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Research Paper

Field Evaluation of Chilli Cultivation Practices and Their Effectiveness in Managing the Leaf Curl Complex under Dry Zone Conditions in Sri Lanka

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Abstract

Currently chilli farmers in Sri Lanka prefer to grow chilli hybrids under insect-proof nets to control the leaf curl complex. However, the effect of this system has not fully evaluated and the information are limited. Therefore, this study aimed to evaluate three different farmer-managed chilli cultivation practices and determine their effectiveness in managing the Chilli Leaf Curl Complex (CLCC) under dry zone field conditions in Sri Lanka. Data were collected from 28 farmers, with two-week intervals. Three treatments, insect-proof nets combined with polythene mulch and a fertigation system (T1), without insect-proof nets but with straw mulch and fertigation (T2), and traditional open-field chilli cultivation using flood irrigation (T3) were used in Completely randomized design (CRD). Thrips & CLCC damage severity, insect count, yield parameters, weather parameters and insecticide application details were recorded. Thrips damage severity did not differ among three farmer practices up to 6 WAP ($p>0.05$). At 8–10 WAP, it was significantly highest in T3 ($p<0.05$) and lowest in T1, followed by T2. Chilli leaf curl severity was significantly higher in T3 from 2–12 WAP ($p<0.05$), while T1 exceeded T2 only at 12 WAP, with no earlier differences.The whitefly abundance at 10 WAP correlated positively with ambient and canopy relative humidity ($p<0.05$).T1 had the highest environmental impact quotient ($p<0.05$), reflecting intensive insecticide use. The yield was significantly higher in T2 ($p<0.05$) than other two practices .Based on the collected data, T2 can be considered the most effective management practice for controlling CLCC compared to the other practices.

Keywords: Chilli Leaf Curl Complex, Environmental Impact Quotient (EIQ), Insect proof nets, Thrips damage Severity, Whitefly abundance

Introduction

Chilli (*Capsicum annuum* L.) is an indispensable spice in Sri Lankan cuisine. It is valued for its pungency, colour, flavour, and high content of vitamin C, carotenoids, and capsaicinoids (Azlan *et al.*, 2022). Despite the release of improved and hybrid varieties, national yields (5–6 t ha^{-1})

remain far below the potential of hybrids (~30 t ha^{-1}). Local production meets only 18–19% of the annual dry chilli demand, leading to heavy reliance on imports (DOA, 2015; DOA, 2024).This yield gap is mainly due to biotic and abiotic stresses, with the Chilli Leaf Curl Complex (CLCC) being the most damaging, causing yield losses of up to 53% (Lewis, 1997; Rajapakse *et al*., 2003).

Sap-sucking pests, including thrips, whiteflies, aphids, and broad mites, inflict direct feeding damage and transmit viruses such as Chilli Leaf Curl Virus (CLCCV) and Tomato Spotted Wilt Virus (TSWV). Thrips alone can reduce yields by over 50% in unmanaged fields (Mandanayake *et al*., 2023). Early planting has been recommended as a cultural practice to escape peak pest populations by enabling crops to complete critical growth stages before outbreaks (Gunawardene, 2002). However, early planting alone is insufficient for sustainable pest management, necessitating integrated pest management (IPM) strategies.

Insect-proof nets also known as anti-insect or exclusion nets, are an eco-friendly approach to pest management. They act as physical barriers that prevent insect entry, reducing feeding damage and virus transmission. Their effectiveness depends on mesh size, selected based on the thoracic width of target pests to ensure exclusion without restricting airflow (Boulard *et al*., 2011; Castellano *et al*., 2019). Insecticide-treated nets provide added protection through mechanical and chemical deterrence (Dader *et al*., 2015a; 2015b), while innovations such as UV-blocking and coloured nets further reduce insect attraction (Kumar & Poehling, 2006; Shimoda *et al*., 2024).

