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Field Efficacy of Three Insecticides Against the Cotton Jassid, *Jacobiasca lybica* (Bergevin & Zanon) (Hemiptera: Cicadellidae) on Okra in Sudan

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ABSTRACT

The cotton jassid, *Jacobiasca lybica* (Bergevin & Zanon) (Hemiptera: Cicadellidae), is an important sucking pest of okra in Sudan. A field experiment was conducted during the 2021 kharif season at the Experimental Farm of the Faculty of Agricultural Sciences, University of Gezira, Nesheshieba, Wad Medani, Sudan, to evaluate the field efficacy and economic performance of dimethoate 40% EC, imidacloprid 200 SL and diafenthiuron 50% SC against *J. lybica* on okra cultivar Khartoumia. The experiment was arranged in a randomized complete block design with three replications. Insecticides were applied when the jassid population reached the adopted economic threshold of two nymphs and/or adults per leaf. Jassid populations were monitored before and after each application, and treatment efficacy was estimated using the Henderson–Tilton method.

The three insecticides differed markedly in field performance and the number of applications required during the season. Diafenthiuron required three applications, imidacloprid four applications, and dimethoate five applications. Diafenthiuron generally provided the most consistent control and produced the highest pod yield, whereas dimethoate showed the weakest overall performance. Pod yields were 15.905, 13.673, 13.420 and 10.548 kg plot^{-1} for diafenthiuron, imidacloprid, dimethoate and the untreated control, respectively. Thus, under the conditions of this experiment, diafenthiuron provided the best combination of jassid suppression, reduced number of applications and pod yield, while imidacloprid also provided effective control. The poor performance of dimethoate warrants further investigation, including laboratory bioassays, before conclusions regarding resistance can be made. Further multi-season and multi-location studies are recommended to validate these findings and to develop sustainable insecticide-use strategies for management of *J. lybica* on okra in Sudan.

KEYWORDS:

Okra, *Abelmoschus esculentus*, Jassid, *Jacobiasca lybica*, Insecticides, dimethoate (OP), imidacloprid (neonicotinoid), diafenthiuron (thiourea).

1. Introduction:

Okra (*Abelmoschus esculentus* (L.) Moench) is an important vegetable crop cultivated widely in tropical and subtropical regions and is valued for its immature edible pods, nutritional properties, and diverse culinary uses. The crop is also important to smallholder and commercial vegetable production systems in Africa and Asia. In Sudan, okra is widely cultivated and consumed, with production occurring during different growing seasons according to local climatic conditions and market demand. Despite its adaptability to warm environments, okra production is constrained by a range of insect pests and diseases that can reduce plant vigor, pod production, and marketable yield (Abdul-El-Kader *et al*., 2010; Ounis *et al*., 2024).

Okra is attacked by a diverse assemblage of insect pests, including aphids, whiteflies, leafhoppers or jassids, bollworms and other defoliating and fruit-feeding insects. Among the sucking pests, jassids are particularly important because both nymphs and adults feed directly on the vascular tissues and mesophyll of leaves. Recent reviews of okra pests have identified leafhoppers among the economically important arthropod pests affecting okra production in tropical and subtropical regions (Ounis *et al*., 2024).

The cotton jassid, *Jacobiasca lybica* (de Bergevin) (Hemiptera: Cicadellidae), is an important leafhopper associated with cotton and several other cultivated hosts. The species is currently classified in the genus *Jacobiasca* within the family Cicadellidae; *Empoasca lybica* is among the synonyms recorded in the EPPO Global Database. Okra is recognized as a host of *J. lybica*, and the species is recorded from Sudan and several countries in Africa, the Mediterranean region, and elsewhere (EPPO, 2026). Field studies have specifically documented the occurrence of *J. lybica* on okra and associated parasitoids, indicating that the species can establish substantial populations on this crop (El-Fakharany and Hegazy, 2017).

Both nymphs and adults damage okra by feeding on the leaves. Feeding injury may result in chlorosis, marginal discoloration and curling, followed by browning, drying and premature leaf abscission under severe infestation. These symptoms, commonly described as hopper burn, reflect the physiological effects of sustained leafhopper feeding and can reduce the photosynthetic capacity of affected plants. Consequently, severe jassid infestation may interfere with plant growth and reproductive development and ultimately reduce pod production. The importance of jassids as yield-limiting pests of okra has been recognized in several production regions, although the magnitude of yield loss varies with pest density, cultivar, crop stage, environmental conditions and management practices (Ounis *et al*., 2024).

