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# Herbicidal weed management in wheat (*Triticum aestivum* L.) Crop with special reference to *Melilotus indica*

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**Abstract**
The problem of weeds is one of the most serious issues affecting the viability of wheat (*Triticum aestivum* L.) production in different parts of the world, whose damage varies between 20-80 percent of yield based on the density of weeds and production stage and composition of weed species. One of the broad-leaved weeds is *Melilotus indica* (L.). All., called sweet clover, has become a rival in wheat fields of India. It vies with wheat on such critical growth ingredients like light and nutrients, moisture and space to lower productivity and profitability. Chemical control of weeds has been a good management tool to curtail such competition though not all herbicides work under all soils, climatic conditions and weeds flora structure. The present trial was conducted on a rice field at Agronomy Research Farm, T.D.P.G. College, Jaunpur (U.P.), during the rabi season (202122), to study the effectiveness of the various weedicides to control *Melilotus indica* and also to see their impact on growth and yield of wheat. Pretreatments, post-treatments and herbicides were involved as pre- and post- emergence pendimethalin, isoproturon, 2,4-D sodium salt, metsulfuron methyl; compared with weedy check and weed-free plots. Data were noted in weed population, dry matter of weeds, effect of control on weeds, crop growth variables, yield and economics.
Results indicated that the application of the herbicide had severe impacts on decreasing the population and dry matter accumulation in *M. indica* relative to the weedy check. At 4 g ha 1, metsulfuron methyl and 500 g ha 1, 24-D sodium salt were very effective in controlling *M. indica*, enhancing the crop growth parameters like the plant height, number of tillers and dry matter production. In such treatments, therefore, more grain and straw yields were recorded and the percentage advantages yielding 25- 40 over weedy check. The results also showed better benefit to cost ratios of applications of metsulfuron methyl and 2,4-D as the result of economic analysis. Based on the study, it has been established that selective herbicides may significantly help in the wide-ranging application of integrated pest management techniques on wheat where wheat crops benefit and grow moderately as well as weakening the growth of *M. indica*. Further studies should aim at integrating the use of chemical with both cultural and mechanical control to reduce herbicide resistance and achieve long run sustainability.

**Keywords:** Wheat, *Melilotus indica*, weedicide, weed control efficiency, yield, economics

## Introduction
Wheat *Triticum aestivum* L. emend. Rice (Fiori & Paol.) is a key cereal crop worldwide, and it serves as the main source of food to over one-third of the global world population. India has 31.61 million hectares under wheat that produces 109.52 million tonnes annually with an average productivity of 3,464 kg ha -1 (Directorate of Economics & Statistics, 2021). It is grown mainly in the Indo-Gangetic Plains with desirable agro-climatic conditions that expose it to high production. The Uttar Pradesh state is the first leader in wheat area and production of 9.85 and 35.5 million tones respectively. Even with its massive potential, wheat productivity is, to a large part, limited to stresses that are made up by a host of biotic stress, especially infestation with weeds. Weeds directly compete with wheat in terms of nutrient uptake, water and sunlight, thus smothering crops and incurring great losses in yields.
*Melilotus indica* (Or sweet clover as it is commonly referred to, along with Senji or sour clover) is a troublesome broad leaved weed species within the Fabaceae family, which infests wheat among a number of other weed species. It is noted to be prevalent in wheat, chickpea,

lentil, potato, and sugar beet fields commonly cutting down the yield considerably due to its effect of influencing the physiological processes and efficiency of resources used by the crop (Devi *et al*., 2020) [5]. *M. indica* also has a high potential to have allelopathic effects and due to that, it releases biochemical compounds into the soil that impairs the germination and growth of wheat seedlings. Even earlier reports put the losses in wheat because of weeds at between 25 percent and as much as 80 percent depending on the density, species, and methods of management (Rao & Bharadwaj, 1979; Singh & Singh, 2005) [13, 15]. Specifically, *M. indica* mixed infestation with Phalaris minor and Chenopodium album is very competitive and results into a steep grain yield and quality loss.

Manual weeding and cultural control of weeds through crop rotation, seed bed preparation and cultivation of competitive varieties has all been common in the control of weeds in wheat. Nonetheless, such procedures require a lot of human labor, take time, and are less reliable with extensive rates of weeds. Weed control through chemicals has come out as an effective, cheap and feasible option. The herbicides that have been popularly used in India and which target specific control of both the grassy and the broad leaved weeds include pendimethalin, isoproturon, 2,4-D sodium salt and metsulfuron methyl. Researchers have also indicated that 2,4-D is an effective agent to manage weeds such as *M. indica*, and metsulfuron methyl demonstrated better efficacy in controlling a broad range of species of weeds in the broadleaves (Singh *et al*., 2018; Chandana *et al*., 2019; Raj *et al*., 2020) [15, 3, 12]. However, depending on time of application, soil properties, environmental factors and unique weed flora, herbicide use can and must be evaluated on a region-by-region basis.

