2.3-3.3 and 4.4-5.8 cm in comparison to control 2.4 and 5.4 cm. In earlier reports also improved germination and better seedlings growth was observed with imidacloprid and thiamethoxam seed treatment in sorghum and maize due to phyto-tonic effects [10, 11, 12].

Table 1: Influence of seed treatment on seedling characteristics

Treatments	Dose ml/kg seed	Seedling length (cm)	Length of primary roots (cm)	Length of secondary roots (cm)
Imidacloprid 600 FS	3ml	12.6	2.8	4.8
Imidacloprid 600 FS	6ml	12.5	2.3	4.9
Imidacloprid 600 FS	7ml	12.6	2.7	4.4
Thiamethoxam 30 FS	5ml	12.7	2.8	4.5
Thiamethoxam 30 FS	7ml	13.1	2.8	5.2
Thiamethoxam 30 FS	10 ml	13.3	3.1	5.1
Fipronil 2.8 EC	5ml	14.0	2.8	5.8
Fipronil 2.8 EC	7ml	13.9	3.3	5.8
Fipronil 2.8 EC	10ml	14.1	3.2	5.8
Malathion 50 EC	625ml/ha	13.2	2.5	5.8
Control	-	13.0	2.4	5.4
CD (p=0.05)		0.61	0.47	0.47

Fecundity The data on number of eggs laid per five plants recorded 14 days after germination (DAG) within each treatment plots revealed non-significant differences, indicating no effect of insecticide treatments on fecundity of *A. soccata*, irrespective of treated or untreated seed. The fecundity was recorded to vary between 3.7- 6.0 across different treatments during both the years of investigation (Table 2 and 3) and in pooled mean the trend was 4.17 to 5.67 eggs per five plants (Table 4).

Deadhearts Reduction of shoot fly damage as per cent deadhearts revealed significant differences amongst different seed dressers at varying doses in comparison to untreated control and even standard treatment of malathion 50 EC. The range of per cent DH (7 DAG) was 5.33-10.33 in all the seed dressing insecticides in comparison to standard (9.67) and control (11.33) during the year 2015 (Table 2). Significantly lower proportion of DH (5.33%) due to shoot fly was recorded in treatment with thiamethoxam @ 10 ml per kg seed and closely followed by fipronil treatment (5.67% DH). Other doses of test insecticides were observed to be at par with recommended foliar application of malathion @ 375 ml ha^{-1}. Thereafter, the per cent deadhearts recorded at different intervals (14, 21 and 28 DAG) also revealed the same trend but there was numerical increase in the per cent deadheart appearance across different insecticide treatments.

Table 2: Efficacy of seed dressing insecticides for the control of *A. soccata* in forage sorghum during *kharif* 2015

Treatments	Dose (ml/kg seed)	Eggs per 5 plants	Deadhearts (%)					GFY (q/ha)
			7DAG	14DAG	21 DAG	28 DAG	Mean	
Imidacloprid 600 FS	3ml	5.33	8.00(16.40)	8.33 (16.58)	9.67(18.07)	14.00 (21.90)	10(18.23)	546
Imidacloprid 600 FS	6ml	5.00	7.33(15.70)	8.00 (16.40)	8.67(17.04)	13.00 (21.08)	9.16(17.45)	584
Imidacloprid 600 FS	7ml	4.33	7.00(15.31)	7.67 (16.06)	8.33(16.76)	11.00 (19.22)	8.16(16.43)	595
Thiamethoxam 30 FS	5ml	4.67	10.33(18.71)	11.67 (19.96)	11.33(19.66)	11.00 (19.35)	11.25(19.66)	584
Thiamethoxam 30 FS	7ml	4.67	9.00(17.43)	8.00 (16.40)	9.33(17.75)	9.67 (18.00)	9.08(17.10)	602
Thiamethoxam 30 FS	10 ml	4.00	5.33(13.34)	6.67 (14.94)	7.33(15.69)	9.33 (17.77)	7.17(16.53)	609
Fipronil 2.8 EC	5ml	5.33	8.33(16.77)	8.33 (16.57)	8.67(17.10)	14.33 (22.16)	9.66(17.80)	585
Fipronil 2.8 EC	7ml	4.33	7.33(15.67)	6.33 (14.56)	7.33(15.69)	13.67 (21.60)	8.16(16.12)	595
Fipronil 2.8 EC	10ml	5.00	5.67(13.75)	6.33 (14.42)	6.67(14.92)	13.67 (21.62)	7.91(17.12)	603
Malathion 50 EC	250ml/acre	4.67	9.67(18.05)	10.00 (18.27)	13.33(21.39)	14.00 (21.94)	11.41(20.19)	556
Control	-	5.00	11.33(19.60)	16.33 (23.67)	19.00(25.79)	19.67 (26.27)	16.58(23.87)	451
CD (p=0.05)		NS	(1.78)	(2.14)	(3.66)	(4.28)	(3.24)	(27.2)