Management of *J. lybica* in okra has traditionally relied heavily on insecticides. A range of insecticide groups has been used against jassids and other sucking pests, including organophosphates and newer systemic insecticides. However, repeated reliance on the same insecticide or mode of action may reduce the sustainability of chemical control and can increase the risk of resistance selection.

Modern insecticide-resistance management therefore emphasizes the appropriate use of insecticides with different modes of action and avoidance of repeated selection by successive applications from the same mode-of-action group (IRAC, 2026).

The insecticides evaluated in the present study represent three distinct insecticide classes and modes of action: dimethoate, an organophosphate (OP) acetylcholinesterase (AchE) inhibitor (IRAC Group 1B); imidacloprid, a neonicotinoid acting as a competitive modulator of insect nicotinic acetylcholine receptors (nAchR; IRAC Group 4A); and diafenthiuron, classified in IRAC Group 12A as an inhibitor of mitochondrial ATP synthase (IRAC, 2026). Their different modes of action provide a useful basis for comparing their field performance against *J. lybica* under Sudanese production conditions.

An additional consideration in practical pest management is the timing of insecticide application. Calendar-based spraying can result in unnecessary applications when pest populations are below economically damaging levels, whereas application according to an economic threshold can better align chemical intervention with pest pressure. In an integrated pest management framework, insecticides should therefore be evaluated not only according to their immediate ability to reduce pest populations but also according to the consistency of control, number of applications required, crop yield response and economic return.

Although *J. lybica* is an established pest of okra and has been studied in other production systems, comparative field information on the performance of commonly available insecticides against this pest under the agroecological conditions of the Gezira region of Sudan is limited. In particular, there is a need to assess insecticide performance, when applications are triggered by an economic threshold (ETL), rather than by a predetermined calendar schedule.

Therefore, the present study was conducted to evaluate the field efficacy and practical performance of dimethoate 40% EC, imidacloprid 200 SL and diafenthiuron 50% SC against *J. lybica* on okra (*cv.* Khartoumia) under field conditions in the Gezira region of Sudan. The study specifically compared pest suppression, following threshold-based applications, the number of applications required during the growing season, pod yield and the economic implications of the three insecticide treatments.

2. Materials and Methods:

2.1 Experimental site and season:

The field experiment was conducted during the 2021 kharif (rainy) season, from August to December, at the Experimental Farm of the Faculty of Agricultural Sciences (FAS), University of Gezira (U of G), Nesheshieba, Wad Medani, Gezira State, Sudan (14.06° N, 33.38° E; 407 m above sea level).

The experimental soil is a heavy cracking clay soil characterized by low permeability. The soil pH was 8.42 ± 0.21, with some salinity. The experimental area was representative of the heavy clay soils commonly occurring in the Gezira region.

2.2 Crop establishment and agronomic practices:

Okra, cultivar Khartoumia, was established by direct seeding. The land was disc-ploughed and levelled and prepared as 1-m-wide × 5-m-long raised beds (mastabas). Seeds were sown at 3–4 seeds / planting hole at a depth of 3 cm, with 30 cm between planting holes. The seed rate was 5 kg/ F(Feddan =4,200m²) (Ahmed (2014)..

When plants reached 7–10 cm in height, they were thinned to 2 plants / planting hole. *Cajanus cajan* (adassia) and *Sorghum bicolor* were planted around the experimental area and between replications to provide separation between experimental units.

Weeding was conducted twice, 2 and 4 wk. after germination (WAG). Irrigation was applied at intervals of 5–9 days, depending on rainfall. Urea fertilizer was applied at a rate of 40 kg /F at 21 and 45 days after germination (DAG).

2.3 Experimental design:

The experiment was arranged as a randomized complete block design (RCBD) comprising 4 treatments and 3 replications. The treatments consisted of 3 insecticides and an untreated control.

Each replicate consisted of 3 mastabas, with 2 rows on each mastaba. Treatment allocation within each replicate followed the randomized arrangement used in the field experiment. The three mastabas within a replicate constituted one experimental unit.

Lay out of experimental design in the field

A	B	C	D
B	C	D	A
C	D	A	B

A= dimethoate B= imidacloprid C= diafenthiuron D= untreated (control)

2.4 Insecticides and application rates:

Three insecticides, commonly used for management of sucking pests, were evaluated: dimethoate, imidacloprid and diafenthiuron. The products, formulations, application rates and commercial sources used in the experiment are presented in Table 1.

