



Synergistic effects of herbicide and nano-fertiliser on weed control, productivity and economics of wheat (*Triticum aestivum*)

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ABSTRACT

Weeds pose a major constraint to wheat (*Triticum aestivum* L.) production and herbicides have been one of the most effective and economical tools for weed management. Meanwhile, the use of nano-fertilisers is gaining traction due to their efficiency and are often applied as top dressing at the same time as post-emergence herbicides. The compatibility between herbicides and nano-fertilisers and their combined impact on weed control and crop performance needs to be understood. Hence, the present study was carried out to evaluate the compatibility of three post-emergence herbicides at recommended doses with nano-fertilisers (nano-urea and nano-DAP, both individually and in combination) in wheat. Wheat variety 'GW-322' was selected for the study during the winter (*rabi*) season of 2023–24 and 2024–25 at ICAR-Directorate of Weed Research, Jabalpur, Madhya Pradesh. Clodinafop + metsulfuron (60 + 4 g ai/ha) combined with nano urea (4 mL/L) (T_6) proved to be most effective, recording the lowest weed density, weed biomass, highest weed control efficiency (94.15%), lowest weed index and normalised difference vegetation index (NDVI) (0.377) between the rows. This treatment also significantly improved wheat growth parameters including plant height, tillers/m², dry matter accumulation, leaf area index, crop growth rate, relative growth rate and net assimilation rate as well as yield attributes such as effective tillers, spike length and weight, grains/spike and test weight. The highest wheat grain yield and straw yield, net returns and benefit cost ratio (3.32) were also recorded with T_6 and were comparable with those recorded with other treatments involving metsulfuron and mesosulfuron + iodosulfuron with nano-urea. Mesosulfuron + iodosulfuron (12 + 2.4 g/ha), applied alone, caused phytotoxicity up to level 3, which was mitigated when used in combination with nano-urea, enabling faster crop recovery.

Keywords: Herbicide compatibility, Nano urea, NDVI, Weed control efficiency

Wheat (*Triticum aestivum* L.) serves as a staple food for nearly 36% of the global population and plays a pivotal role in ensuring food security worldwide. The crop's rising productivity has significantly contributed to self-sufficiency in food grain production in several countries. Globally, wheat is cultivated over 242 mha, with a total production of 790 mt and an average productivity of 3.26 t/ha (FAO 2022). In India, during 2023–24, wheat covered 31.8 mha of area, yielding 113.29 mt with an average productivity of 3.56 t/ha (DA&FW 2024). Meeting the growing food demand will require further enhancements in wheat productivity. One of the primary constraints to achieving higher yields is weed infestation, which competes with wheat for essential resources such as light, water, nutrients and space leading to substantial yield losses. Uncontrolled weed growth can reduce yields by 17–30%, depending on weed species and infestation levels (Bhullar *et al.* 2020). Effective weed

management, especially during the critical early growth period of 30–45 days after sowing (DAS), is therefore essential. Among the various control methods, herbicide usage remains the most reliable and cost-effective.

In parallel, nutrient management is a key determinant of wheat productivity. The advent of nano-fertilisers has introduced a new dimension to nutrient delivery, offering precise and controlled release of nutrients that enhance uptake efficiency while minimising environmental impact (Jastrotia *et al.* 2018). Their use is becoming increasingly popular, particularly as a top-dressing option applied alongside post-emergence herbicides. In the context of modern agriculture, integrating effective weed control with optimised nutrient management is critical for improving wheat yields sustainably. Post-emergence herbicides are essential for mitigating weed pressure, while nano-fertilisers support improved plant nutrition and growth. However, the concurrent application of these two inputs raises questions about their compatibility and potential interactions. Investigating this compatibility is essential to ensure synergistic effects, promote resource-use efficiency and enhance wheat productivity within a sustainable farming

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framework. Hence, a study was carried out to investigate the response of herbicides in combination with nano-fertilisers on weed dynamics, crop growth, yield and the economic viability of wheat production.

