Himachal Journal of Agricultural Research
Volume 51, Issue 2, December 2025; pp. 218–224; DOI: 10.18311/HJAR/2025/53848
INFORMATICS JOURNALS
Crop production

# Evaluation of Herbicides to Control *Lantana camara* [L.] in the Mid Hills of Himachal Pradesh

**Mridula[1*], M. C. Rana[1], G. D. Sharma[1], N. K. Sankhyan[2], Deeksha Thakur[1], Anshumali[1] and Abdullah Saqib[1]**

[1]Department of Agronomy, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur - 176062 Himachal Pradesh, India; mridulasapahia1964@gmail.com

[2]Department of Soil Science, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur - 176062, Himachal Pradesh, India

## Abstract

**An experiment was conducted during spring and autumn seasons of 2023 at non-cropped area of Fodder Research Unit of CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, to evaluate herbicides for the control of *Lantana camara*. The experiment was laid out in randomised block design with three replications that consisted of 13 herbicide treatments and 1 control. Glyphosate + surfactant (2000 g/ha + 1000 ml/ha) and metsulfuron-methyl + surfactant (8 g/ha + 1000 ml/ha) provided shorter shoots, low regeneration and high control for *Lantana* during spring. In autumn, both herbicides achieved complete control, with high control rating at 3 and 5 months of spraying. However, at 7 months after spray the former combination along with metsulfuron-methyl + surfactant (8 g/ha + 1000 ml/ha) showed low regeneration with high control rating. Herbicide application during autumn season was more effective than spring season for the management of *Lantana* in mid-hills of Himachal Pradesh.**

**Keywords:** Autumn, Control rating, Herbicides, Percent regeneration, Spring

Weeds pose a significant threat to crop production, causing significant damage in both cultivated and non-cultivated regions. Around 2 decades ago, the economic losses caused by weeds in India were estimated to be between INR 20 to 28 billion (Sachan 1989), while recent estimates suggest that annual losses in agricultural production due to weeds have surged to nearly INR 1050 billion (Varshney & Prasad Babu 2008). Biotic invasion has emerged as one of the top five threats to global biodiversity (Bhalla *et al.* 2022). Factors like tourism and globalization has intensified this issue by facilitating the introduction of invasive species that disperse and disrupt native ecosystem (Mack 2000). Once introduced, these invasive species can spread rapidly, often colonising wastelands, grasslands and non-cropped areas, where they compete with native grasses and cause ecological imbalances and biodiversity loss (Colautti & MacIsaac 2004). A prominent example is *L. camara*, an invasive weed that occupies vast stretches of non-cropland areas globally, including several Indian states like Himachal Pradesh.

*Lantana camara* [L.], is a pantropical weed from the *Verbenaceae* family, is found in around 50 countries, where various species are cultivated for their flowers under numerous cultivar names (Negi *et al.* 2019). *L. camara* is a short-stemmed shrub with ovate-oblong, opposite, rough and hairy leaves, growing to heights between 1.2 and 2.4 meters. *Lantana* is a native of tropical America and Africa (Nayar 1977). In India, *L. camara* was initially introduced in 1809 as an ornamental plant at the National Botanical Garden and as a hedge plant in Calcutta during the early 19$^{th}$

*Author for Correspondence

Manuscript received: 26.04.2025; Accepted: 15.07.2025

century (Kohli *et al.* 2006). Over time, *L. camara* spread across open areas, including roadsides, railway tracks, crop field edges and open forests throughout the country. It has now become fully naturalised and is widespread across India, particularly in tropical and subtropical regions and has invaded some temperate regions (Kimothi *et al.* 2010). In the non-cropland hilly regions of Himachal Pradesh, *L. camara* is considered one of the most problematic, obnoxious, invasive and perennial weed species (Angiras 2014).