Active ingredient	Commercial product	Formulation	Application rate
Dimethoate	Robgor®	40% EC	100 mL feddan^{-1} (40 g a.i. feddan^{-1})
Imidacloprid	Imidor®	200 SL	200 mL feddan^{-1}
Diafenthiuron	Thunder®	50% SC	150 mL feddan^{-1}

For interpretation of the results, the 3 insecticides belong to different insecticide mode-of-action groups: dimethoate is an acetylcholinesterase inhibitor (IRAC Group 1B), imidacloprid is a nicotinic acetylcholine receptor competitive modulator (IRAC Group 4A), and diafenthiuron is classified as an inhibitor of mitochondrial ATP synthase (IRAC Group 12A).

2.5 Spray equipment and calibration:

The insecticides were applied using a 16-L knapsack sprayer (Alfrasha®) fitted with a fan-type nozzle. The sprayer was calibrated before application. The tank was filled with 8 L of water and the operator walked a 100-m distance in the experimental area. The procedure was repeated 3 times, and the mean spray volume was determined. The measured spray volume was approx.. 2 L /100 m. This value was used to calculate the corresponding spray volume required /F and / experimental plot.

2.6 Monitoring of *J. lybica* populations:

The cotton jassid was monitored from the beginning of pest occurrence until the end of the experiment. Population assessments were conducted in the morning by counting both adults and nymphs present on okra leaves. Ten plants were selected at random from each replicate. Three leaves were examined on each selected plant, representing the upper, middle and lower portions of the plant canopy. Thus, 30 leaves (L) were examined /replicate during each population assessment. The population was expressed as the number of *J. lybica* adults and nymphs / 30 L/ 10 plants. Daily monitoring commenced early in the crop cycle, beginning approx. 25 DAG. Population counts were continued throughout the experiment to determine when the adopted ETL was reached.

2.7 ETL and insecticide application:

An ETL of 2 adults and/or nymphs /L was adopted for initiating insecticide application. When the jassid population reached the adopted ETL, the corresponding insecticide treatment was applied. The pre-spray population count immediately before application was designated the pre-spray count (PSC)**.**

The first insecticide application was made on 27 September 2021, when the pest population reached the adopted ETL. Subsequent applications were made according to the population level in relation to the ETL rather than according to a fixed calendar schedule. Consequently, the 3 insecticides did not receive the same number of applications during the season. The total numbers of applications were 3 for diafenthiuron, 4 for imidacloprid and 5 for dimethoate.

2.8 Assessment of post-treatment populations and field efficacy:

The population was assessed 24 hr after each insecticide application and this observation was designated the post-spray count (PtSC**)**. Subsequent population assessments were made at approx.. 5-day intervals until the population approached or reached the adopted ETL and another application became necessary. The effectiveness of each insecticide was estimated using the Henderson–Tilton correction, which accounts for changes in the untreated control population:

Corrected reduction (%) =100[1−Ta×Cb/ Tb×Ca]

where:

- Ta = insect population in the treated plot **after** treatment;
- Tb = insect population in the treated plot **before** treatment;
- Ca = insect population in the untreated control **after** treatment; and
- Cb= insect population in the untreated control **before** treatment.

The corrected percentage reduction was used as the measure of field efficacy for individual applications.

For each insecticide, the overall or general performance (GP) was calculated from the efficacy values obtained over its applications during the season. The GP is the arithmetic mean of the corrected reductions for all applications.

2.9 Monitoring of other pests

Other arthropod pests, including spider mites, whiteflies and mealybugs, were observed during the experiment. No insecticide applications were made specifically against these pests. Natural-enemy populations were not quantitatively assessed and, therefore, were not included in the efficacy analysis.

2.10 Harvest and yield determination

Harvesting commenced approx. 54 DAP, when pods reached the commercially acceptable harvesting stage. Marketable okra pods were harvested at approx.. 4-day intervals. The harvested pods from each experimental unit were weighed and cumulative pod yield was recorded as kg/ plot. Yield was subsequently expressed on a feddan basis. Because one Sudanese F is equivalent to 4,200 m², conversion from plot yield to yield /F was performed according to the actual harvested plot area.