MATERIALS AND METHODS

A field experiment was conducted during the winter (*rabi*) season of 2023–24 and 2024–25 at ICAR-Directorate of Weed Research, Jabalpur (23°13'2"N, 79°59'2"E; at an elevation of 388 m amsl), Madhya Pradesh. Thirteen treatments, viz. Post-emergence application of metsulfuron (4 g/ha) (T_1); Metsulfuron (4 g/ha) + nano urea (4 mL/L) (T_2); Metsulfuron (4 g/ha) + nano DAP (4 mL/L) (T_3); Metsulfuron (4 g/ha) + nano urea (4 mL/L) + nano DAP (2 + 2 mL/L) (T_4); Clodinafop + metsulfuron (60 + 4 g/ha) (T_5); Clodinafop + metsulfuron (60 + 4 g/ha) + nano urea (4 mL/L) (T_6); Clodinafop + metsulfuron (60 + 4 g/ha) + nano DAP (4 mL/L) (T_7); Clodinafop + metsulfuron (60 + 4 g/ha) + nano urea + nano DAP (2 + 2 mL/L) (T_8); Mesosulfuron + iodosulfuron (12 + 2.4 g/ha) (T_9); Mesosulfuron + iodosulfuron (12 + 2.4 g/ha) + nano urea (4 mL/L) (T_{10}); Mesosulfuron + iodosulfuron (12 + 2.4 g/ha) + nano DAP (4 mL/L) (T_{11}); Mesosulfuron + iodosulfuron (12 + 2.4 g/ha) + nano urea + nano DAP (2+2 mL/L) (T_{12}) and an unweeded control (T_{13}) were evaluated during the study. The experiment was laid out in a randomised block design (RBD) with three replications.

The experimental site featured clayey soil, neutral pH, with medium organic carbon content (0.56%), low available nitrogen (268 kg/ha), high phosphorus levels (24.6 kg/ha) and medium potassium (254 kg/ha). Wheat variety 'GW-322' was used in this study. Land preparation involved two passes with a tractor-drawn cultivator followed by rotavator. Sowing was done using a seed drill at a row spacing of 22.5 cm and a seed rate of 100 kg/ha. The recommended fertiliser dose of $N:P_2O_5:K_2O$ (120:60:40 kg/ha) was applied, with half of the nitrogen and the full doses of phosphorus and potassium incorporated as basal application, while the remaining nitrogen was top-dressed in two equal splits after the first and second irrigations. In addition, nano-fertilisers were supplemented to synchronise nutrient application with post-emergence herbicide sprays, thereby reducing labour and input costs and to mitigate crop stress caused by herbicide application, ultimately improving crop performance.

Herbicides and nano-fertilisers applications were carried out at 30–35 DAS using a knapsack sprayer equipped with a flat-fan nozzle, delivering 375 L/ha of spray solution. Prior to field application, a laboratory compatibility test was conducted for each herbicide and nano-fertiliser combination. No signs of physical incompatibility such as separation, foaming or sedimentation were observed, confirming suitability for tank mixing.

Weed density and biomass were assessed at 60 DAS using a 0.25 m² quadrat (0.5 m × 0.5 m) placed randomly at two locations within each plot; the average was extrapolated to a per square meter basis. Collected weed samples were

initially shade-dried, followed by oven drying at $65 \pm 2^\circ\text{C}$ until a constant weight was achieved. Weed data were square root transformed prior to analysis to normalise variance, while original weed biomass data were used to calculate weed control efficiency (WCE). The Normalised Difference Vegetation Index (NDVI) was recorded at 60 DAS using a Greenseeker handheld sensor, with readings taken between two crop rows at a height of 60 cm. Crop growth and yield attributes were also recorded as per standard procedures. Statistical analysis was performed using analysis of variance (ANOVA) following the F-test as described by Gomez and Gomez (1984). Treatment means were compared using the critical difference (CD) at the 5% significance level.