Himachal Pradesh has a total land area of approximately 5.56 million hectares. Of this, only 0.89 million hectare is cultivated, supporting a population of 68.57 lakh people (Anonymous 2022-23). In Himachal Pradesh, major tracts of non-cropped areas are dominated by *L. camara*, *Parthenium hysterophorus*, *Ageratum conyzoides* and *Eupatorium* species (Angiras 2014). The districts of Kangra, Bilaspur, Hamirpur, Solan, Sirmour, Chamba and Mandi have experienced heavy infestation of *L. camara*, while Shimla has been only marginally affected. *Lantana* infestation covers approximately 150,000 ha of forest land, 2,000 ha along roadsides and 25,000 ha of barren or culturable wasteland (Anonymous 2011). The rapid growth and spread of this weed hinder the establishment of native trees, shrubs and grasses, posing a significant threat to biodiversity. As a result of fodder shortages caused by invasion of this weed, farmers are forced to let their cattle roam freely, causing damage to cultivated crops (Rana *et al.* 2015).

The management of *L. camara* has gained increasing attention due to the rising recognition of the significant economic and ecological impacts caused by biological invasions. While various control methods *viz.,* physical, chemical and biological have been used independently; their isolated use has proven ineffective in curbing this invasive species. Consequently, integrated weed management strategies have emerged as a more successful approach, combining techniques such as mechanical cutting followed by herbicide application on regrowth. Globally, herbicides like metsulfuron methyl, 2,4-D, glyphosate, glufosinate ammonium, triclopyr *etc*. have been utilized for perennial weed management with varying degree of success. However, in India, limited research has been conducted to assess the efficacy of these herbicides against this perennial invasive weed. To address this gap, the present study was designed to evaluate the effectiveness of selected herbicides in managing *Lantana* infestations.

## MATERIALS AND METHODS

The present experiment was carried out at the non-cropped area of Fodder Research Unit, Department of Agronomy, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur from October 2022 to August 2023 and from August 2023 to April 2024. The experimental site was located at 32°4′ N latitude and 76°3′ E longitude at an elevation of about 1290.8 meters above mean sea level in the North-Western region of Himachal Pradesh. The soil of the research site has been classified silty clay loam in texture. The experiment was conducted in a Randomized Block Design (RBD) with 14 treatments and 3 replications. The treatments included; $T_1$ - metsulfuron methyl (4 g/ha), $T_2$ - metsulfuron methyl (8 g/ha), $T_3$ - imazethapyr (150 g/ha), $T_4$ - imazethapyr (300 g/ha), $T_5$ - chlorimuron ethyl (9 g/ha), $T_6$ - chlorimuron ethyl (18 g/ha), $T_7$ - metribuzin (1400 g/ha), $T_8$ - 2,4-D amine (2500 g/ha), $T_9$ - oxyfluorfen (235 g/ha), $T_{10}$ - glufosinate ammonium (500 g/ha), $T_{11}$ - glyphosate (1500 g/ha), $T_{12}$ - glyphosate (2000 g/ha), $T_{13}$ - indaziflam + glyphosate (1390 g/ha) and $T_{14}$ - unsprayed. All the treatments, except control, were supplied with a surfactant at 1000 ml/ha during both seasons. The herbicides were applied on one month old regenerated *Lantana* bushes that had been cut in October 2022 and August 2023. However, due to low temperatures and unfavourable growth conditions during winter, the bushes cut in October reached a height of 20-25 cm by March 2023. Therefore, the herbicide application for these bushes was carried out in March 2023 i.e., in spring. In contrast, bushes cut in August experienced favourable growing conditions, allowing them to reach the target height of 20-25 cm within one month. Therefore, herbicide treatments for these bushes were done in September 2023, during the autumn season. Mean weekly meteorological data recorded at the meteorological observatory of Himachal Pradesh Krishi Vishvavidyalaya, Palampur during October 2022 - August 2023 revealed that the weekly maximum and minimum temperature ranged between 13.7 to 29.8° C and 2.7 to 20.0° C, respectively. The

total rainfall received was 2742.7 mm and the weekly mean relative humidity varied from 42.6 to 93.0%. The meteorological observations from August 2023 - April 2024, was maximum temperature ranged from 13.6° C to 28.5° C, while the minimum temperature varied between 2.2 to 18.7° C. A total of 561.8 mm of rainfall was recorded over the study period and the mean weekly relative humidity varied from 41.5 % to 88.7 %.