DAG (Days after germination); GFY (green fodder yield); Figures in parentheses are arc sine transformed values

Table 3: Efficacy of seed dressing insecticides for the control of *A. soccata* in forage sorghum during *kharif* 2016

Treatments	Dose (ml/kg seed)	Eggs per 5 plants	Deadhearts (%)					GFY (q/ha)
			7DAG	14DAG	21DAG	28 DAG	Mean	
Imidacloprid 600 FS	3ml	6.00	11.33(19.64)	15.00(22.77)	14.67(22.50)	14.00(21.93)	13.75(21.46)	574
Imidacloprid 600 FS	6ml	5.00	10.67(19.04)	11.33(19.65)	12.00(20.25)	10.00(18.38)	11.00(19.94)	581
Imidacloprid 600 FS	7ml	3.70	7.67(16.04)	10.33(18.71)	10.00(18.37)	8.33(16.77)	9.08(18.28)	588
Thiamethoxam 30 FS	5ml	4.30	9.67(18.07)	11.00(19.31)	11.00(19.35)	9.67(18.09)	10.33(18.10)	588
Thiamethoxam 30 FS	7ml	4.30	8.33(16.77)	9.33(17.75)	9.33(17.78)	8.67(17.11)	8.92(18.73)	591
Thiamethoxam 30 FS	10 ml	4.70	5.00(12.87)	7.67(16.06)	8.33(16.73)	7.33(15.70)	7.08(17.55)	616
Fipronil 2.8 EC	5ml	5.30	12.67(20.80)	15.67(23.29)	13.00(22.72)	12.33(20.53)	13.42(22.93)	582
Fipronil 2.8 EC	7ml	5.70	12.00(20.22)	12.33(20.53)	12.75(22.23)	10.00(19.04)	11.77(17.28)	595
Fipronil 2.8 EC	10ml	4.30	7.33(16.0)	9.00(17.22)	9.67(17.36)	10.00(18.10)	8.83(18.65)	595
Malathion 50 EC	250ml/acre	3.70	10.33(18.62)	14.25(23.29)	11.00(19.66)	11.00(19.66)	11.65(22.0)	556
Control	-	4.00	16.67(24.08)	17.67(24.83)	19.00(25.80)	17.00(24.33)	17.58(24.60)	469
CD (p=0.05)	-	NS	(2.87)	(2.14)	(2.54)	(1.58)	(2.61)	30.8
Figures in parentheses are arc sine transformed values								

Table 4: Pooled analysis on efficacy of different seed dressing insecticides for the control of *A. soccata* in forage sorghum