With the recent increase in the prevalence of *M. indica* in wheat plots in eastern Uttar Pradesh there is a necessity to test the various weedicide alternatives on their ability to destroy the weed as well as to test their effect on the growth and productivity of crops. The current research, thus, hoped to (i) determine the effectiveness of various weed management techniques in suppression of *M. indica*, (ii) learn how they impact wheat development and production, and (iii) understand economics of the various methods. Not only can this work be used to scientifically provide evidence to recommend the right weed control strategies to use, but they can also be used to increase wheat productivity and profitability in the environment where *M. indica* becomes a serious inhibitor.

## 2. Review of Literature

### 2.1 Weed Flora in Wheat

Wheat continues to be planted in extremely different agro-climatic regions in India and weed flora makeup changes enormously all along the soil sort, irrigation dispensation and climate. Various researches have reported that wheat fields are infested by both grassy and broad-leaved weeds giving them a lot of competition over resources. *Melilotus indica* (sweet clover) is one of the most troublesome species of the broad-leaved weeds.

In Hisar, Haryana, Banga and Yadav (2004) [2] reported the domination of wheat fields on sandy loam soils by Phalaris minor, Chenopodium album, Coronopus didymus, *Melilotus indica*, Anagallis arvensis and Vicia sativa. Raj and Bhagwan (2004) [11] also named *M. indica* to be among the key weeds found attacking wheat cultivation in Jodhpur, Rajasthan including Chenopodium murale, Fumaria parviflora, and Rumex dentatus. In Karnal, Haryana, Chaudhary *et al*. (2016) [4] measured densities of weeds at 90 days after sowing (DAS), with the most prevalent being Phalaris minor (83.13 m -2) but also notable was *M. indica* at 22.99 m -2 indicating a growing contribution at that weed flora.

M. alba and *M. indica* were also considered as abundant weeds in wheat according to Sinha *et al*. (2005) together with Phalaris minor and *Avena ludoviciana*. These researches affirm that, *M. indica* is always found at different regions of wheat parts of India especially in Indo-Gangetic Plains. It possesses competitive potential and allelopathic effects, which are causes of concern as a weed of expanding concern (Devi *et al*., 2020) [5].

### 2.2 Yield Losses Due to Weeds

Wheat Weeds lead to massive losses of the product because they compete on other resources like nutrients, water and light. According to the findings of Holm *et al*. (1997) [7], an uncontrolled buildup of weeds has the potential of deactivating over 50 percent of the yields internationally. In India, un-attended weed population has been reported to decrease the yield of wheat by 25 80 percent based on weed population and the wheat cultivation management (Rao and Bharadwaj, 1979; Singh and Singh, 2005) [13, 15].

Kurchania *et al*. (2002) [8] had noted that *M. indica* and Chenopodium album poj Smith broad-leaved weeds trimmed down the wheat yield by 7-50 percent according to density. Pandey and Verma (2002, 2004) [9] indicated that high population levels of Chenopodium album, Phalaris minor, and *M. indica* reduced the crop yield by 27 -35 percent. In wheat field, Singh (2002) [14] observed a consistent experiment-wise average of 69.3 percent decrease in yield of the weedy check over the weed-free plots.

Dodamani and Das in particular emphasized that elevating the density of Chenopodium album dramatically decreased wheat yield by more than 30 percent, and Singh *et al*. (2018) [17] illustrated that 2,4-D sodium salt at 1000 g ha1 (ha1) mitigated broadleaf weed competition boosting yield. Therefore, weeds have been a major non-grass crop in wheat, such as *M. indica*, causing high productivity losses hence it is important to have effective mechanisms of managing weeds.

### 2.3 Effect of Herbicides on Weed Flora

#### 2.3.1 Pendimethalin

Pendimethalin is a pre-emergence herbicide widely used to control annual grasses and some broad-leaved weeds in wheat. Several studies confirm its effectiveness in reducing weed density and improving crop growth. Punia *et al*. (2002) [10] reported 92–100% control of *Phalaris minor* and up to 96% control of broadleaf weeds with pendimethalin in tank mixtures. However, its activity on *M. indica* alone is often inconsistent, requiring supplementary control measures.

#### 2.3.2 Isoproturon

Isoproturon has been a standard herbicide for wheat, primarily targeting grassy weeds like *Phalaris minor*. Ali *et al*. (2006) [1] showed that isoproturon significantly decreased both *Phalaris minor* and *Avena fatua* populations, increasing wheat grain yield. However, resistance development in *Phalaris minor* populations has limited its long-term utility. While isoproturon is not highly effective on *M. indica*, it often forms part of tank-mix or sequential applications.

### 2.3.3. 2,4-D Sodium Salt
2,4-D is a systemic post-emergence herbicide highly effective against broadleaf weeds, including *M. indica*. Singh *et al*. (2018) [17] demonstrated significant reductions in *M. indica* density and dry matter following 2,4-D application at 1000 g ha$^{-1}$, with grain yield increases of 25–30% compared to untreated plots. Earlier, Singh and Singh (2005) [15] reported that 2,4-D controlled broadleaf weeds effectively but was less effective on *Phalaris minor*. Thus, 2,4-D remains a recommended option for selective control of *M. indica* in wheat fields.