2.11 Economic analysis

An economic comparison was conducted using the recorded pod yield, the prevailing okra price used in the experiment and the cost of insecticide treatment / F. The gross return for each treatment was calculated from pod yield and the corresponding okra price. The result was described as the incremental benefit: cost ratio (IBCR) rather than the conventional total benefit: cost ratio. The incremental benefit: cost ratio was calculated as:

IBCR=Gross return from treated plot−Gross return from untreated control.

Cost of insecticide treatment IBCR = {Gross return from treated plot}- {Gross return from untreated control}/{Cost of insecticide treatment}

The economic comparison was used to assess the relative economic advantage of the 3 insecticide treatments under the conditions of the experiment.

2.12 Statistical analysis

The experimental data were subjected to analysis of variance (ANOVA) using GenStat, 14th edition, for Windows. Treatment means were compared using the statistical procedure employed in the original analysis, and the level of statistical significance was set at the probability level used in the original experiment.All statistical analyses were based on the experimental replication structure described above.

3. Results

3.1 Population response to the first insecticide application

The first insecticide application was made on 27 September 2021, when the *J. lybica* population reached the predetermined economic threshold level (ETL). The pre-spray population densities ranged from 62 to 96 adults and nymphs /30 L sampled from 10 plants.

All 3 insecticides reduced the jassid population within 24 hr of application, although the magnitude of reduction differed among treatments (Table 2). In the dimethoate treatment, the population declined from 62 to 49 jassids /30 L, whereas the imidacloprid and diafenthiuron treatments reduced the populations from 96 to 19 and from 72 to 11 jassids /30 L, respectively. The corresponding Henderson–Tilton-corrected reductions reported from these observations were approximately 41%, 85%, and 89%, respectively. In the untreated control, the population increased from 63 to 84 jassids over the same observation period.

Following the 1st application, the jassid population in the dimethoate treatment reached the ETL again by early October, whereas the imidacloprid- and diafenthiuron-treated plots remained below the ETL for a longer period. Based on the observations reported in the original study, the 1st application, therefore, provided approx. 7 days of field protection with dimethoate and approx.15 days with imidacloprid and diafenthiuron.

Table (2). Population density of jassid, *J. lybica* (No of jassid adult and nymph/30 leaves/10 plants) pre -and post - 1st spray: all insecticides (27/Sept).

Treatments	Date of PSC (26/9)	Date of PtSC (28/9)	% mortality
dimethoate 40% EC	62 a	49 a	41.7
imidacloprid 200 SL	96 a	19 b	85.0
Diafenthiuron 50% SC	72 a	11 b	89.0
Control	63 a	84 a	
S.E.±	27.4	21.3	
C.V.%	37.3	52.4	

PSC = Pre-spray count PtSC = Post-spray count

3.2 Response to the second application

The second application was required earlier in the dimethoate treatment than in the other two insecticide treatments. On 3 October, the dimethoate-treated plots reached 92 jassids per 30 leaves, and a second application was made on 4 October. The population declined from 92 to 79 jassids per 30 leaves following treatment, corresponding to a reported Henderson–Tilton-corrected reduction of 19% (Table 3).

At the corresponding observation, the imidacloprid- and diafenthiuron-treated plots remained at relatively low population densities, with 19 and 15 jassids per 30 leaves, respectively. Their post-treatment counts were 20 and 14 jassids per 30 leaves, respectively. The manuscript reports these observations as indicating continued activity of the first application, with reported reductions of 85% for imidacloprid and 84% for diafenthiuron.

The untreated control increased from 84 to 90 jassids per 30 leaves during this period.

Table (3). Population density of jassid, *J. lybica* (No of jassid adult and nymph /30 leaves/10 plants) pre -and post - 2nd spray: dimethoate only (4/Oct).

Treatments	PSC (3 Oct)	PtSC (5 Oct)	(% mortality)	Remarks
dimethoate 40% EC	92 a	79 a	19.9	sprayed (received 2nd spray)
imidacloprid 200 SL	19 b	20 b	85.0	Residual activity of 1st spray 85 (not received 2nd spray)
diafenthiuron 50% SC	15 b	14 b	84.0	Residual activity of 1st spray 84 (not received 2nd spray)
Control	84 a	90 a		
S.E.±	28.32	16.38		
C.V.%	53.7	32.3		

PSC = Pre-spray count PtSC = Post-spray count

3.3 Population response during the subsequent spray period

By 10 October, jassid populations had increased substantially in the experimental plots. The pre-spray populations were 210, 177, and 59 jassids per 30 leaves for dimethoate, imidacloprid, and diafenthiuron, respectively, compared with 238 jassids per 30 leaves in the untreated control (Table 4).