Treatments	Dose ml/kg seed	Eggs per 5 plants	Deadhearts (%)					GFY (q/ha)
			7DAG	14DAG	21DAG	28 DAG	Mean	
Imidacloprid 600 FS	3ml	5.67	9.67(18.04)	11.67(19.77)	11.83(20.04)	13.50(21.55)	11.67(19.93)	560
Imidacloprid 600 FS	6ml	5.00	8.83(17.20)	9.67(18.04)	10.17(18.54)	11.17(19.45)	9.96(18.37)	583
Imidacloprid 600 FS	7ml	4.00	7.17(15.44)	8.84(17.25)	9.17(17.60)	10.00(18.41)	8.79(17.21)	591
Thiamethoxam 30 FS	5ml	4.50	10.33(18.73)	11.00(19.36)	11.17(19.51)	10.33(18.73)	10.71(19.09)	586
Thiamethoxam 30 FS	7ml	4.50	8.83(17.28)	8.67(17.10)	10.17(18.57)	9.17(17.61)	9.21(17.60)	598
Thiamethoxam 30 FS	10 ml	4.33	5.83(13.96)	7.50(15.87)	9.17(17.53)	8.33(16.74)	7.71(16.06)	612
Fipronil 2.8 EC	5ml	5.33	10.00(18.27)	12.00(20.04)	10.83(19.12)	12.17(20.33)	11.25(19.57)	583
Fipronil 2.8 EC	7ml	5.00	8.67(16.80)	9.33(17.56)	10.04(18.31)	10.96(19.19)	9.75(18.17)	592
Fipronil 2.8 EC	10ml	4.67	8.17(16.29)	9.67()17.85	9.33(17.61)	10.71(18.92)	9.47(17.89)	599
Malathion 50 EC	250ml/acre	4.17	9.33(17.76)	12.13(20.30)	12.17(20.39)	12.50(20.66)	11.53(19.81)	553
Control	-	4.50	14.00(21.88)	17.00(24.34)	19.00(25.83)	18.34(25.33)	17.08(24.36)	460
CD(p=0.05)	-	NS	(2.8)	(4.17)	(3.80)	(5.66)	(1.91)	32.03
Figures in parentheses are arc sine transformed values								

indicating dilution of insecticide efficacy in all the treatments irrespective of dose. However the mean data on per cent deadheart count from all the observations revealed the superiority of seed treatment with thiamethoxam 30 FS @ 10 ml per kg seed and closely followed by fipronil @ 10 ml per kg seed and Gaucho @ 7ml per kg seed (7.17, 7.91 & 8.16% DH, respectively) in comparison to standard (11.41) and untreated control (16.58) (Table 2).

The perusal of data as mentioned in Table 3. during *kharif* 2016 revealed the same trend of deadheart reduction in case of seed dressing with thiamethoxam @ 10 ml per kg seed and closely followed by fipronil (10 ml) and imidacloprid (7 ml). The mean data on per cent deadheart reduction in all the test insecticides also showed superiority of thiamethoxam (10 ml) showing only 7.08 per cent deadhearts which was followed by fipronil 10 ml (8.83%) and imidacloprid 7 ml (9.08), whereas treatment plots with malathion spray recorded (11.65%) and significantly higher DH proportion. The pooled data of two years observation period as indicated in Table 4 also revealed the same trend, wherein promising treatment (thiamethoxam 30 FS @ 10 ml per kg seed) showed overall 7.71 per cent DH only, followed by other two treatments of fipronil and imidacloprid recording 8.79 and 9.47 per cent deadhearts only which were significantly better in terms of control in comparison to recommended insecticide treatment. The present investigation is in conformity with Sandhu [17], suggesting that seed treatment with thiamethoxam 30 FS @ 5 ml/kg seed and imidacloprid 600 FS @ 7 ml/kg seed were effective in reducing shoot fly incidence. Khandare, *et. al.*,[13] suggested that sorghum seed treatment provided highest germination percentage (92%) as observed in the seed treatment with thiamethoxam 35 FS @ 5 ml/ kg seed and minimum numbers of deadhearts (9.56%) were found on thiamethoxam 35 FS @ 5 ml/ kg seed as compared to control (51.28%). However Aggarwal *et al.*, [1] reported that mean shoot fly incidence (leaf injury and deadhearts) was significantly lower in imidacloprid 600 FS (8.79 and 2.28%) and carbofuran 3 G (16.96 and 7.49%) treatments as compared to the incidence in thiamethoxam 30 FS @ 6 g per kg seed (27.97 and 15.71%). *Yue et al.* [21], suggested