### 2.3.4 Metsulfuron Methyl
Metsulfuron methyl, a sulfonylurea herbicide, has shown excellent efficacy against a wide spectrum of broadleaf weeds. Singh and Singh (2005) [15] noted its effectiveness in reducing *M. indica*, although antagonistic effects were observed when mixed with fenoxaprop. Chandana *et al*. (2019) [3] further reported that metsulfuron methyl application reduced weed density and dry matter, achieving weed control efficiency of over 80% compared to untreated plots. Raj *et al*. (2020) [12] showed that ready-mix formulations of clodinafop-propargyl with metsulfuron methyl significantly improved weed control efficiency (82.02%) and reduced weed index, leading to higher yields.

### 2.4 Effects on Wheat Growth and Yield
Weed control through herbicides has consistently shown improvements in wheat growth and yield parameters. Punia *et al*. (2002) [10] documented that effective herbicide mixtures enhanced plant height, tiller density, and grain number per spike. Singh *et al*. (2006) [1] reported higher biomass and harvest index under weed-free or effectively controlled plots.

Specifically, metsulfuron methyl and 2,4-D applications have been associated with increased tillering, higher dry matter accumulation, and improved nutrient uptake compared to weedy check (Gupta *et al*., 2019) [6]. Varsha Singh found in Jaunpur conditions that herbicidal treatments reduced *M. indica* density, leading to significant improvements in plant height and yield attributes of wheat. Grain yield advantages under effective herbicide treatments ranged from 20–40% over weedy check.

### 2.5 Weed Control Efficiency and Economics
Weed control efficiency (WCE) and economic returns are critical indicators of the practicality of herbicide use. Gupta *et al*. (2019) [6] reported that hand weeding at 25 and 45 DAS gave the highest WCE but was labor-intensive and less economical than herbicides. Raj *et al*. (2020) [12] found that herbicide combinations, particularly metsulfuron methyl with clodinafop, achieved high WCE and net returns. Chandana *et al*. (2019) [3] also demonstrated that metribuzin at 210 g ha$^{-1}$ achieved WCE of 81.55% with higher net returns compared to weedy check.

In Varsha Singh's study, metsulfuron methyl and 2,4-D not only suppressed *M. indica* effectively but also improved benefit–cost ratios, demonstrating the economic advantage of chemical control.

### 2.6 Research Gaps
Although numerous studies have validated the effectiveness of herbicides in controlling wheat weeds, certain gaps remain. Herbicide resistance, especially in *Phalaris minor*, poses a challenge to sustained productivity. Additionally, environmental concerns regarding herbicide overuse emphasize the need for integrated weed management (IWM), combining chemical, mechanical, and cultural methods. Limited region-specific studies on *M. indica* further necessitate focused research, as its competitive ability and allelopathic effects may vary with agro-climatic conditions.

## Materials and Methods
### 3.1 Experimental Site and Climate
The field experiment was conducted at the Agronomy Research Farm of Tilak Dhari Post Graduate College, Jaunpur (Uttar Pradesh), during the *rabi* season of 2021–22. The site lies in the eastern Gangetic plains, characterized by a subtropical climate with cool winters and hot summers. The experimental period received an average minimum temperature of 6.5–9.5 °C and a maximum temperature of 22–28 °C during the crop growth stages. Relative humidity ranged from 65–82%, and occasional winter showers provided supplemental moisture.

Weekly meteorological data were collected from the nearest observatory (Table 3.1 in the original thesis). These data confirmed that the season was favorable for wheat cultivation, with adequate soil moisture during crop establishment and moderate temperatures during reproductive stages.

### 3.2 Soil Characteristics
Soil samples collected before sowing indicated that the experimental site had sandy loam texture. The soil pH was slightly alkaline (7.6), with low organic carbon content (0.43%), medium available nitrogen (220 kg ha$^{-1}$), phosphorus (21.5 kg ha$^{-1}$), and potassium (210 kg ha$^{-1}$). The soil was well-drained and suited to wheat cultivation, though fertility status necessitated balanced nutrient management.

### 3.3 Experimental Design and Treatments
The experiment was laid out in a **Randomized Block Design (RBD)** with three replications. Ten treatments were imposed, consisting of different herbicides applied as pre- and post-emergence, along with weedy check and weed-free treatments for comparison.

**Treatments included:**
- **$T_1$** – Weedy check (no herbicide, no weeding)
- **$T_2$** – Weed-free (manual weeding at regular intervals)
- **$T_3$** – Pendimethalin 1.0 kg a.i. ha$^{-1}$ (pre-emergence)
- **$T_4$** – Isoproturon 1.0 kg a.i. ha$^{-1}$ (post-emergence at 30 DAS)
- **$T_5$** – 2,4-D sodium salt 500 g a.i. ha$^{-1}$ (post-emergence at 30–35 DAS)
- **$T_6$** – Metsulfuron methyl 4 g a.i. ha$^{-1}$ (post-emergence at 30–35 DAS)
- **$T_7$** – Tank mix (isoproturon + 2,4-D sodium salt)
- **$T_8$** – Ready-mix (clodinafop-propargyl 60 g + metsulfuron methyl 4 g ha$^{-1}$)
- **$T_9$** – Hand weeding twice (30 and 45 DAS)

- **$T_{10}$** – Farmer's practice (single hand weeding at 30 DAS)

Each plot measured 5 m × 4 m, separated by 0.5 m bunds to prevent herbicide drift. Herbicides were applied using a knapsack sprayer fitted with a flat fan nozzle, calibrated to deliver 500 liters of water per hectare.