Globally, Insect-proof nets are used in crops like chilli, capsicum, tomato, and leafy vegetables. In Israel, they effectively exclude Bemisia tabaci and prevent TSWV (Antignus *et al*., 1998). In Kenya and Tanzania, pest infestations declined by over 80% (Martin *et al*., 2019), while in West Africa pest attacks dropped by over 60% and pesticide use by up to 70% (Assogba-Komlan *et al*., 2021). Similar benefits were reported in China (Wen *et al*., 2022).

Insect-proof nets improve yield, fruit quality, and water-use efficiency while reducing pesticide dependence (Ashraf *et al*., 2018; Murtiningsih *et al*., 2023; Wen *et al*., 2022). However, limitations include high costs, microclimate changes, and restricted pollination (Mutwiwa & Tantau, 2009; Yang *et al*., 2018; Hardin *et al*., 2023), which can be mitigated through improved design and IPM integration (Martin *et al*., 2019; Dader *et al*., 2015b).

Nutrient and water management also influence chilli productivity. Fertigation, the application of water-soluble fertilizers via irrigation, enhances nutrient uptake, promotes vegetative growth, and increases yield compared to soil fertilization (Reddy *et al*., 2016). Combining drip fertigation with mulching further improves water- and nutrient-use efficiency. Mulching with plastic film or straw reduces evaporation, suppresses weeds, and regulates soil temperature, supporting crop establishment and growth (Sathiyamurthy *et al*., 2017; Kumari *et al*., 2024). Studies indicate that polyethylene mulching with fertigation improves water-use efficiency and growth parameters compared to non-mulched conditions (Reddy *et al*., 2016).

Synthetic insecticides are commonly used but overreliance raises environmental, resistance, and health concerns. Therefore, integrated approaches combining fertigation, mulching, and judicious insecticide use are increasingly recommended to enhance sustainability and productivity (Nasrin *et al*., 2019; Mi & GIAO., 2022).

In Sri Lanka, farmers have increasingly adopted IPNs, particularly for high-value hybrid cultivars, to manage CLCC. However, systematic research on their effectiveness, cost-benefit ratio, and adaptability under local conditions is limited. Given the substantial yield losses caused by CLCC and its vectors, evaluating the efficacy, practicality, and economic viability of IPNs with other management practices under Dry Zone conditions is essential. This study aims to assess the effectiveness of three farmer practice packages in suppressing insect vectors and vector-borne diseases, evaluating pest damage severity and comparing environmental impacts. The findings will support the development of sustainable, eco-friendly, and economically viable strategies for improving chilli productivity in Sri Lanka.

Materials and Methods

Study location and farmer cultivation practices

The study was conducted in chilli-growing farmer fields located in Tirappane region in Anuradhapura District of Sri Lanka. Twenty-eight farmer fields, each ranging from 0.25 acres, were selected for the data collection. Among these, eleven farmers cultivated chilli under insect-proof nets combined with polythene mulch and a fertigation system (T1). Another six open-field fields were selected where chilli was grown without insect-proof nets but with straw mulch and fertigation (T2). Experimental design was Completely Randomized Design (CRD).Further, eleven farmers practiced traditional open-field chilli cultivation using flood irrigation (T3). All selected farmers cultivated the chilli variety MICH Hy 1.

Assessment of thrips damage severity

In each field, sixty plants were randomly selected and tagged for data collection. Thrips damage severity was assessed through visual observation at weekly intervals using the designated rating scale mentioned in table 1. (Mandanayake *et al*., 2023). Data collection began two weeks after planting and continued until the completion of the third harvest.

Table 1. Rating scale used to assess thrips damage severity
(Mandanayake *et al*., 2023)

Scale	Level of appearance of symptoms (% of leaves affected)	Remarks
1	0	No symptoms
2	1–5	
3	5–10	
4	10–20	
5	20–30	
6	30–45	
7	45–60	
8	60–75	Brown discoloration, stunting
9	>75	leaves affected; severe stunting, leaf shedding or plant death

Severity indices were calculated by using the following equation.

P = ∑ V. n/ N. Z × 100,

Where,

P= Severity index, V = Score value (table value), n= Number of plants having the same scale, N=Total number of individual chilli plants observed, Z= Highest number of scales

Plants with leaves exhibiting multiple symptom levels, the plant was assigned the score corresponding to the most frequently observed symptom level among its leaves.