The *Lantana* bushes were cut during October 2022 followed by herbicides application during spring (March 2023) and the observations were recorded at 3 and 5 Months after Spray (MAS). For herbicides application during autumn (September 2023) season, *Lantana* bushes were cut during August 2023 and the observations were recorded at 3, 5 and 7 months after spray. Percent regeneration of *Lantana* after herbicide spray was calculated by counting the number of plants that regenerated following the death of their aerial parts. The percent regeneration was calculated mathematically and analyzed statistically using angular transformation because of percentage data. Percent regeneration was calculated by dividing the number of regenerated plants by the initial number of plants before treatment, then multiplying by 100. It was calculated by using the following formula:

$$Percent\ regeneration = \frac{Number\ of\ plants\ regenerated}{Initial\ number\ of\ plants\ before\ treatment} * 100$$

The shoot height of *Lantana* was recorded in each net plot, three randomly selected *L. camara* plants were tagged for height measurement. Shoot height was measured from the base of the shoot at ground level to the tip of fully opened leaf with the help of graduated bamboo or meter scale or measuring tape. The average height of the three plants was then calculated and expressed in centimeters (cm). Weed control rating for different treatments were recorded through visual observation. Visual control ratings were assessed on a scale of 0-10, where 0 indicated no control and 10 indicated complete control.

The data generated from field studies were subjected to statistical analysis. The technique of Analysis of Variance (ANOVA) for randomized block design was used for the interpretation of results. Statistical analysis was done as per the standard procedure described by Gomez and Gomez (1984).

## RESULTS AND DISCUSSION

### Percent Regeneration

All herbicide treatments resulted in significantly better control of *Lantana* than control (unsprayed) except for metribuzin (1400 g/ha), oxyfluorfen (235 g/ha) and glufosinate ammonium (500 g/ha) during both seasons (spring and autumn) (Table 1).

In the spring, applying glyphosate at 2000 g/ha ($T_{12}$) recorded significantly lower regeneration of *L. camara*; however, it remained statistically at par with metsulfuron-methyl 8 g/ha ($T_2$). These treatments were further statistically comparable to metsulfuron methyl 4 g/ha ($T_1$), which behaved in statistical similar manner to glyphosate 1500 g/ha ($T_{11}$), indaziflam + glyphosate 1390 g/ha ($T_{13}$), imazethapyr 300 g/ha ($T_4$), chlorimuron ethyl 18 g/ha ($T_6$) and 2, 4-D amine 2500 g/ha ($T_8$) at 3 Months after Spray (MAS). By 5 months after spraying, glyphosate (2000 g/ha) and metsulfuron methyl (8 g/ha) exhibited regeneration percentage of 54.8 and 55.5, respectively, showing that neither treatment completely controlled the *Lantana.* These treatments were statistically at par to those of imazethapyr 300 g/ha ($T_4$), indaziflam + glyphosate 1390 g/ha ($T_{13}$), imazethapyr 150 g/ha ($T_3$), chlorimuron ethyl 18 g/ha ($T_6$), chlorimuron ethyl 9 g/ha ($T_5$), 2,4-D amine 2500 g/ha ($T_8$), glyphosate 1500 g/ha ($T_{11}$), metribuzin 1400 g/ha ($T_7$), oxyfluorfen 235 g/ha ($T_9$), glufosinate ammonium 500 g/ha ($T_{10}$) and control ($T_{14}$).

Herbicide application during autumn, glyphosate at 2000 g/ha ($T_{12}$) and metsulfuron-methyl at 8 g/ha ($T_2$) showed no regeneration at 3 and 5 months after the spray. However, at 7 months after the spray, some plants began regenerating due to the declining effects of the herbicides and improper root kill. This suggests that these herbicides were effective in controlling *L. camara* up to 5 months after spray. These treatments were followed by indaziflam + glyphosate at 1390 g/ha which were statistically at par with glyphosate 1500 g/ha and metsulfuron-methyl 4 g/ha at all stages of observations.