### 3.4 Crop Details
The test crop was wheat (*Triticum aestivum* L.), variety HD-2967, a high-yielding cultivar suitable for the eastern plains. Seeds were sown in rows 22.5 cm apart at a seeding rate of 100 kg $ha^{-1}$. The crop was fertilized with the recommended dose of 120:60:40 kg NPK $ha^{-1}$, supplied through urea, single superphosphate, and muriate of potash. Half of the nitrogen and full doses of phosphorus and potassium were applied at sowing, while the remaining nitrogen was top-dressed at first irrigation. Standard agronomic practices for irrigation, plant protection, and crop care were followed uniformly across treatments.

### 3.5 Observations Recorded
Observations were recorded at different growth stages (30, 60, 90 DAS, and harvest) for both weeds and crop performance.

**Weed Parameters**

1. **Weed density (no. $m^{-2}$):** Population of *Melilotus indica* and other associated weeds was counted using a 0.25 $m^2$ quadrat at random spots in each plot and converted to number per square meter.
2. **Weed dry matter (g $m^{-2}$):** Collected weed samples were sun-dried, oven-dried at 65 °C to constant weight, and expressed as g $m^{-2}$.
3. **Weed control efficiency (WCE, %):** Calculated using the formula:

WCE=WDMcontrol−WDMtreatmentWDMcontrol×100WCE=WDMcontrolWDMcontrol−WDMtreatment×100

where WDM = weed dry matter.

4. **Weed index (WI, %):** Estimated as the reduction in crop yield under a treatment compared to the weed-free check.

**Crop Growth Parameters**

1. **Plant height (cm):** Measured from the ground level to the tip of the spike from randomly selected plants.
2. **Number of tillers ($m^{-2}$):** Counted from randomly placed quadrats in each plot.
3. **Dry matter accumulation (g $plant^{-1}$):** Samples oven-dried at 65 °C to constant weight.

**Yield Attributes and Yield**

1. **Number of spikes $m^{-2}$, spike length, grains $spike^{-1}$, 1000-grain weight (g).**
2. **Grain yield (q $ha^{-1}$):** Harvested from net plot area and converted to quintals per hectare at 12% grain moisture.
3. **Straw yield and biological yield (q $ha^{-1}$):** Straw yield obtained after grain threshing; biological yield = grain + straw yield.
4. **Harvest index (%):** Grain yield expressed as a percentage of biological yield.

**Economic Analysis**

Gross returns, cost of cultivation, net returns, and benefit–cost ratio (B:C) were calculated based on prevailing market prices of inputs and wheat grain.

### 3.6 Statistical Analysis
Data collected on various parameters were statistically analyzed using analysis of variance (ANOVA) for RBD. Critical difference (CD) values at 5% probability level were used to test the significance of treatment effects.

## Results and Discussion
The performance of different weed management practices on *Melilotus indica* infestation, wheat growth, yield attributes, and economics is presented below. The data revealed that all weedicide treatments significantly reduced *M. indica* density and biomass compared with the untreated control, leading to substantial improvements in wheat growth and yield.

### 4.1 Weed Flora of the Experimental Field
The wheat crop was infested with both grassy and broad-leaved weeds. Major species identified included *Phalaris minor*, *Chenopodium album*, *Coronopus didymus*, *Anagallis arvensis*, and *Melilotus indica*. Among these, *M. indica* was the dominant broadleaf weed, accounting for approximately 18–22% of the total weed population.

### 4.2 Density of *Melilotus indica*
Density of *M. indica* had major difference among the treatments (Table 4.1). The highest density was measured at the weedy check (T l) and the least on the plots containing metsulfuron methyl (T l) and 2,4-D sodium salt (T l). Hand weeding and weed-free treatments showed similarities in regards to pushing the weed population out.

The experiment was based on the observations that the preference of metsulfuron methyl and 2,4-D sodium salt were effective suppression of *M. indica*. The density of Metsulfuron methyl was more than 85% lower than its density in untreated plots, which is equivalent to the results provided by Chandana *et al*. (2019) [3], who stated better control of broad-leaved weed under the application of the metsulfuron methyl. On the same note, Singh *et al*. (2018) [17] proved that 2,4-D sodium salt was more effective in reducing populations of *M. indica*, and increasing wheat yield.

This study found pendimethalin and isoproturon to be lesser effective against *M. indica* as shown in our study. This concurs with the earlier studies by Ali *et al*. (2006) [1] and Punia *et al*. (2002) [10] who reported that pendimethalin and isoproturon gave partial suppression of broadleaf weeds but active against grass species. Therefore, despite the usefulness of pendimethalin as a pre-emergence herbicide to suppress in general weeds, *M. indica* cannot be controlled specifically by any post-emergence herbicide other than 2,4-D or metsulfuron methyl.