Assessment of chilli leaf curl complex (CLCC) damage severity

In each field, sixty plants were randomly selected and tagged for data collection. CLCC damage severity was assessed through visual observation at weekly intervals using the Leaf Curl Index (LCI) scale (table 2) adapted from Latha & Hanumantharaya (2018) with modifications. The data collection was started two weeks after planting and continued until the completion of the third harvest. CLCC severity index was calculated using the same formula used in the previous section.

Assessment of whitefly population

Yellow sticky traps (10×25 cm) were placed two weeks after planting at the rate of 62 traps/ha and replaced in two-week intervals. Number of adult whiteflies, caught on the each trap, was counted and recorded.

Weather parameters

Relative humidity, minimum temperature, and maximum temperature were measured bi-weekly using a digital minimum–maximum thermo-hygrometer installed at each sampling site.

Yield assessment

Green chilli yield was recorded (t ha^{-1}) for each field from first to third harvest. Yield was taken from the plot size around 1000m^2 with having 3500 plants approximately and harvesting was done with 10 day intervals.

Table 2. Leaf curl index (LCI) for assessing CLCC damage severity
(Latha & Hanumantharaya 2018)

LCI/Grade (1-5)	Symptoms
1	1-25 per cent leaves/plant show curling, less damage
2	26-45 per cent leaves/ plant show curling, moderately damaged
3	45-60 plant show curling, moderately damaged, malformation of growing points
4	60-75 per cent leaves/plant show curling, heavily damaged, malformation of growing points and reduction in plant height
5	> 76 per cent leaves/ plant show curling, severe and complete destruction of growing points, and drastic reduction in plant height, defoliation and severe malformation.

Calculation of Environmental Impact Quotient (EIQ)

The Field use Environmental Impact Quotient (FUEIQ) was calculated for each chilli field using the formula introduced by Cornell University, Ithaca, United States, as shown below.

Field use EIQ=EIQ value × % active ingredient x rate (kg ha^{-1} or lbs $acre^{-1}$)

Information on the types of pesticides applied, their application rates, and the number of applications made by farmers throughout the study period was recorded. Fields which have been done for multiple pesticide applications, the individual EIQ values were summed to obtain the total EIQ for each farmer's practice.

Statistical analysis

The data on thrips damage severity, leaf curl damage severity, field use EIQ values, and yield were first assessed for normality using the Shapiro–Wilk test (α = 0.05). Because the data for thrips damage severity ($p < 0.01$) and leaf curl damage severity ($p < 0.03$) were not normally distributed, they were analyzed using a generalized linear model. Field use EIQ values ($p = 0.72$) and yield ($p = 0.69$) were normally distributed and therefore analyzed using analysis of variance (ANOVA). Means were compared using Tukey's test at the 0.05 significance level. Whitefly counts were analyzed using a negative binomial model due to over dispersion, with Tukey–Kramer adjustment for mean separation. Correlations between whitefly counts and weather parameters were evaluated using Spearman's correlation

Results and Discussion

Assessment of thrips damage severity

The data of this study shows clear significant differences in pest suppression (figure 1) among the three treatments ($F_{(2,25)}$ =4.01, $p<0.05$). The interaction between treatments and sampling time (WAP) was also significant ($F_{(2,23)}$ =4.75, $p<0.05$). Figure 1 shows the temporal variation of thrips damage in different treatments. Throughout the early weeks (2–6 WAP), there was no significant difference in thrips severity among treatments. However, T1 consistently exhibited the lowest severity of thrips damage among treatments. However, during 8-12 WAP, there was a significant difference among treatments. Damage under T1 treatment significantly increased during 10–12 WAP compared to the T2, indicating that the exclusion effect may weaken over time probably due to thrips intrusion or altered microclimate dynamics under the net. In contrast, the T2 showed a more gradual increase in damage, implying that straw mulch may moderate thrips pressure. The T3 had the highest thrips severity by 12 WAP, likely because in the absence of a physical barrier, or a mulch, thrips population can build up substantially over the cropping cycle.