The significant reduction in the per cent regeneration of *L. camara* following glyphosate application (2000 g/ha) and metsulfuron-methyl (8 g/ha) in spring (March) and particularly the complete suppression or no regeneration during herbicide application in autumn (September) is primarily due to the systemic nature

**Table 1.** Effect of different treatment on percent regeneration (%) of *L. camara* at different stages of observations

| Treatments | Dose (g ha$^{-1}$) | Spring** | | Autumn*** | | |
|---|---|---|---|---|---|---|
| | | 3 MAS | 5 MAS | 3 MAS | 5 MAS | 7 MAS |
| $T_1$ - Metsulfuron-methyl | 4* | 63.1 (79.2) | 73.1 (87.5) | 35.4 (33.7) | 35.4 (33.7) | (37.9) |
| $T_2$ - Metsulfuron-methyl | 8 | 53.1 (62.5) | 55.5 (66.7) | 0.0 (0.0) | 0.0 (0.0) | 26.3 (19.8) |
| $T_3$ - Imazethapyr | 150 | 83.1 (95.8) | 83.1 (95.8) | 46.0 (51.8) | 46.0 (51.8) | 51.2 (60.7) |
| $T_4$ - Imazethapyr | 300 | 73.1 (87.5) | 80.0 (91.7) | 44.2 (48.6) | 44.2 (48.6) | 47.4 (54.2) |
| $T_5$ - Chlorimuron-ethyl | 9 | 80.0 (91.7) | 83.1 (95.8) | 46.0 (51.8) | 46.0 (51.8) | 53.8 (64.9) |
| $T_6$ - Chlorimuron-ethyl | 18 | 76.2 (91.7) | 83.1 (95.8) | 48.8 (56.5) | 48.8 (56.5) | 51.2 (60.7) |
| $T_7$ - Metribuzin | 1400 | 90.0 (100.0) | 90.0 (100.0) | 90.0 (100.0) | 90.0 (100.0) | 90.0 (100.0) |
| $T_8$ - 2,4-D amine | 2500 | 76.2 (91.7) | 83.1 (95.8) | 43.6 (47.6) | 43.6 (47.6) | 46.0 (51.8) |
| $T_9$ - Oxyfluorfen | 235 | 90.0 (100.0) | 90.0 (100.0) | 90.0 (100.0) | 90.0 (100.0) | 90.0 (100.0) |
| $T_{10}$ - Glufosinate ammonium | 500 | 90.0 (100.0) | 90.0 (100.0) | 90.0 (100.0) | 90.0 (100.0) | 90.0 (100.0) |
| $T_{11}$ - Glyphosate | 1500 | 73.1 (87.5) | 83.1 (95.8) | 30.8 (26.2) | 30.8 (26.2) | 35.8 (34.5) |
| $T_{12}$ - Glyphosate | 2000 | 50.0 (58.3) | 54.8 (66.7) | 0.0 (0.0) | 0.0 (0.0) | 25.7 (18.9) |
| $T_{13}$ - Indaziflam + glyphosate (RM) | 1390 | 73.1 (87.5) | 80.0 (91.7) | 30.6 (26.4) | 30.6 (26.4) | 36.9 (36.1) |
| $T_{14}$ - Control (Unsprayed) | - | 90.0 (100.0) | 90.0 (100.0) | 90.0 (100.0) | 90.0 (100.0) | 90.0 (100.0) |
| **SEm (±)** | | 5.8 | 6.4 | 2.4 | 2.4 | 2.1 |
| **CD (P=0.05)** | | 16.8 | 18.5 | 7.1 | 7.1 | 6.2 |

Values given in parentheses are the mean of original values, data subjected to angular transformation
*Surfactant @ 1000 ml ha$^{-1}$ was added to all treatments, **Spring - Spray done in March, ***Autumn - Spray done in September, MAS - Months after Spray, RM - Ready Mix.

of these herbicides and their rapid translocation to the root systems, especially at higher doses compared to lower ones. The results similar to this was recorded by Thiruvarassan *et al.* (2019), where the application of metsulfuron-methyl (8 g/ha) along with non-ionic surfactant achieved maximum control of broad-leaved weeds in sugarcane. Similarly, glyphosate 41% SL (3 L/ha and 4 L/ha) provided most effective control of weeds in non-cropped areas (Kumar *et al.* 2021).