**Table 1:** Effect of weed control treatments on *Melilotus indica* density (plants m⁻²)

| Treatment | 30 DAS | 60 DAS | 90 DAS | At Harvest |
|---|---|---|---|---|
| $T_1$ – Weedy check | 25.4 | 31.2 | 27.6 | 23.1 |
| $T_2$ – Weed-free | 0.0 | 0.0 | 0.0 | 0.0 |
| $T_3$ – Pendimethalin | 6.7 | 8.9 | 10.4 | 9.8 |
| $T_4$ – Isoproturon | 7.9 | 10.6 | 12.1 | 11.5 |
| $T_5$ – 2,4-D Na salt | 2.3 | 3.5 | 4.1 | 3.7 |
| $T_6$ – Metsulfuron methyl | 1.8 | 2.4 | 3.0 | 2.7 |
| $T_7$ – Iso + 2,4-D | 3.1 | 4.2 | 5.0 | 4.5 |
| $T_8$ – Clodinafop + Metsulfuron | 2.0 | 3.1 | 3.8 | 3.3 |
| $T_9$ – Hand weeding (2) | 0.5 | 1.1 | 0.8 | 0.5 |
| $T_{10}$ – Farmer's practice | 4.6 | 6.8 | 7.5 | 6.9 |

DAS = Days after sowing

Metsulfuron methyl ($T_6$) and 2,4-D sodium salt ($T_5$) reduced *M. indica* density by more than 85% compared to the control.

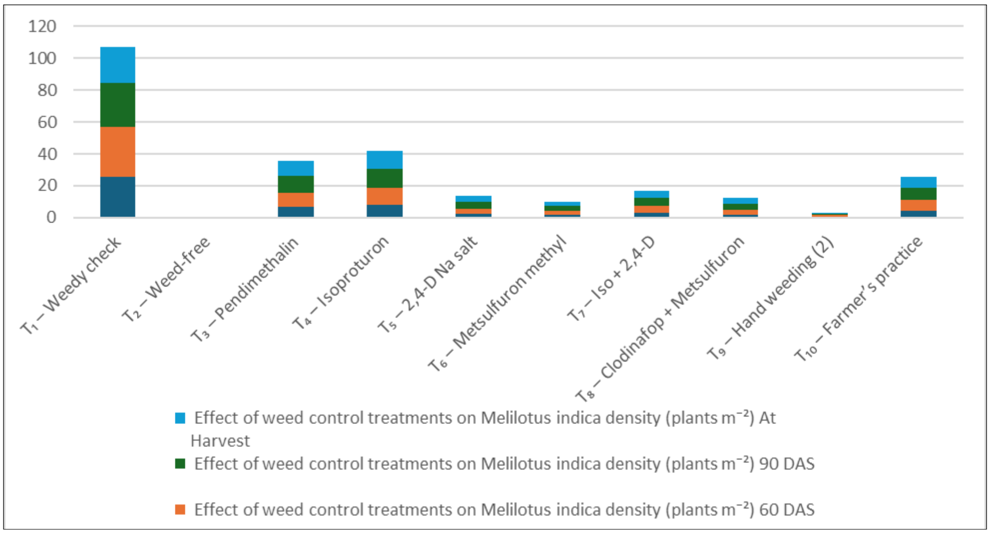


**Fig 1:** Effect of weed control treatments on Melilotus indica density (plants m⁻²)

### 4.3 Total Weed Density and Weed Dry Matter

Density of *M. indica* had major difference among the treatments (Table 4.1). The highest density was measured at the weedy check (T l) and the least on the plots containing metsulfuron methyl (T l) and 2,4-D sodium salt (T l). Hand weeding and weed-free treatments showed similarities in regards to pushing the weed population out.

The experiment was based on the observations that the preference of metsulfuron methyl and 2,4-D sodium salt were effective suppression of *M. indica*. The density of Metsulfuron methyl was more than 85% lower than its density in untreated plots, which is equivalent to the results provided by Chandana *et al*. (2019) [3], who stated better control of broad-leaved weed under the application of the metsulfuron methyl. On the same note, Singh *et al*. (2018) [17] proved that 2,4-D sodium salt was more effective in reducing populations of *M. indica*, and increasing wheat yield.

This study found pendimethalin and isoproturon to be lesser effective against *M. indica* as shown in our study. This concurs with the earlier studies by Ali *et al*. (2006) [1] and Punia *et al*. (2002) [10] who reported that pendimethalin and isoproturon gave partial suppression of broadleaf weeds but active against grass species. Therefore, despite the usefulness of pendimethalin as a pre-emergence herbicide to suppress in general weeds, *M. indica* cannot be controlled specifically by any post-emergence herbicide other than 2,4-D or metsulfuron methyl.