These findings are consistent with previous research. The use of reflective plastic mulches significantly reduces thrips populations in tomatoes, especially during early plant establishment, although the effect has been declined as plant canopy grow and matured (Khan *et al*., 2023). Similarly, Riley *et al*. (2012) found that reflective mulches were more effective than black plastic or no mulch in reducing thrips abundance in tomatoes.

On the other hand, some studies suggest limitations to exclusion strategies. Efficient thrips netting requires very fine mesh (≤ 150–200 µm), and even then, thrips may penetrate or exploit micro-openings, especially over time (Harmanto, 2006). Moreover, in long-duration field crops, reflective mulch performance may degrade as canopy closure reduces light reflection, which may reduce its repellent effect on thrips (Khan *et al*., 2023). Thus, while our findings emphasize the importance of physical and cultural barriers (netting, mulch), they also highlight that such strategies may not fully eliminate thrips pressure through the entire crop cycle. These insights suggest a need for integrated pest management (IPM) approaches combining physical exclusion with other control tactics to maintain thrips suppression over time.

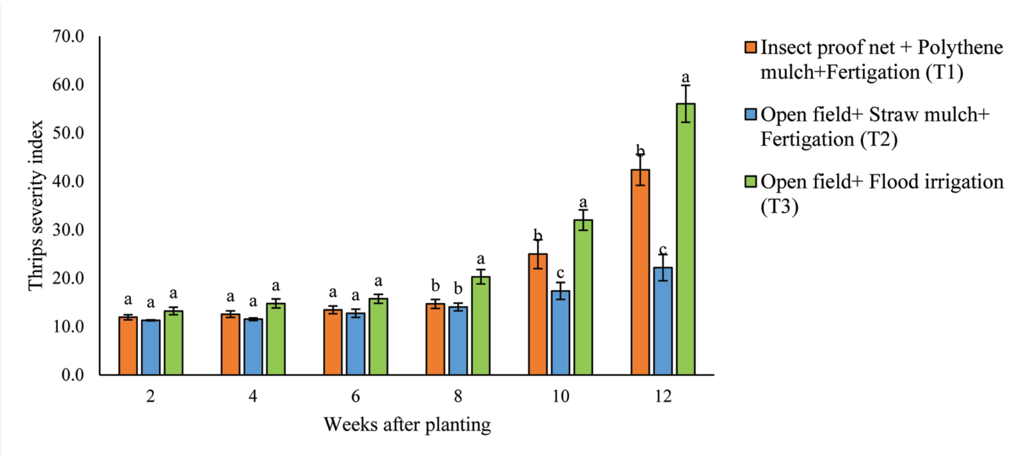

Figure 1. Temporal variation of thrips Severity index in chilli crop, cultivated under three packages of farmer practices. Means with the same letters are not significantly different at p >0.05

Assessment of chilli leaf curl complex (CLCC) damage severity

Figure 2 shows the LCC damage severity over 12 weeks, highlighted significant differences among the three management practices ($p<0.05$). T1 consistently exhibited numerically low damage severity throughout the study period, though it was not significantly different from T2, upto the 10th week. Damage seviarity of T1 ranges, starting approximately 4 units at 2 weeks after planting and increasing only to around 30 units by week 12. In contrast, T3 showed the highest severity at every observation, rising steeply from about 10 units at week 2 to more than 60 by week 12. T2 displayed intermediate levels, reaching approximately 50 by week 12. These results showed the protective role of physical barriers and mulching in reducing vector-mediated viral diseases. Similar reductions in chilli leaf curl incidence due to insect-proof netting have been reported by Sirisena *et al*. (2023), who attributed the effect to decreased whitefly activity, the primary vector of the virus. The beneficial influence of polythene mulching aligns with findings in pepper systems where plastic mulch suppressed virus severity and improved plant vigor by modulating microclimatic conditions (Arogundade *et al*., 2019). Furthermore, damage severity increase under flood irrigation agrees with studies showing that irrigation regimes influence leaf curl dynamics; micro-irrigation combined with mulch has previously been shown to reduce damage severity relative to traditional flooding (Maheswaren *et al*., 2017). However, the present results differ somewhat from studies demonstrating even stronger suppression when reflective silver mulch or integrated chemical vector management is practiced, as reported by Abhishek *et al*. (2024). Additionally, some literature emphasizes that the effectiveness of cultural controls is strongly genotype-dependent, with the resistant cultivars showing markedly reduced symptom expression (Mangal *et al*., 2024). Overall, the present findings support the view that insect exclusion, mulch choice, and irrigation method significantly influence the epidemiology of chilli leaf curl disease, while also highlighting that the degree of control may vary depending on additional factors such as mulch type, vector pressure, and host resistance.