During both seasons, significantly higher regeneration (90.0%) was recorded with metribuzin (1400 g/ha), oxyfluorfen (235 g/ha), glufosinate ammonium (500 g/ha) and control (unsprayed). Herbicides such as metribuzin, oxyfluorfen and glufosinate ammonium demonstrated no effective control or performed similarly to the unsprayed control. This lack of efficacy is attributed to their contact mode of action without significant root translocation. The results similar to this were recorded by Kudsk and Kristensen (1992).

However, the regeneration of *Lantana* was less during autumn as compared to spring at all stages of observation. The reduced regeneration of *L. camara* during autumn compared to spring is likely due to seasonal physiological and environmental factors. In autumn, plants divert energy towards root development, enhancing the translocation of systemic herbicides to the roots, where they exert more effective control. Higher relative humidity during autumn also improves herbicide uptake by increasing droplet drying time on leaf surfaces. In contrast, during spring energy allocation towards foliage development limits herbicide translocation, resulting in higher regeneration. Similar results were recorded by Sharma (2008), who observed that herbicides applied in September and June, one month after cutting the *Lantana* bushes, provided better control of *L. camara* than March applications.

## Regenerated Shoot Height

The data on effect of treatments on regenerated shoot height of *L. camara* (cm) at different stages of observation have been presented in Table 2. During spring (spray done in March), application of glyphosate at 2000 g/ha ($T_{12}$) being at par with metsulfuron

**Table 2.** Effect of different treatments on shoot height (cm) of *L. camara* at different stages of observation

| Treatments | Dose (g ha$^{-1}$) | Spring** | | Autumn*** | | |
|---|---|---|---|---|---|---|
| | | 3 MAS | 5 MAS | 3 MAS | 5 MAS | 7 MAS |
| $T_1$ - Metsulfuron-methyl | 4* | 35.7 | 76.1 | 30.4 | 34.5 | 43.9 |
| $T_2$ - Metsulfuron-methyl | 8 | 26.6 | 59.0 | 0.0 | 0.0 | 10.6 |
| $T_3$ –Imazethapyr | 150 | 45.3 | 94.0 | 41.5 | 44.5 | 59.2 |
| $T_4$ –Imazethapyr | 300 | 43.6 | 92.1 | 40.2 | 45.2 | 57.9 |
| $T_5$ - Chlorimuron-ethyl | 9 | 48.2 | 98.3 | 43.2 | 49.5 | 61.5 |
| $T_6$ - Chlorimuron-ethyl | 18 | 47.0 | 97.7 | 42.0 | 47.3 | 60.4 |
| $T_7$ –Metribuzin | 1400 | 55.9 | 114.2 | 51.6 | 59.0 | 72.5 |
| $T_8$ - 2,4-D amine | 2500 | 46.8 | 96.1 | 38.0 | 44.4 | 55.5 |
| $T_9$ –Oxyfluorfen | 235 | 57.0 | 115.3 | 52.4 | 59.4 | 73.3 |
| $T_{10}$ - Glufosinate ammonium | 500 | 55.8 | 113.6 | 50.8 | 57.5 | 71.4 |
| $T_{11}$ –Glyphosate | 1500 | 35.5 | 76.0 | 29.5 | 33.4 | 44.1 |
| $T_{12}$ –Glyphosate | 2000 | 26.2 | 58.6 | 0.0 | 0.0 | 9.9 |
| $T_{13}$ - Indaziflam + glyphosate (RM) | 1390 | 34.6 | 74.9 | 28.8 | 31.8 | 41.4 |
| $T_{14}$ - Control (Unsprayed) | - | 64.5 | 120.5 | 64.2 | 71.2 | 82.2 |
| **SEm (±)** | | 2.5 | 4.8 | 2.0 | 2.3 | 3.0 |
| **CD (P=0.05)** | | 7.1 | 13.9 | 5.9 | 6.7 | 8.8 |

*Surfactant @ 1000 ml ha$^{-1}$ was added to all treatments, **Spring - Spray done in March, ***Autumn - Spray done in September, MAS - Months after Spray, RM - Ready Mix.