RESULTS AND DISCUSSION

Weed flora composition: The experimental field was predominantly infested with broad-leaved weeds, primarily *Medicago polymorpha* (56%), followed by *Lathyrus aphaca* and *Vicia sativa* (9%), *Physalis minima* (7%), *Sonchus oleraceus* (5%) and *Solanum nigrum* (3%). Grassy weeds included *Avena ludoviciana* (6%) and *Digitaria sanguinalis* (5%). Similarly, the relative weed biomass comprised *Medicago polymorpha* (47%), *Sonchus oleraceus* (8%), *Lathyrus aphaca* (6%), *Physalis minima* (6%), *Vicia sativa* (5%) and *Solanum nigrum* (4%), along with grasses such as *Avena ludoviciana* (16%) and *Digitaria sanguinalis* (8%). Overall, the weed flora was dominated by broad-leaved weed species, with *Medicago polymorpha* being the most predominant.

Combined effect of weed management and nano fertilisers: All herbicide treatments, applied either stand-alone or in tank-mix combination with nano-fertilisers, significantly reduced weed infestation (Table 1 and 2). Clodinafop + metsulfuron (60 + 4 g/ha) combined with nano urea (4 mL/L) (T_6) was most effective and recorded the lowest total weed density and biomass. Both clodinafop + metsulfuron (T_5) and mesosulfuron + iodosulfuron (T_9) combinations proved to be highly effective against grassy weeds. Specifically, the application of T_6 resulted in the minimum density (Table 1) and biomass (Table 2) of *Digitaria sanguinalis* and *Avena ludoviciana*. However, *Solanum nigrum* showed tolerance to most of the treatments. These weeds were slightly less severe when nano urea was included, although control remained suboptimal. The highest weed control efficiency (WCE) (85.5%) was recorded with (Table 4), followed closely by clodinafop + metsulfuron along with nano urea + nano DAP (T_8) (83.6%). Metsulfuron alone (4 g/ha) (T_1) was the least effective (WCE of 62.7%), underscoring its limited efficacy over the weed flora prevailing in experimental field. The integration of clodinafop + metsulfuron (60 + 4 g/ha) with nano urea significantly reduced weed density and biomass confirming the findings of Malik *et al.* (2013) and Mishra and Singh (2024).

Phytotoxicity rating scale: Phytotoxicity symptoms were assessed at 7 and 14 days after herbicide application (DAHA) (Table 3). At 7 DAHA, the highest level of

Table 1 Effect of herbicides and nano-fertilisers treatments on weed density at 60 days after sowing of wheat (two years pooled data)