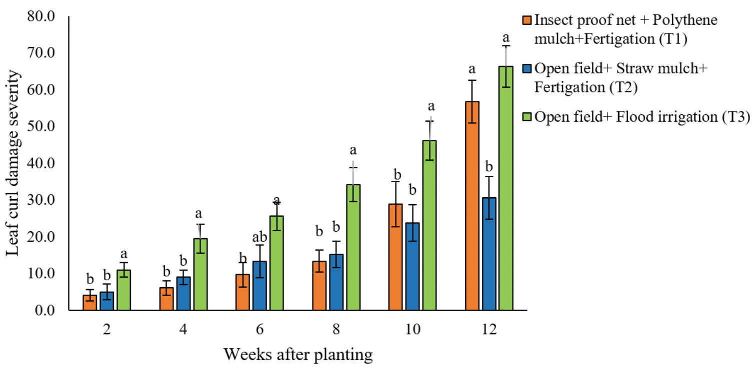

Figure 2. Temporal variation of leaf Curl Severity index in chilli crop cultivated under three packages of farmer practice. Means with the same letters are not significantly different at p >0.05

Assessment of whitefly population

Whitefly populations were significantly different among treatments at week 6 ($F_{(2, 25)}$ =4.01 $p<0.05$) as well as at week 10 ($F_{(2, 23)}$ =4.75 p=0.01). T3 had significant higher population level, but it was not significantly different from T1. No significant difference in population levels was found between T1 and T3 (Figure 3). At week 10, T3 had significantly higher population level compared to T1 and T2 while T1 and T2 were not significantly different. These findings are consistent with studies showing that insect proof netting serves as an effective mechanical barrier to *Bemisia tabaci* colonization (Summers *et al*., 2004), while reflective polyethene or metallic mulches disrupt host finding behavior via altered light reflectance and significantly reduce whitefly landing, colonization, and subsequent population build-up (Summers *et al*., 2004; Krugner *et al*., 2020). Evidence from vegetable cropping systems further supports that such combinations not only suppress whitefly densities but also enhance plant vigor and yield (Rutz *et al*., 2023). Additionally, reflective mulches have been shown to delay or reduce the onset of whitefly-transmitted viral diseases by reducing vector landing rates (UC IPM, 2022). Fertigation complements these physical barriers by maintaining optimal plant nutrition without generating excessive surface moisture that might otherwise favor whitefly proliferation. The insect-proof netting may alter microclimatic conditions, particularly increasing temperature or humidity, potentially encouraging secondary pest outbreaks or fungal pathogens when ventilation is insufficient (Kumar *et al*., 2021). Moreover, by restricting insect movement, netting may inadvertently limit the activity of natural enemies such as parasitoids and predatory arthropods, reducing the contribution of biological control. The intermediate whitefly counts observed in the straw-mulched treatment are consistent with literature indicating that organic mulches, although beneficial for soil health, may create refugia that shelter pest pupae or reduce the reflective deterrent effect found in synthetic mulches (Frank & Liburd, 2005). The higher whitefly densities observed under flood irrigation in the present study are consistent with earlier reports showing that surface and furrow irrigation methods, which maintain higher soil moisture and promote vigorous vegetative growth, support significantly greater *Bemisia tabaci* populations than sprinkler or drip irrigation systems (Gencsoylu & Sezgin, 2003). Economic and practical considerations further complicate adoption: netting, reflective mulch, and fertigation involve higher upfront costs, require maintenance, and may not be accessible to all farmers, especially in smallholder systems (Rutz *et al*., 2023). Further, overreliance on physical barriers or specific mulches risks potential pest behavioral adaptation or reduced long-term efficacy if not balanced with rotation or complementary IPM strategies.