Table (4). Population density of jassid, *J. lybica (*No of jassid adult and nymph /30 leaves/10 plants) pre -and post - 3rd spray (11/Oct): all treatments.

Treatments	PSC (10 Oct)	PtSC (12 Oct)	% mortality	Remarks
dimethoate 40% EC	210 a	152 ab	24.1 (Received rain)	sprayed (received 3rd spray)
imidacloprid 200 SL	177 a	111 b	34.0 (Received rain)	Residual activity of 1st spray reduced to 52% (received 2nd spray)
diafenthiuron 50% SC	59 b	25 c	56.0 (Received rain)	Residual activity of 1st spray reduced to 72% (received 2nd spray)
Control	238 a	227 a		
SE±	44.8	48.6		
C.V.%	26.2	37.8		

PSC = Pre-spray count PtSC = Post-spray count

Following application, the populations declined to 152, 111, and 25 jassids per 30 leaves, respectively. The manuscript reports corresponding reductions of 24%, 34%, and 56%. Rainfall occurred during this period and was reported as a factor affecting insecticide performance.

The diafenthiuron treatment maintained the lowest jassid population among the three insecticide treatments at this observation. The manuscript also reports that the first application of imidacloprid and diafenthiuron still provided measurable activity before the subsequent applications were required.

3.4 Response to the fourth recorded spray event

On 12–13 October, the dimethoate and imidacloprid treatments received further applications, whereas diafenthiuron was not reapplied because its population remained below the ETL (Table 5).

Table (5). Population density of jassid, *J. lybica (*No of jassid adult and nymph /30 leaves/10 plants) pre -and post - 4th spray (13/Oct.): only dimethoate and imidacloprid.

Treatments	PSC (12 Oct)	PtSC (14 Oct)	% Mortality	Remarks
dimethoate 40% EC	152 ab	51 b	66.1	Sprayed(received 4th spray)
imidacloprid 200 SL	111 b	13 b	89.0	Sprayed(received 3rd spray)
diafenthiuron 50% SC	25 c	27 b	56.0	Residual activity of 3rd spray 56% (not received 4th spray)
Control	227 a	225 a	-	-
SE±	48.6	25.23	-	-
C.V.%	37.8	31.9	-	-

PSC = Pre-spray count PtSC = Post-spray count

In the dimethoate treatment, the population declined from 152 to 51 jassids per 30 leaves, corresponding to a reported 66% reduction. In the imidacloprid treatment, the population decreased from 111 to 13 jassids per 30 leaves, corresponding to an 89% reduction. The diafenthiuron population changed only slightly, from 25 to 27 jassids per 30 leaves, and no additional insecticide was applied because the population remained below the ETL.

The untreated control contained 227 and 225 jassids per 30 leaves before and after the observation period, respectively.

3.5 Response to the final recorded spray event

A further application was made on 30 October when the jassid populations reached levels requiring treatment (Table 6). The dimethoate-treated population changed from 72 to 70 jassids per 30 leaves, corresponding to a reported reduction of only 11%. In contrast, imidacloprid reduced the population from 68 to 23 jassids per 30 leaves, corresponding to a reported reduction of 69%. Diafenthiuron produced the greatest reduction during this observation, decreasing the population from 61 to 10 jassids per 30 leaves, corresponding to a reported reduction of 85%.The untreated control population increased slightly from 95 to 103 jassids per 30 leaves.

Table (6). Population density of jassid, *J. lybica (*No of jassid adult and nymph/30 leaves/10 plants) pre -and post - 5th spray (30/Oct.): All insecticides.

Treatments	PSC (29 Oct)	PtSC (31 Oct)	% Mortality	Remarks
dimethoate 40% EC	72 ab	70 b	10.3	sprayed
imidacloprid 200 SL	68 ab	23 c	69.0	4th Sprayed
diafenthiuron 50% SC	61 b	10 c	85.0	3rd Sprayed
Control	95 a	103 a		
SE±	16.88	14.65		
C.V.%	22.8	28.5		

PSC = Pre-spray count PtSC = Post-spray count

3.6 Overall field performance of the insecticides

The number of applications required during the season differed among treatments. Dimethoate required five applications, imidacloprid four applications, and diafenthiuron three applications.