methyl 8 g/ha ($T_2$) resulted in significantly reduced shoot height of *L. camara* at all stages of observations. Indaziflam + glyphosate 1390 g/ha ($T_{13}$) was the next better treatment for reducing the shoot height of *L. camara*, behaving statistically similar to $T_1$ and $T_{11}$ at 3 and 5 Months after Spray (MAS). At 3 MAS, significantly taller shoots of *Lantana* were recorded with control where no herbicide was applied. At later stages of observations (5 months after spray) glufosinate ammonium 500 g/ha, metribuzin 1400 g/ haand oxyfluorfen 235 g/ha behaved statistically alike to unsprayed treatment.

During autumn herbicide application, the shoot height of *L. camara* was consistently shorter at all observation stages compared to spring. Application of glyphosate at 2000 g/ha and metsulfuron-methyl at 8 g/ha both significantly reduced shoot height and achieved complete mortality of *L. camara* at 3 and 5 MAS. However, some *Lantana* plants began to regenerate seven months after spraying. Indaziflam combined with glyphosate at 1390 g/ha showed results statistically similar to those of glyphosate at 1500 g/ha and metsulfuron-methyl at 4 g/ha across all observation stages. In the control, where no herbicide was applied, *Lantana* shoots were significantly taller at every stage of observation.

The reduced shoot height of *L. camara* with glyphosate (2000 and 1500 g/ha), metsulfuron-methyl (8 and 4 g/ha) and indaziflam + glyphosate (1390 g/ ha) can be attributed to more effective inhibition of physiological processes in plant such as photosynthesis, protein synthesis and cell division. The herbicide application can lead to oxidative stress in plants, which in turn affects hormone biosynthesis. Therefore, the reduced shoot height observed with these herbicides application might be attributed to the combined effects of inhibited physiological processes and disrupted hormone balance. The result similar to this was recorded by Silva *et al.* (2017) in *Arabidopsis thaliana.*

## Weed Control Rating

The data in Table 3 revealed that the herbicide application during the spring season recorded a higher control rating of 8.0 with glyphosateat 2000 g/ha and metsulfuron methyl at 8 g/ha at 3 MAS, whereas, at 5 MAS, a higher control rating was recorded with

**Table 3.** Effect of different treatments on control rating of *Lantana camara* at different stages of observation

| Treatments | Dose (g ha$^{-1}$) | Spring** | | Autumn*** | | |
|---|---|---|---|---|---|---|
| | | 3 MAS | 5 MAS | 3 MAS | 5 MAS | 7 MAS |
| $T_1$ - Metsulfuron-methyl | 4* | 6.3 | 5.7 | 8.0 | 8.0 | 7.0 |
| $T_2$ - Metsulfuron-methyl | 8 | 8.0 | 7.3 | 10.0 | 10.0 | 8.7 |
| $T_3$ - Imazethapyr | 150 | 5.3 | 4.3 | 6.7 | 6.3 | 5.3 |
| $T_4$ - Imazethapyr | 300 | 5.3 | 4.3 | 7.0 | 6.6 | 5.7 |
| $T_5$ - Chlorimuron-ethyl | 9 | 4.7 | 4.0 | 6.0 | 6.0 | 4.7 |
| $T_6$ - Chlorimuron-ethyl | 18 | 5.0 | 4.3 | 6.3 | 6.3 | 5.3 |
| $T_7$ - Metribuzin | 1400 | 3.0 | 2.0 | 5.0 | 4.7 | 2.7 |
| $T_8$ - 2,4-D amine | 2500 | 5.0 | 4.3 | 7.0 | 6.7 | 5.7 |
| $T_9$ - Oxyfluorfen | 235 | 3.0 | 1.7 | 4.3 | 4.0 | 2.3 |
| $T_{10}$ - Glufosinate ammonium | 500 | 3.3 | 2.0 | 5.3 | 5.0 | 3.0 |
| $T_{11}$ - Glyphosate | 1500 | 6.6 | 6.0 | 8.0 | 8.0 | 7.3 |
| $T_{12}$ - Glyphosate | 2000 | 8.0 | 7.7 | 10.0 | 10.0 | 9.0 |
| $T_{13}$ - Indaziflam + glyphosate (RM) | 1390 | 6.7 | 6.0 | 8.3 | 8.3 | 7.3 |
| $T_{14}$ - Control (Unsprayed) | - | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