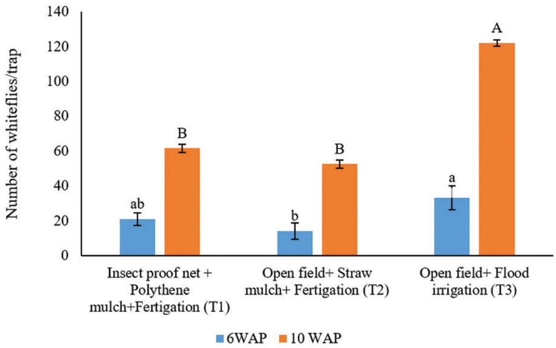

Figure 3. Whitefly population at 6 & 10 WAP in culli crops cultivated under three packages of farmer practices. Means with the same letters are not significantly different at p >0.05

Relationship between whitefly population and weather parameters

Tables 3 and 4 show the relationships between whitefly counts at 6 and 10 weeks after planting and the corresponding temperature and relative humidity (RH). Outside temperature and RH were measured for all three treatments, while inside temperature and RH were measured only for Treatment 1 where an insect-proof net was used. Whitefly counts at 6 WAP did not show any significant correlation with any individual weather variable, either inside or outside the canopy ($p > 0.05$). In contrast, number of whiteflies at 10 WAP was significantly and positively correlated with outside RH at 6 ($p=0.005$), 8 ($p=0.01$) and 10 ($p=0.001$) suggesting that elevated humidity during later crop stages may favor to develop whitefly population. Among the inside weather parameters (available only for Treatment 1), RH at 8 ($p=0.04$) & 10 ($p=0.04$) WAP showed significant correlation. These findings are consistent with previous research indicating that whitefly populations are strongly influenced by relative humidity during later crop stages, particularly in open-field conditions. The inside RH showed a significant correlation previous observations that microclimatic modifications through netting or physical barriers may buffer the impact of external weather, although high RH can still favor whitefly under poorly ventilated conditions (Kumar *et al*., 2021). In contrast, several studies suggest that whitefly abundance is not solely dependent on RH and can also be strongly influenced by temperature fluctuations, light intensity, and host plant quality, which were not strongly correlated in this study (Byrne & Bellows, 1991; Liu *et al*., 2020). Optimum whitefly development occurs at 25–30 °C, with reduced fecundity at higher or lower temperatures, and this temperature effect may interact with humidity to influence population growth (Wang & Tsai, 1996). The lack of significant correlation between early-stage whitefly counts and environmental variables may reflect temporal lag effects or the influence of other factors such as natural enemies, host plant resistance, or microclimate variability not captured by single-point measurements. Studies have shown that while relative humidity and other abiotic drivers clearly play a role, whitefly population dynamics are strongly shaped by biotic interactions, including predator communities and plant resistance traits (Kedar *et al*., 2024).

Table 3. Spearman Correlation between Whitefly Counts (WFC) and Outside Weather Parameters (n = 28)

Weather Variable	WFC at 6 WAP		WFC at 10 WAP	
	r	p-value	r	p-value)
Outside Temperature (4 WAP)	0.14	0.59	0.27	0.16
Outside Temperature (6 WAP)	-0.17	0.79	-0.09	0.64
Outside Temperature (8 WAP)	-	-	-0.01	0.96
Outside Temperature (10 WAP)	-	-	0.05	0.79
RH outside (4 WAP)	0.09	0.81	0.04	0.88
RH outside (6 WAP)	0.06	0.40	**0.07**	**0.005**
RH outside (8 WAP)	-	-	**0.45**	**0.01**
RH outside (10 WAP)	-	-	**0.49**	**0.001**

Significant correlations (p < 0.05) are bolded

Table 4. Spearman Correlation between Whitefly Counts (WFC) and Inside Weather Parameters (Treatment 1 only, n = 11)