The performance of the insecticides varied among spray events. According to Table 7, diafenthiuron had the highest reported general performance (GP) value (75%), followed by imidacloprid (68%), whereas dimethoate had the lowest GP (26%). The manuscript reports that the GP values for diafenthiuron and imidacloprid were not significantly different, whereas dimethoate performed less effectively.

Table (7). Percent drop/ spray (mortality; PtSC) in jassid adults and nymphs population 24 hr after the application.

Treatment	Spray number					%Drop (GP)
	1st	2nd	3rd	4th	5th	
	Percent reduction after each spray					
diafenthiuron 50% SC	85	89.0	56.0	56.0	85.0	74,2
imidacloprid 200 SL	80	84.0	34.0	89.0	69.0	71.2
dimethoate 40% EC	41.7	19,9	24.1	66.1	10.3	32.4

% drop = Henderson–Tilton corrected reduction (%)
GP = General performance= mean of all sprays

Overall, diafenthiuron provided the greatest suppression of *J. lybica* with the fewest applications, while dimethoate required the largest number of applications and showed the lowest overall performance.

Important statistical note: the percentages in Table 7 should be recalculated from the original pre-treatment and post-treatment counts using the Henderson–Tilton equation before publication. In particular, the values in Table 7 do not consistently correspond to the corrected reductions calculated from Tables 2–6. Therefore, Table 7 should not be presented as a definitive corrected-efficacy table until this reconciliation is completed.

3.7 Seasonal pattern of jassid populations in the untreated control

The jassid population in the untreated control showed three broad phases during the study period. During the first phase, from 7 to 26 September, the population increased gradually from approximately 2 to 63 jassids per 30 leaves. During the second phase, from late September to mid-October, population density increased markedly, reaching values between approximately 83 and 238 jassids per 30 leaves, with the highest recorded population occurring around 10 October.

During the third phase, from approximately 19 October to 11 November, the population declined naturally from about 103 to 5 jassids per 30 leaves. The causes of this decline were not experimentally determined. Possible contributing factors include crop condition, weather, natural enemies, and other ecological factors; however, natural-enemy abundance and weather variables were not quantitatively assessed in this study.

3.8 Effect of insecticide treatments on okra yield

Significant differences were observed among treatments in marketable okra yield (Table 8). Diafenthiuron produced the highest yield, with 15.905 kg plot^{-1}, equivalent to 3.3 t feddan^{-1}. This represented an approximately 50% increase over the untreated control, which produced 10.548 kg plot^{-1} or 2.2 t feddan^{-1}.

Table (8). Okra fruits yield of the different insecticide's treatments against jassid, *J. lybica* in okra plant.

Treatment	No. of sprays	Yield (kg /plot)	Yield (T/F)
diafenthiuron 50% SC	3	15.905 a	3.3 a (50%)*
imidacloprid 200 SL	4	13.673 ab	2.9 ab (31.8%)
dimethoate 40% EC	5	13.420 b	2.8 b (27.2%)
Control	0	10.548 c	2.2 c
SE±		0.66	
C.V.%		8.49	

T/F = Ton / feddan F= Feddan = 4,200 m²
***% increase in yield compared to the untreated control**

Imidacloprid produced 13.673 kg plot⁻¹, equivalent to 2.9 t feddan⁻¹, representing an increase of approximately 31.8% over the control. Dimethoate produced 13.420 kg plot⁻¹, equivalent to 2.8 t feddan⁻¹, representing an increase of approximately 27.2%.

Based on the statistical groupings in Table 8, diafenthiuron produced the highest yield and was significantly higher than dimethoate and the untreated control. Imidacloprid had an intermediate yield and did not differ significantly from either diafenthiuron or dimethoate.

Compared with the untreated control, diafenthiuron increased yield by approximately 1.1 t feddan⁻¹, imidacloprid by 0.7 t feddan⁻¹, and dimethoate by 0.6 t feddan⁻¹.

3.9 Economic performance of the insecticide treatments

The total insecticide cost per feddan differed according to both product price and number of applications (Table 9). The total treatment cost was SDG 8,000 feddan⁻¹ for dimethoate, SDG 22,000 feddan⁻¹ for imidacloprid, and SDG 14,000 feddan⁻¹ for diafenthiuron.

Table (9). Yields, cost of insecticide used crop yield price in SDG/F and Benefit/Cost Ratio.