exposure of European corn borer and Indian meal moth larvae to Cruiser (thiamethoxam) and Gaucho (imidacloprid) @ 250-500 ppm for 4-6 days gives sufficient mortality. Daware *et al.* [5], also propounded that either seed treatment with thiamethoxam 70 WS @ 3 g/kg seed alone or in addition to seed treatment one spray with endosulfan @ 0.07 per cent or NSKE @ 5 per cent at 45 days after crop emergence, could be recommended for the effective management of all the three major pests of sorghum including shoot fly, shoot bug and aphids.

Green fodder yield (GFY) At harvest the **s**uperiority of green fodder yield (q/ha) was also reflected in promising treatment. The range of GFY (q/ha) during the year 2015 was 546-609 and 551-616 in the following *kharif* 2016, respectively (Table 2 and 3). The GFY as recorded in promising treatment was 609-612 during the both years of study period. The pooled analysis on green fodder yield also revealed the same pattern with 612 q/ha green fodder yield in the seed treatment with thiamethoxam (10ml/kg seed) which was statistically superior to standard and untreated control treatment (Table 4). The other treatments, *viz.* fipronil @10 ml per kg seed and gaucho were also recorded to be at par (599 & 598 q/ha respectively) with promising treatment. However, the seed treatment with thiamethoxam @ 10 ml per kg seed has numerical advantage as compared to other treatments under investigation (Table 4). These results are in conformity to findings of Khandre *et al* [13], advocating, seed treatment with thiamethoxam 35 FS @ 5 ml/kg seed produced highest grain yield (3462 kg/ha). The maximum net monetary returns 1:56.25 (ICBR) were realized by the treatment thaimethoxam 35 FS @ 5 ml/kg seed. Kumar and Prabhuraj [14], also observed that the efficacy of different seed treatment insecticides with respect to control of sorghum shoot fly; grain yield and green fodder yield and suggested thiamethoxam 70 WS at 2 g/kg recorded lower infestation of deadheart (7.9%) with less shoot bug population (5.83/5 plant), and higher grain yield (31.93 q/ha) besides, higher fodder yield (56.92 q/ha). Further, the author reported that imidacloprid 70 WS at 5 g/ha, endosulfan 35 EC seed soaking (8 h) at 2 ml/litre/kg and carbosulfan 25 DS at 40 g/kg were the next best treatments and were on par with each other

Economic comparison: The economic evaluation in terms of advantage in green fodder yield and economic gain has been presented in Table 5. This analysis revealed that protection against shoot fly damage lead to yield advantage of green fodder 93-153 q/ha yielding a net return of Rs. 11805-19370 /ha. The superior treatment with less number of deadhearts has also yielded highest net return of Rs. 19370/ha. Other treatments gave net returns of Rs.17890 and 16035/ha. Balakai and Bhagwat [2] also supported the superiority of thiamethoxam 70 FS @ 3g/ kg combined with endosulfan spray at 45 days after emergence recorded highest net return of Rs.6954 per hactare. However thiamethoxam (3g/kg seed) alone yielded Rs. 6072 /ha. Furthermore, Balakai [3] supported the effectiveness of thiamethoxam 70 WS (3g/kg seed) for achieving higher yield and net returns in comparison to imidacloprid 70 WS (5g/kg seed). Therefore, it is advocated that seed treatment before sowing is a useful option to control sorghum shoot fly, especially in case the crop is grown for fodder purpose as there is reduction of 31.67-54.85 per cent deadheart in comparison to untreated control (Fig.1). The seed treatment also useful in achieving higher GFY as compared to untreated control. The additional green fodder yield in different sets of seed treatment was recorded to be in range of 9.3-15.2 q/ha (Fig 2).