Weather Variable	WFC at 6WAP		WFC at 10WAP(r)	
	r	p-value	r	p-value
Inside Temperature (4WAP)	-0.21	0.58	-0.14	0.53
Inside Temperature (6WAP)	0.25	0.6	0.33	0.21
Inside Temperature (8 WAP)	-	-	-0.28	0.56
Inside Temperature (10 WAP)	-	-	0.02	0.72
RH inside(4 WAP)	-0.31	0.35	-0.28	0.52
RH inside(6 WAP)	-0.4	0.22	-0.13	0.64
RH inside(8 WAP)	-	-	0.57	0.04
RH inside(10 WAP)	-	-	0.16	0.04

Significant correlations (p < 0.05) are bolded

Environmental Impact Quotient (EIQ)

Table 5 shows the insecticides and acaricides used under three chilli management systems. T1 relied on the largest number of active ingredients, including both synthetic chemicals and botanicals such as azadirachtin, indicating a more intensive pest-management approach. T3 used a moderate range of chemicals, while T2 used lowest number.

Table 6 indicates the field use EIQ values for different farmer practices.T1 showed a significantly higher value than T2 and T3. The higher EIQ in T1 likely reflects the impact of intensive use of insecticides and the acaricides (Sulphur which having higher EIQ for active ingredient) within the system. While such systems are effective in reducing pest pressure and improving yield, they may inadvertently increase environmental burden due to higher input frequency and concentration (Yuan & Zhang, 2021).

Table 5. Insecticides and Acericides used by farmenrs in 3 different management systems

	Different management practices		
	Insect proof net+ fertigation+ polythene mulch (T1)	Open field +straw mulch+ fertigation (T2)	Open field +flood irrigation (T3)
Insecticides & Acericides used	Abamectin 18 g L^{-1} EC	Abamectin 18 g L^{-1} EC	Abamectin 18 g L^{-1} EC
	Acephate 75% SP	Carbosulfan 200 g L^{-1} SC	Carbosulfan 200 g L^{-1} SC
	Acetamiprid 20% SP	Fenobucarb 500 g L^{-1} EC	Fenobucarb 500 g L^{-1} EC
	Azadirachtin 10g L^{-1} EC	Fipronil 50 g L^{-1} SC	Fenobucarb 500 g L^{-1} EC
	Carbosulfan 200 g L^{-1} SC	Imidacloprid 200 g L^{-1} SC	Fipronil 50 g L^{-1} SC
	Fenobucarb 500 g L^{-1} EC	Pymetrozine 50% WG	Imidacloprid 200 g L^{-1} SC
	Fipronil 50 g L^{-1} SC	Pyridaben	Pymetrozine 50% WG
	Imidacloprid 200 g L^{-1} SC	Spinetoram 25% WG	Pyridaben
	Lufenuron 50 g L^{-1} SC	Thiocyclam (Hydrogen Oxalate) 50%	Spinetoram 25% WG
	Profenophos 500 g L^{-1} EC		Sulfoxaflor 50%WG
	Pymetrozine 50% W G Pyridaben		Thiocyclam (Hydrogen Oxalate) 50%
	Spinetoram 25% WG		
	Spinosad 25 g L^{-1} SC		
	Sulfoxaflor 50% WG		
	Sulphur 80% WP		
	Thiamethoxam 20% WG		

These observations are consistent with previous findings that protected cultivation systems often achieve superior pest control and crop performance at the cost of higher chemical and nutrient input loads (Singh *et al*., 2020). Studies have noted that insect-proof nets, while mechanically excluding pests, can modify microclimatic conditions such as temperature and humidity, potentially necessitating more frequent interventions or pesticide applications to manage secondary pests (Kumar *et al*., 2021). Similarly, research in greenhouse tomato and cucumber systems found that fertigation combined with protective covers improves yield and reduces pest damage but may elevate environmental impact due to concentrated nutrient and pesticide runoff if not carefully managed (Geng *et al*., 2022; UC IPM, 2022). Contradictorily, some studies suggest that the high EIQ associated with protected cultivation may be mitigated through precision input management and integrated pest management (IPM) strategies. For instance, the use of biopesticides, beneficial insects, and targeted fertigation can maintain high productivity while reducing chemical load, challenging the idea that protected systems are inherently more environmentally influenced (Jawdah *et al*., 2024). Additionally, low-input, open-field systems (like T2 and T3) are often portrayed as more sustainable; however, they may require higher long-term labor inputs or experience episodic pest outbreaks, which can indirectly increase pesticide use or economic costs (Cornell Turfgrass Program, 2023). Therefore, while the current results support the observed EIQ differences, the ecological trade-offs of protected versus open-field systems are context-specific and can be influenced by adoption of complementary IPM and precision agriculture practices.