Treatments	<i>Medicago polymorpha</i>	<i>Lathyrus aphaca</i>	<i>Vicia sativa</i>	<i>Physalis minima</i>	<i>Sonchus oleraceus</i>	<i>Solanum nigrum</i>	<i>Digitaria sanguinalis</i>	<i>Avena ludoviciana</i>	Total weed density
T ₁	2.67 (6.71)	1.66 (2.33)	1.76 (2.67)	1.55 (1.93)	1.27 (1.13)	1.91 (3.20)	2.12 (4.10)	2.01 (3.72)	9.04 (25.79)
T ₂	1.67 (2.38)	1.44 (1.63)	1.34 (1.37)	1.34 (1.3)	1.14 (0.82)	1.63 (2.21)	2.01 (3.72)	1.74 (2.85)	7.26 (16.27)
T ₃	2.20 (4.39)	1.56 (1.99)	1.56 (2.03)	1.43 (1.57)	1.22 (1.01)	1.88 (3.09)	2.12 (4.12)	1.92 (3.52)	8.15 (21.71)
T ₄	1.76 (2.63)	1.52 (1.81)	1.49 (1.78)	1.38 (1.42)	1.17 (0.89)	1.83 (2.87)	2.04 (3.83)	1.85 (3.32)	7.58 (18.57)
T ₅	1.58 (2.07)	1.39 (1.47)	1.2 (1.03)	1.25 (1.07)	1.07 (0.69)	1.64 (2.21)	1.35 (1.39)	1.26 (1.15)	6.38 (11.08)
T ₆	1.23 (1.05)	1.16 (0.87)	1.03 (0.61)	1.09 (0.69)	1.04 (0.59)	1.57 (1.99)	1.28 (1.18)	1.13 (0.83)	5.55 (7.80)
T ₇	1.57 (2.00)	1.31 (1.25)	1.2 (0.98)	1.22 (1.00)	1.06 (0.68)	1.63 (2.21)	1.43 (1.61)	1.26 (1.21)	6.29 (10.96)
T ₈	1.44 (1.62)	1.34 (1.31)	1.16 (0.88)	1.15 (0.82)	1.06 (0.63)	1.57 (1.99)	1.33 (1.32)	1.20 (0.96)	6.06 (9.52)
T ₉	2.78 (7.30)	1.76 (2.64)	1.84 (2.93)	1.59 (2.10)	1.35 (1.35)	1.97 (3.43)	1.56 (2.08)	1.81 (2.78)	9.14 (24.61)
T ₁₀	1.86 (3.07)	1.54 (1.89)	1.43 (1.75)	1.38 (1.43)	1.18 (0.93)	1.75 (2.65)	1.44 (1.74)	1.37 (1.45)	7.31 (14.91)
T ₁₁	2.48 (5.70)	1.61 (2.17)	1.63 (2.23)	1.48 (1.79)	1.23 (1.06)	1.86 (3.09)	1.51 (1.91)	1.58 (2.02)	8.25 (19.97)
T ₁₂	2.25 (4.64)	1.58 (2.02)	1.57 (2.05)	1.44 (1.60)	1.2 (0.99)	1.80 (2.87)	1.46 (1.80)	1.54 (2.02)	7.87 (17.97)
T ₁₃	7.90 (62.30)	3.18 (9.60)	3.18 (9.69)	2.94 (8.13)	2.40 (5.31)	2.07 (3.82)	2.46 (5.69)	2.76 (7.15)	17.40 (111.67)
CD ($p=0.05$)	0.43	0.34	0.50	0.25	0.35	NS	0.39	0.42	0.70

Figures in parentheses are the original value and outside values are transformed values. NS, Non-significant. Treatment details are given under Materials and Methods.

phytotoxicity (score 3) was recorded with T₉ and its combination with nano DAP (T₁₁). Moderate symptoms (score 2) were observed with mesosulfuron + iodosulfuron in combination with nano urea, either alone (T₁₀) or together with nano DAP (T₁₂). No phytotoxicity symptoms were detected with other treatments. By 14 DAHA, symptoms had subsided significantly. The phytotoxicity score declined from 3 to 2 with T₉ and T₁₁. Complete recovery was observed in treatments that included mesosulfuron + iodosulfuron with nano urea alone or in combination with nano DAP. These findings indicate that the incorporation of nano urea and nano DAP facilitates quicker recovery from initial herbicide-induced phytotoxicity, likely by promoting plant growth and vigour.

GreenSeeker reading (NDVI): The GreenSeeker sensor, which measures greenness between rows, recorded the highest NDVI value (0.704) at 60 DAS in the unweeded control (T₁₃), corresponding with the highest weed biomass. In contrast, the lowest NDVI value (0.377) was observed

with T₆ (Table 3), reflecting effective weed control. Other herbicide treatments showed intermediate NDVI values ranging from 0.384 to 0.467, further indicating variation in their weed control efficacy.

Crop growth and physiological parameters: The crop growth and physiological parameters were significantly influenced by application of herbicides stand-alone or in combination with nano-fertilisers (Table 3). The crop growth improved progressively over time, reaching its peak at harvest. The treatment T₆ led to significant increases in growth parameters such as plant height, number of tillers, plant biomass and LAI and physiological parameters such as crop growth rate (CGR), relative growth rate (RGR) and net assimilation rate (NAR).