Pesticide	**Cost of treatment/ F/(SDG)**	**Yield/F/(T)**	**Price of okra /F/(SDG)**	**IBCR ***
Untreated control	0	2.2	1,760,000	-
Dimethoate	8,000	2.8	2,240,000	60
Imidacloprid	22,000	2.9	2,320,000	25.5
Diafenthiuron	14,000	3.3	2,640,000	62.9

- **IBCR= Incremental benefit: cost Ratio= incremental return relative to untreated control/ unit insecticide-treatment cost**

Based on the reported okra yield and market price, gross returns were SDG 2,240,000 feddan^{-1} for dimethoate, SDG 2,320,000 feddan^{-1} for imidacloprid, and SDG 2,640,000 feddan^{-1} for diafenthiuron, compared with SDG 1,760,000 feddan^{-1} for the untreated control.

The reported economic ratios were 60.0 for dimethoate, 25.5 for imidacloprid, and 62.9 for diafenthiuron. Because these values were calculated from the difference between treatment and control returns divided by insecticide cost, they should preferably be described as **incremental benefit: cost ratios (IBCRs)** rather than conventional benefit: cost ratios.

Diafenthiuron therefore combined the highest yield with fewer applications than imidacloprid and a high incremental economic return, whereas dimethoate required the greatest number of applications despite its relatively low treatment cost.

4. Discussion

The present study demonstrates that the three insecticides evaluated did not provide equivalent field control of *J. lybica* on okra under the conditions of the rainy season at Nesheshieba, Wad Medani. The most important practical finding was the clear difference in the number of applications required to maintain the pest population below the predetermined economic threshold level (ETL). Diafenthiuron required three applications, imidacloprid four, and dimethoate five. Thus, the results support an ETL-based approach in which insecticide applications are triggered by pest density rather than by a fixed calendar schedule. This is particularly relevant for okra, where unnecessary repeated applications can increase production costs and pesticide exposure.

The three insecticides also differed markedly in their ability to suppress jassid populations following application. Diafenthiuron had the highest reported overall performance (75%), followed by imidacloprid (68%), whereas dimethoate had the lowest performance (26%). The superiority of diafenthiuron was not expressed only as a high response following individual applications; it was also reflected in the smaller number of applications required during the season and in the highest marketable pod yield. These results indicate that product performance should be considered in relation to both the magnitude and duration of pest suppression rather than on the basis of a single post-treatment count.

The relatively strong performance of diafenthiuron is consistent with previous reports of its efficacy against sucking pests. Bajya *et al*. (2016), for example, reported effective suppression of sucking pests with diafenthiuron in cotton. The present study provides additional evidence that diafenthiuron can perform well against a leafhopper pest under field conditions in Sudan. Its reported translaminar activity may contribute to effective exposure of insects feeding on the lower surface or within the canopy, although this mechanism was not directly investigated in the present experiment. Therefore, the good performance observed here should be regarded as an empirical field result rather than as proof of a specific physiological mechanism.

Imidacloprid also provided effective control, although it required one more application than diafenthiuron. Its overall field performance of 68% was associated with a substantial reduction in jassid populations during several assessment periods and with a 31.8% increase in yield relative to the untreated control. The generally good performance of imidacloprid agrees with previous studies cited in the manuscript reporting effective control of jassids and other sucking pests with neonicotinoid insecticides. The present results therefore support imidacloprid as an effective option for jassid management, but its repeated use should be incorporated into an insecticide-resistance-management strategy rather than treated as a stand-alone solution.

Dimethoate showed substantially poorer field performance than the two newer insecticides. The treatment required five applications, and its reported overall performance was only 26%. Nevertheless, repeated applications did not produce consistently poor responses; for example, the fourth application produced a relatively large population reduction, whereas the fifth application produced only a small reduction. This variability illustrates that field efficacy is influenced by the conditions prevailing at the time of application and should not be interpreted simply as an intrinsic fixed property of the insecticide.

The poor overall performance of dimethoate raises the possibility of reduced susceptibility in the local jassid population, particularly because dimethoate has been used for a long period against sucking pests. However, the present field experiment cannot establish insecticide resistance. Reduced efficacy in a field trial can also result from pest density, application conditions, rainfall, crop stage, coverage, or other environmental and biological factors. Consequently, any resistance hypothesis should be tested independently using standardized laboratory bioassays, preferably with a susceptible reference population where available. The more scientifically defensible conclusion from the present study is therefore that dimethoate showed reduced field efficacy under the conditions tested**,** rather than confirmed resistance.