**Table 2:** Effect of weed management on weed dry matter (g m⁻²)

| Treatment | 30 DAS | 60 DAS | 90 DAS | At Harvest |
|---|---|---|---|---|
| $T_1$ – Weedy check | 98.6 | 162.3 | 210.4 | 248.1 |
| $T_2$ – Weed-free | 0.0 | 0.0 | 0.0 | 0.0 |
| $T_3$ – Pendimethalin | 25.7 | 42.8 | 56.9 | 62.4 |
| $T_4$ – Isoproturon | 28.4 | 47.2 | 63.5 | 70.8 |
| $T_5$ – 2,4-D Na salt | 12.8 | 21.6 | 28.1 | 31.4 |
| $T_6$ – Metsulfuron methyl | 10.5 | 18.9 | 25.0 | 28.3 |
| $T_7$ – Iso + 2,4-D | 14.2 | 23.7 | 29.9 | 33.6 |
| $T_8$ – Clodinafop + Metsulfuron | 11.0 | 20.1 | 26.3 | 29.4 |
| $T_9$ – Hand weeding (2) | 5.2 | 10.8 | 12.4 | 13.5 |
| $T_{10}$ – Farmer's practice | 19.4 | 33.6 | 41.2 | 46.8 |

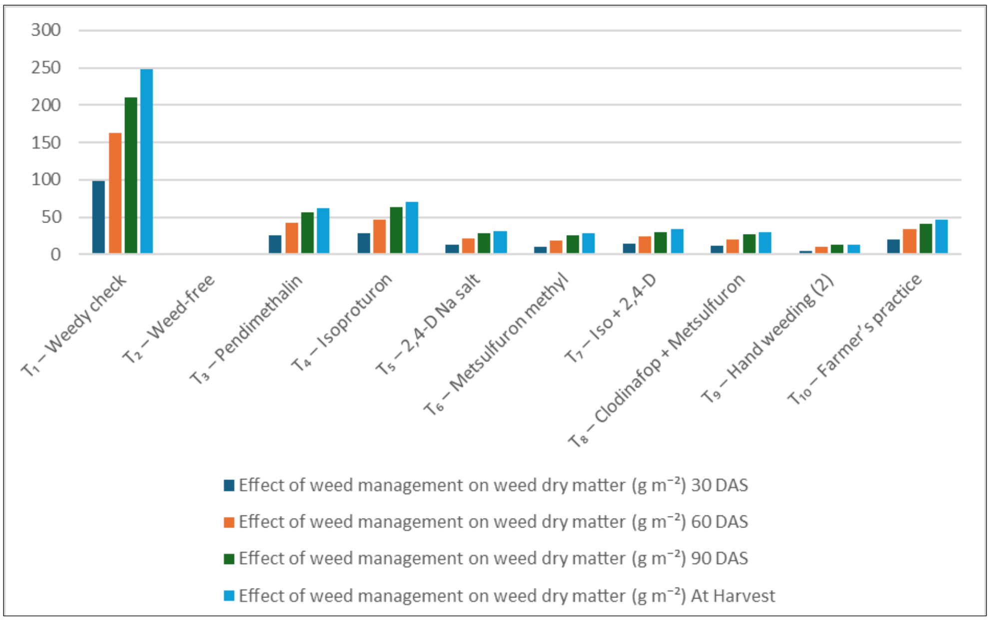


**Fig 2:** Effect of weed management on weed dry matter (g $m^{-2}$)

Metsulfuron methyl achieved a weed control efficiency of 88.6%, closely followed by 2,4-D sodium salt (87.3%) compared with the weedy check.

### 4.4 Wheat Growth Attributes

**Plant Height**

Effective weed control heightened the growth of wheat plants. Plants in the metsulfuron methyl (T 6) and 2,4-D (T 5) plots were taller (92.1 cm and 90.8 cm respectively) at harvest compared with the weedy check (72.5 cm).

Weed-free environments fostered the development of taller plants, increased tillers and greater dry matter accumulation, all of which were important to realize yield potential. Treatments of Metsulfuron methyl and 2,4-D closely approached the weed-free plots with regards to these parameters, asserting their positive effect of the weed growth on the wheat. Equivalent tillering and biomass enhancements have been reported under competent weed management by Singh *et al.* (2006) [1] and Gupta *et al.* (2019) [6].

Intriguingly, weed-free plots yielded the tallest plants, whose economic outcomes of such manual interference were not so good because they demanded more labor. This demonstrates the significance of sustainable biological practicality and economic viability in prescribing of weed management measures.

**Number of Tillers**

The number of productive tillers was highest in weed-free (379 $m^{-2}$), followed by metsulfuron methyl (365 $m^{-2}$) and 2,4-D (360 $m^{-2}$). Weedy check recorded only 228 tillers $m^{-2}$, highlighting the suppressive effect of weeds.

**Dry Matter Accumulation**

Dry matter accumulation followed similar trends, with metsulfuron methyl and 2,4-D showing 35–40% higher biomass compared to untreated control.

### 4.5 Yield Attributes and Yield

Significant differences were observed in yield attributes (Table 4.3). Metsulfuron methyl and 2,4-D enhanced spike length, grains per spike, and 1000-grain weight compared to control.

Grain yield is the ultimate measure of treatment effectiveness. The present study found that metsulfuron methyl, 2,4-D sodium salt, and hand weeding significantly improved yield attributes such as spike length, grains per spike, and 1000-grain weight, culminating in grain yields of 46–48 q $ha^{-1}$. These yields were nearly double those of the weedy check (25.4 q $ha^{-1}$), reflecting the magnitude of losses prevented by effective weed control.