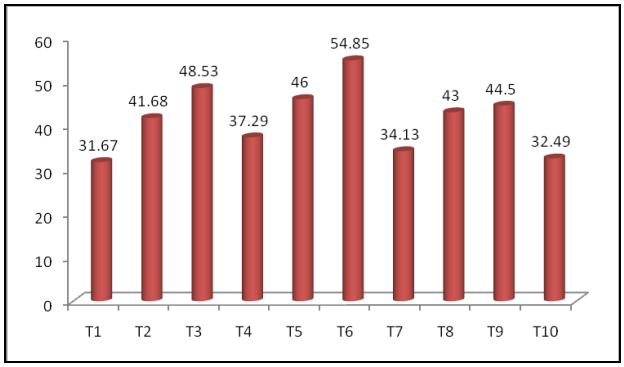

Fig 1: Effect of seed treatments in reduction of deadheart percentage in comparision to control

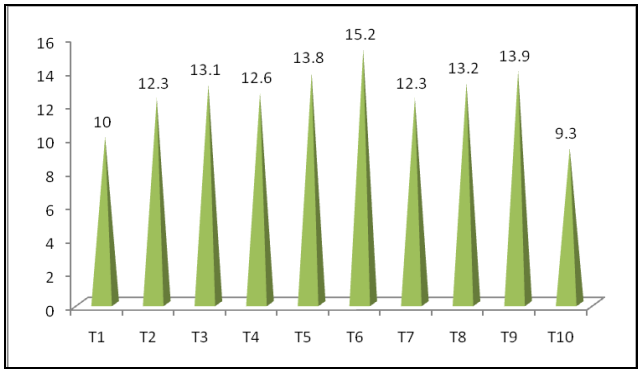

Fig 2: Yield advantage (GFY q/ha) due to treatment effect in comparision to control

Table 5: Yield advantage and economic returns from insecticide treatments against *A. soccata*

Treatments	Dose ml/kg seed	Per cent reduction in DH	GFY (q/ha)	Yield advantage (q/ha)	Gross returns over control (Rs.)	Cost of seed treatment (Rs./ha)	Net returns Over control (Rs/ha)
Imidacloprid 600 FS	3ml	31.67	560	100	13500	850	12650
Imidacloprid 600 FS	6ml	41.68	583	123	16605	1450	15155
Imidacloprid 600 FS	7ml	48.53	591	131	17685	1650	16035
Thiamethoxam 30 FS	5ml	37.29	586	126	17010	700	16310
Thiamethoxam 30 FS	7ml	46.00	598	138	18630	880	17750
Thiamethoxam 30 FS	10 ml	54.85	612	152	20520	1150	19370
Fipronil 2.8 EC	5ml	34.13	583	123	16605	563	16042
Fipronil 2.8 EC	7ml	43.00	592	132	17820	688	17132
Fipronil 2.8 EC	10ml	44.50	599	139	18765	875	17890
Malathion 50 EC	625ml/ha	32.49	553	93	12555	750	11805
Control	-	-	460	-		-	-

Market price of green fodder Rs. 135/q

Cost of seed treatment (Cost of insecticide + labour @ Rs100/ha); Spray of insecticide (200/ha)

Price of Insecticides: Slair: Rs 1800/l; Gaucho: Rs.400/ 100 ml; Regent: Rs. 1254/l; Malathion 400/lt

Conclusion

Seed treatment with thiamethoxam 30 FS @ 10 ml per kg seed emerged as good option for the shoot fly control with lesser incidence of deadhearts and higher monetary returns. Managing the pest in established sorghum ecosystem through chemical spraying has limited scope as repeated application of insecticides is required to achieve desirable control level and it may also lead to increased cost of production and phyto-toxic effect on plant foliage. Therefore seed treatment at the time of sowing may be advocated for shoot fly management as a part of integrated pest management strategy against sorghum shoot flies sorghum.

Acknowledgement

The authors are thankful to AICRP (Sorghum) for providing funding and necessary technical support for carrying out this investigation.

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