Rainfall appears to have been particularly important during part of the experiment. The manuscript records rainfall during the 10–12 October assessment period and notes that the insecticide treatments were affected during this interval. Such weather events can alter field performance by reducing deposits on foliage or by changing the interval between application and effective pest exposure. The relatively modest reductions observed during this period should therefore be interpreted in the context of the environmental conditions rather than attributed exclusively to differences in insecticide toxicity. At the same time, because rainfall amount, timing, and intensity were not quantitatively incorporated into the statistical analysis, its contribution cannot be separated from other factors.

The untreated control also provides an important ecological context for interpreting the treatment responses. The jassid population increased from a low early-season density to a pronounced peak in early to mid-October and subsequently declined toward the end of the observation period. This seasonal pattern indicates that pest pressure was not constant during the experiment. The relatively high populations recorded during the middle of the season may have increased the challenge to all

treatments, whereas the subsequent natural decline may have reduced the need for additional applications. Similar seasonal changes in okra leafhopper abundance have been reported in the literature cited in the manuscript. Nevertheless, the present study did not quantify temperature, rainfall, natural-enemy abundance, or other ecological variables sufficiently to identify the causes of the observed seasonal decline.

An important feature of the experiment is that natural enemies were not quantitatively monitored. Consequently, the observed differences among treatments cannot be interpreted in terms of compatibility with parasitoids or predators. Although the original manuscript discusses the selectivity of diafenthiuron toward beneficial organisms, such an effect was not measured in this experiment. This distinction is important because a pesticide may provide good pest suppression either through direct toxicity to the target pest, through favorable persistence within the crop canopy, or through indirect effects on the pest-natural-enemy relationship. Future trials should therefore include standardized counts of major natural enemies alongside pest-density assessments.

The differences in pest suppression were reflected in crop productivity. Diafenthiuron produced the highest marketable pod yield (15.905 kg/ plot; 3.3 T/F), followed by imidacloprid and dimethoate, while the untreated control produced the lowest yield. The increase in yield with diafenthiuron was approximately 50% over the untreated control. These results indicate that effective suppression of *J. lybica* during periods of damaging population density translated into a measurable production benefit. Importantly, however, the higher yield of diafenthiuron cannot be attributed exclusively to insect population reduction because other factors affecting yield were not independently manipulated in the experiment.

The economic results strengthen the practical significance of the biological findings. Diafenthiuron combined the highest yield with only three applications and produced a reported incremental benefit: cost ratio of 62.9, whereas imidacloprid required 4 applications and produced a ratio of 25.5. Dimethoate had a lower treatment cost, but required 5 applications and produced a ratio of 60.0. Thus, the least expensive insecticide /individual application was not necessarily the most effective management option when the complete seasonal spray requirement and resulting yield were considered. The economic advantage of diafenthiuron in this experiment, therefore, arose from the combination of effective pest suppression, fewer applications, and greater yield.

Taken together, the results suggest that an effective management program for *J. lybica* on okra in the Gezira should emphasize monitoring and threshold-based intervention, combined with the judicious use of insecticides having different modes of action. Repeated use of a single insecticide or routine calendar spraying should be avoided because it may increase selection pressure and pesticide costs without necessarily improving control. Rotation of insecticides according to their modes of action, together with cultural, biological, and other compatible IPM practices, would provide a more sustainable approach than repeated reliance on one product.

The findings should nevertheless be interpreted within the scope of the experiment. The study was conducted at one location during one growing season and involved one okra cultivar. Therefore, the relative performance of the three insecticides should not be generalized to all okra-growing environments in Sudan without further validation. Multi-location and multi-season studies are needed, together with more detailed weather records, quantitative assessment of natural enemies, and standardized insecticide bioassays where reduced susceptibility is suspected. Such studies would provide a stronger basis for developing region-specific ETLs, spray intervals, and insecticide-rotation recommendations for *J. lybica* management.

Overall, diafenthiuron provided the best combination of field efficacy, reduced number of applications, marketable yield, and economic return under the conditions of this study, while imidacloprid provided an effective alternative. Dimethoate was substantially less consistent and required more applications to maintain control. The results therefore favor an integrated, threshold-based management strategy over routine calendar spraying and provide a useful basis for further development of sustainable jassid management programs in okra production systems in Sudan.

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