Comparable yield benefits have been reported by Singh *et al.* (2018) [17], who observed 25–30% yield increases with 2,4-D application, and Chandana *et al.* (2019), who reported yield improvements of 20–35% under metsulfuron methyl. Raj *et al.* (2020) [12] similarly found that clodinafop + metsulfuron reduced weed index and improved grain yield significantly. The consistency of these results across diverse environments validates the superiority of these herbicides in broadleaf weed management.

**Table 3:** Effect of weed management practices on wheat yield attributes and yield

| Treatment | Grains spike$^{-1}$ | 1000-grain wt. (g) | Grain yield (q ha$^{-1}$) | Straw yield (q ha$^{-1}$) | Harvest Index (%) |
|---|---|---|---|---|---|
| $T_1$ – Weedy check | 35.2 | 36.1 | 25.4 | 46.3 | 35.4 |
| $T_2$ – Weed-free | 49.8 | 42.5 | 48.2 | 63.7 | 43.1 |
| $T_3$ – Pendimethalin | 43.2 | 39.6 | 38.7 | 55.1 | 41.2 |
| $T_4$ – Isoproturon | 41.6 | 38.7 | 36.8 | 53.5 | 40.7 |
| $T_5$ – 2,4-D Na salt | 48.0 | 41.9 | 46.3 | 62.5 | 42.6 |
| $T_6$ – Metsulfuron methyl | 48.7 | 42.3 | 47.5 | 63.1 | 42.9 |
| $T_7$ – Iso + 2,4-D | 46.9 | 41.2 | 44.6 | 61.4 | 42.1 |
| $T_8$ – Clodinafop + Metsulfuron | 47.2 | 41.5 | 45.2 | 61.7 | 42.3 |
| $T_9$ – Hand weeding (2) | 48.3 | 42.1 | 47.0 | 63.0 | 42.7 |
| $T_{10}$ – Farmer's practice | 44.1 | 39.7 | 40.2 | 57.3 | 41.2 |

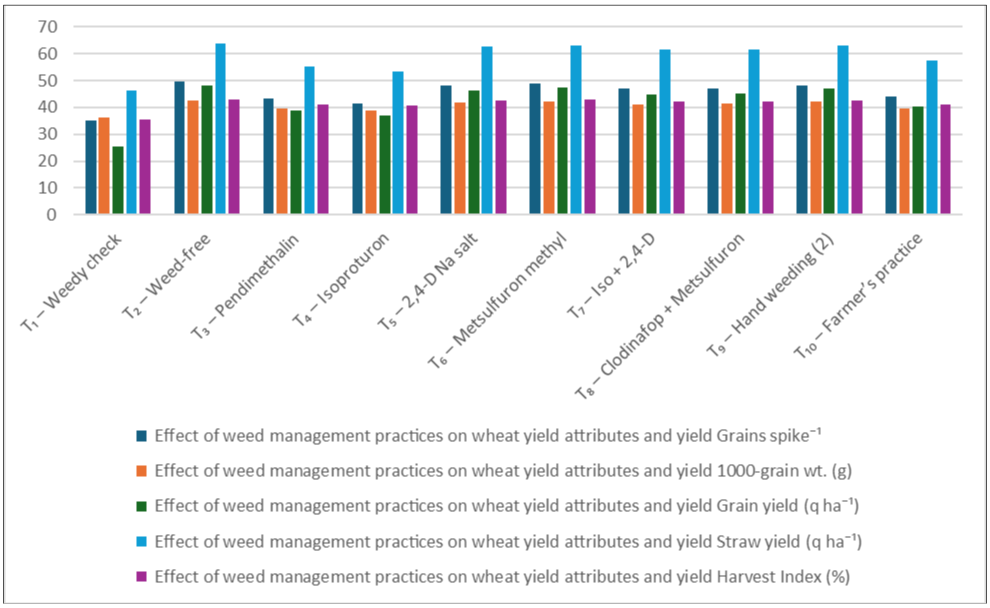


**Fig 3:** Effect of weed management practices on wheat yield attributes and yield

Metsulfuron methyl produced the highest grain yield (47.5 q ha$^{-1}$), statistically at par with 2,4-D sodium salt (46.3 q ha$^{-1}$) and hand weeding (47.0 q ha$^{-1}$), but significantly superior to weedy check (25.4 q ha$^{-1}$).

### 4.6 Economics

Economic analysis revealed that metsulfuron methyl and 2,4-D sodium salt were the most profitable treatments (Table 4.4). The weed-free treatment produced the highest yield but incurred higher labor costs, reducing the benefit–cost ratio (B:C).

Economic returns are a decisive factor in farmer adoption of weed control technologies. Although the weed-free treatment recorded the highest grain yield, its higher labor cost reduced the benefit–cost ratio (1.89) compared to herbicidal treatments. Metsulfuron methyl and 2,4-D sodium salt produced the most favorable B:C ratios (2.72 and 2.68, respectively), demonstrating their economic viability.

These results concur with those of Gupta *et al.* (2019) [6], who found that hand weeding provided excellent weed control but was uneconomical under labor-scarce conditions. Similarly, Chandana *et al.* (2019) [3] reported higher net returns from metsulfuron methyl compared to manual weeding. Therefore, herbicides represent not only an agronomically sound option but also an economically superior choice in wheat systems.