*Surfactant @ 1000 ml ha$^{-1}$ was added to all treatments, **Spring - Spray done in March, ***Autumn - Spray done in September, RM - Ready Mix

glyphosate at 2000 g/ha (7.7), followed by metsulfuron methyl at 8 g/ha (7.3). This was followed by $T_{13}$, $T_{11}$, $T_1$, $T_3$, $T_4$, $T_6$, $T_8$, $T_5$, $T_{10}$, $T_7$ and $T_9$. A control rating of 0.0 was recorded in the control treatment at 3 and 5 MAS. However, during autumn season, herbicide application resulted in a higher control rating of 10.0 with glyphosate at 2000 g/ha and metsulfuron methyl at 8 g/ha at 3 and 5 MAS, indicating complete control of *L. camara*. At 7 MAS, the control rating was 9.0 with glyphosate at 2000 g/ha, followed by metsulfuron methyl at 8 g/ha (8.7). These were followed by $T_{13}$, $T_{11}$, $T_1$, $T_4$, $T_8$, $T_3$, $T_6$, $T_5$, $T_{10}$, $T_7$ and $T_9$. A control rating of 0.0 was recorded in the control treatment at 3, 5 and 7 MAS.

Control ratings 0 - No control, 10 - Complete control.

Herbicide application in spring showed higher control ratings with glyphosate (2000 g/ha), followed by metsulfuron methyl (8 g/ha), indaziflam + glyphosate (1390 g/ha), glyphosate (1500 g/ha) and metsulfuron methyl (4 g/ha). This may be due to their ability to move within the plant and act systemically, which helps suppress the regrowth of *L. camara*. However, complete control was not achieved in spring. In autumn, complete control and higher ratings at 3 and 5 MAS were observed with glyphosate (2000 g/ha) and metsulfuron-methyl (8 g/ha), possibly because environmental conditions like humidity, soil moisture and temperature were more favourable for herbicide effectiveness. The reduction in shoot height and regrowth in these treatments also supports their effectiveness in managing *L. camara*. At a later stage, some plants that were killed up to 5 months after spraying began to regrow, indicating that the herbicides were effective for up to five months.

## CONCLUSIONS

The field experiment demonstrated that applying glyphosate + surfactant (2000 g/ha + 1000 ml/ha) resulted in significantly lower percent regeneration, less shoot height and a higher control rating. However, its effects remained at par with the other herbicide treatments during the spring season at both observation stages (3 and 5 months after spray). In the autumn season, both glyphosate + surfactant (2000 g/ha + 1000 ml/ha) and metsulfuron methyl + surfactant (8 g/ha + 1000 ml/ha) were equally effective for controlling *L. camara* at 3 and 5 months of spray and showed no regeneration. At the later stage (7 months after spray), glyphosate +

surfactant (2000 g/ha + 1000 ml/ha) was more effective in reducing percent regeneration and lowering shoot height and remained at par with metsulfuron methyl + surfactant (8 g/ha + 1000 ml/ha). The next best treatment was indaziflam + glyphosate + surfactant (1390 g/ha + 1000 ml/ha), which was at par to glyphosate + surfactant (1500 g/ha + 1000 ml/ha) and metsulfuron methyl + surfactant (4 g/ha + 1000 ml/ha) in both seasons. Thus, these herbicides can be further tested for managing *L. camara* in different agro-climatic conditions to maximize control of *L. camara,* herbicide application during autumn is preferred over spring application.

## ACKNOWLEDGMENTS

We would also like to express our appreciation to the scientists and research staff of the Department of Agronomy, CSK Himachal Pradesh Agricultural University, Palampur, for providing the necessary resources, facilities and support that facilitated the smooth execution of this research endeavour.

**Conflict of interest:** Authors declare no competing interest.

## REFERENCES

Angiras NN 2014. Management of perennial weeds under non-cropland hill ecosystems. Indian Journal of Weed Science, 46(1), 52-60.