Yield assessment

Table 7 revealed the green chilli yield obtained under different farmer practices. Chilli crop produced a significantly higher yield when cultivated under T2 than under both T1 and T3. Yields under T1 and T3 were significantly different from each other. These results align with previous studies showing that straw or organic mulches improve soil, nutrient availability, and promote crop productivity in open-field systems (Li *et al*., 2021). Fertigation, by supplying nutrients in a timely and efficient manner, has also been widely reported to improve yield in vegetable crops under both open-field and protected cultivation (He *et al*., 2025). The comparable yields of T1 and T3 suggest that, although insect-proof nets and polythene mulch can reduce pest pressure, their potential benefits may be offset by microclimatic effects, such as altered temperature or humidity, which can limit crop growth if not carefully managed (Kumar *et al*., 2021). Conversely, some literature highlights that protected cultivation systems often enhance yield by reducing pest damage and stress compared to open-field systems (Singh *et al*., 2020). The lower yield of T1 in this study may therefore reflect system-specific constraints, such as suboptimal net ventilation or nutrient competition, rather than a general limitation of protected systems. Similarly, although T3 exhibited the lowest yield, other studies have reported that flood irrigation can be highly effective in water-abundant regions, highlighting that irrigation efficiency and local climate conditions critically influence outcomes (Imbulana & Manoharan, 2020).

Table 6. Field use EIQ values for different farmer practices. Means with the same letters are not significantly different at p >0.05

Treatment	Field use EIQ
Insect proof net + Polythene mulch+ Fertigation (T1)	67.9 a± 7.3
Open field+ Straw mulch + Fertigation (T2)	23.6 b ± 2.5
Open field+ Flood irrigation (T3)	22.4 b ± 2.3

Table 7. Green chilli yield under different farmer practices. Means with the same letters are not significantly different at p >0.05

Treatment: package of practices in cultivation	Yield (t ha^{-1})
Insect proof net + Polythene mulch+ Fertigation (T1)	11.09 b± 1.5
Open field+ Straw mulch + Fertigation (T2)	13.12 a ± 1.1
Open field+ Flood irrigation (T3)	10.85 b ± 1.3

Conclusion

The study demonstrates the effects of three different management practices on pest dynamics, environmental impact, and crop productivity. Treatments 1 and 2 showed similar levels of thrips damage severity up to 8 WAP, after which damage was significantly lower in T2 than in T1. For leaf curl damage severity, no differences were observed up to 10 WAP; however, T2 showed significantly lower damage than T1 thereafter. Treatment 3 consistently recorded the highest pest damage and whitefly abundance, highlighting the vulnerability of conventional open-field systems without physical or cultural interventions. Correlation analyses revealed that increased relative humidity, both outside and inside the canopy, was positively associated with higher whitefly abundance at later growth stages, underscoring the influence of environmental conditions on pest dynamics. The field-use EIQ was significantly higher in T1, whereas T2 and T3 maintained lower environmental impacts. The highest green chilli yield was obtained from Treatment 2. Overall, T2 emerged as the most balanced strategy, combining effective pest suppression, high yield, and a lower ecological footprint. In contrast, T1, although effective in reducing pest pressure, poses higher environmental risks due to the type of chemical inputs used. These results provide a baseline understanding of how different management practices influence chilli sucking pest management, environmental impact, and yield. However, further studies are needed to determine the specific contribution of each component used in the farmer management practices for chilli pest management.

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