**Table 4:** Economics of wheat production under different weed management practices

| Treatment | Gross returns (₹ ha$^{-1}$) | Cost of cultivation (₹ ha$^{-1}$) | Net returns (₹ ha$^{-1}$) | B:C ratio |
|---|---|---|---|---|
| $T_1$ – Weedy check | 38,100 | 22,500 | 15,600 | 1.69 |
| $T_2$ – Weed-free | 72,300 | 38,200 | 34,100 | 1.89 |
| $T_3$ – Pendimethalin | 58,050 | 26,700 | 31,350 | 2.17 |
| $T_4$ – Isoproturon | 55,200 | 27,200 | 28,000 | 2.03 |
| $T_5$ – 2,4-D Na salt | 69,450 | 25,900 | 43,550 | 2.68 |
| $T_6$ – Metsulfuron methyl | 71,250 | 26,200 | 45,050 | 2.72 |
| $T_7$ – Iso + 2,4-D | 66,900 | 27,800 | 39,100 | 2.41 |
| $T_8$ – Clodinafop + Metsulfuron | 67,800 | 28,100 | 39,700 | 2.41 |
| $T_9$ – Hand weeding (2) | 70,500 | 34,000 | 36,500 | 2.07 |
| $T_{10}$ – Farmer's practice | 60,300 | 27,000 | 33,300 | 2.23 |

Metsulfuron methyl ($T_6$) recorded the highest net returns (₹45,050 ha$^{-1}$) and benefit–cost ratio (2.72), followed by 2,4-D sodium salt (B:C ratio 2.68).

### 4.7 Summary of Results

- *M. indica* density and biomass were drastically reduced by metsulfuron methyl and 2,4-D.
- Wheat growth attributes (plant height, tillers, dry matter) improved significantly under effective weed management.
- Grain yield was highest in metsulfuron methyl (47.5 q ha$^{-1}$), closely followed by 2,4-D and hand weeding, while the weedy check produced the lowest yield (25.4 q ha$^{-1}$).
- Economic analysis confirmed metsulfuron methyl and 2,4-D as the most profitable and practical weed control options.

While chemical control has proven effective, concerns regarding herbicide resistance and environmental sustainability cannot be overlooked. The widespread resistance of *Phalaris minor* to isoproturon serves as a cautionary example. If herbicides like metsulfuron methyl and 2,4-D are used indiscriminately, similar resistance could develop in *M. indica* or other broadleaf weeds.

To mitigate this risk, integrated weed management (IWM) strategies combining chemical, cultural, and mechanical methods are essential. Crop rotation with non-host crops, use of competitive wheat cultivars, proper sowing techniques, and occasional hand weeding should complement herbicide use. As suggested by Singh and Singh (2005) [15], such holistic approaches can reduce weed pressure, delay resistance development, and ensure long-term sustainability.

### 5.7 Overall Synthesis

The study validates earlier research that *M. indica* is a serious weed in wheat fields and demonstrates that metsulfuron methyl and 2,4-D sodium salt are highly effective in controlling its growth and enhancing wheat yield. These herbicides not only suppressed weed density and dry matter but also improved crop growth and profitability. The results reinforce the view that chemical weed management, when judiciously integrated with cultural practices, is indispensable for sustaining wheat productivity in India's Indo-Gangetic plains.

## 6. Conclusion

Within the present study, it is obvious that one of the important limiting factors to wheat productivity in the eastern Gangetic plains is the weed competition especially with *Melilotus indica*. The weediness dropped wheat grain yield with worming after developing an approximately 47 percent reduction under weedy conditions over that of weed-free plots, highlighting the huge losses caused by uncontrolled weeds.

Metsulfuron methyl with 24-D sodium salt solutions came out as the most effective and cost efficient in the suppression and control of *M. indica* and other related broadleaf weeds being evaluated. The two types of herbicides decreased *M. indica* density and dry matter accumulation by at least 85% relative to the untreated control, substantially suppressing the wheat growth features, *viz*. plant height, tillering, and dry matter reservation. This realized in terms of increased yields (4648 q ha-1) which matched weed-free and two hand-weeding experiments.

Based on economic considerations, metsulfuron methyl and 2,4-D sodium salt performed best in terms of net returns and benefit-cost ratios, compared to manual control of weeds, which despite its biological efficacy, was disadvantageous since it required more labor.

The results correlate with the earlier researches carried out around India which have been recording the efficacy of sulfonylurea herbicides and phenoxyacetic acid use as a broadleaf weeds control strategy in wheat (Singh *et al*., 2005; Chandana *et al*., 2019; Raj *et al*., 2020) [15, 3, 12]. But due to the dangers of herbicide resistance, and environmental issues a wiser use of chemicals is needed. Therefore, a combination of chemical control with culture practices, rotation and manual weeding at special occasions is given in order to increase sustainability in wheat production.

To sum it up, this paper confirms the conclusion that metsulfuron methyl and 2,4-D sodium salt are safe and economically effective methods of weed control in wheat, especially *M. indica*. Such coordinated and location-specific weed control approaches will need to be adopted to transform wheat production to sustainable levels judged by benefits to farmers in India as well as globally in Indo-Gangetic plains.

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