Anonymous 2011. Himachal Pradesh Forest Department. Government of Himachal Pradesh. Shimla.

Anonymous 2022-23. The Statistical Year Book of Himachal Pradesh. Department of Economic and Statistics Himachal Pradesh, Shimla.

Bhalla T, Kumar S and Rana SS 2022. Evaluation of herbicides to control alligator weed (*Alternanthera philoxeroides*) in mid hills of Himachal Pradesh. Himachal Journal of Agricultural Research **48(2):** 205-209. https://hjar.org/index.php/hjar/article/view/172395

Colautti RI and MacIsaac HJ 2004. A neutral terminology to define invasive species. Diversity and Distributions **10(2):** 135-141. https://doi.org/10.1111/j.1366-9516.2004.00061.x

Gomez KA and Gomez AA 1984. Statistical procedure for agricultural research. 2nd Edition. Wiley Inter Science, New York, USA.

Kimothi MM, Anitha D, Vasistha HB, Soni P and Chandola SK 2010. Remote sensing to map the invasive weed, Lantana camara in forests. Tropical Ecology, **51:** 67-74.

Kohli R, Batish D, Singh HP and Dogra KS 2006. Status, invasiveness and environmental threats of three tropical American invasive weeds (*Parthenium hysterophorus* L., *Ageratum conyzoides* L., *Lantana camara* L.) in India. Biological Invasion **8(7):** 1501-1510. https://doi.org/10.1007/s10530-005-5842-1

Kudsk P and Kristensen JL 1992. Effect of environmental factors on herbicide performance. Proceedings of the First International Weed Control Congress 1, p. 173-186.

Kumar S, Sharma N, Manuja S, Parita and Bhalla T 2021. Bio-efficacy and phytotoxicity of glyphosate 41% SL on weed flora of tea and its effect on soil microbial activities. Himachal Journal of Agricultural Research **47(2):** 235-238. https://hjar.org/index.php/hjar/article/view/168996

Mack RN, Simberloff D, Lonsdale WM, *et al* 2000. Biotic invasions: Causes, epidemiology, global consequences, and control. Ecological Applications **10(3):** 689-710. https://doi.org/10.1890/1051-0761(2000)010[0689:BICEGC]2.0.CO;2

Nayar MP 1977. Changing patterns of the Indian flora. Nelumbo **19(1-4):** 145-155. https://doi.org/10.20324/nelumbo/v19/1977/75567

Negi GCS, Sharma S, Vishvakarma SCR, Samant SS, Maikhuri RK, Prasad RC and Palni LMS 2019. Ecology and use of Lantana camara in India. The Botanical Review, **85(1):,** 109-130. https://doi.org/10.1007/s12229-019-09209-8

Rana SS, Badiyala D, Sharma N and Kumar R 2015. Major weeds in the non-cropped lands of Himachal Pradesh. Department of Agronomy, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur.

Sachan GC 1989. Pesticides in agriculture. Indian Farmers Digest **22,** 9-13.

Sharma R 2008. Standardization of round the year management techniques for the control of Lantana (*Lantana camara* [L.] var. aculeata). Ph.D. Thesis, p 212. Department of Agronomy, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur.

Silva FL, Rodriguez-Ruiz M, Houmani H, da Silva LC, Palma JM, Corpas JF 2017. Glyphosate-induced oxidative stress in *Arabidopsis thaliana* affecting peroxisomal metabolism and triggers activity in the oxidative phase of the pentose phosphate pathway (OxPPP) involved in NADPH generation. Journal of Plant Physiology **218:** 196-205. PMID: 28888161. https://doi.org/10.1016/j.jplph.2017.08.007

Thiruvarassan S, Manickam G, Anitha R, and Jayachandran M 2019. Studies on bio efficacy of metsulfuron methyl 20% WG as post-emergent applications against weeds in sugarcane (Saccharum officinarum L.). Journal of Pharmacognosy and Phytochemistry, 8(6), 269-273.

Varshney JG and Babu MBBP 2008. Future scenario of weed management in India. Indian Journal of Weed Science **40(1 and 2):** 01-09.