This was attributed to reduced crop-weed competition, resulting in better availability of sunlight, water, nutrients and carbon dioxide, which enhanced photosynthesis (Choudhary *et al.* 2021, Choudhary *et al.* 2023). Additionally, nano urea contributed to improved nitrogen availability, promoting

Table 2 Effect of herbicides and nano-fertilisers treatments on weed biomass in wheat (two years pooled data)

Treatments	<i>Medicago polymorpha</i>	<i>Lathyrus aphaca</i>	<i>Vicia sativa</i>	<i>Physalis minima</i>	<i>Sonchus oleraceus</i>	<i>Solanum nigrum</i>	<i>Digitaria sanguinalis</i>	<i>Avena ludoviciana</i>	Total weed biomass
T ₁	2.00 (3.50)	1.18 (0.91)	1.07 (0.68)	1.14 (0.80)	1.20 (1.00)	1.76 (2.63)	1.99 (4.04)	2.4 (6.88)	4.58 (20.44)
T ₂	1.31 (1.26)	1.05 (0.62)	0.93 (0.39)	1.02 (0.54)	1.1 (0.76)	1.51 (1.82)	1.91 (3.74)	2.19 (5.87)	3.94 (15.01)
T ₃	1.69 (2.42)	1.12 (0.76)	1.01 (0.55)	1.07 (0.65)	1.18 (0.95)	1.73 (2.55)	2.01 (4.13)	2.40 (7.15)	4.44 (19.17)
T ₄	1.37 (1.41)	1.09 (0.70)	0.97 (0.47)	1.04 (0.59)	1.14 (0.85)	1.69 (2.36)	1.94 (3.84)	2.33 (6.90)	4.20 (17.13)
T ₅	1.25 (1.11)	1.03 (0.57)	0.89 (0.31)	0.97 (0.44)	1.06 (0.66)	1.52 (1.82)	1.18 (0.92)	1.22 (1.14)	2.73 (6.97)
T ₆	1.02 (0.57)	0.91 (0.34)	0.83 (0.20)	0.88 (0.28)	1.01 (0.56)	1.45 (1.64)	1.10 (0.73)	1.07 (0.75)	2.36 (5.08)
T ₇	1.25 (1.09)	0.99 (0.49)	0.88 (0.28)	0.95 (0.42)	1.01 (0.65)	1.51 (1.82)	1.30 (1.24)	1.22 (1.25)	2.78 (7.24)
T ₈	1.16 (0.85)	1.00 (0.50)	0.87 (0.27)	0.91 (0.34)	1.02 (0.57)	1.45 (1.64)	1.16 (0.85)	1.15 (0.89)	2.53 (5.91)
T ₉	2.07 (3.80)	1.23 (1.01)	1.11 (0.78)	1.17 (0.87)	1.26 (1.14)	1.81 (2.82)	1.32 (1.28)	1.67 (2.47)	3.83 (14.19)
T ₁₀	1.42 (1.55)	1.10 (0.72)	0.99 (0.51)	1.05 (0.61)	1.13 (0.87)	1.61 (2.18)	1.23 (1.02)	1.31 (1.43)	3.07 (8.90)
T ₁₁	1.86 (2.99)	1.16 (0.86)	1.04 (0.61)	1.11 (0.76)	1.17 (0.97)	1.71 (2.55)	1.30 (1.22)	1.49 (1.91)	3.52 (11.87)
T ₁₂	1.70 (2.41)	1.13 (0.80)	1.01 (0.56)	1.08 (0.68)	1.14 (0.89)	1.66 (2.36)	1.25 (1.08)	1.49 (2.09)	3.37 (10.87)
T ₁₃	5.82 (33.41)	2.23 (4.50)	1.89 (3.16)	2.17 (4.22)	2.35 (5.80)	1.91 (3.14)	2.30 (5.52)	3.10 (11.12)	8.45 (70.87)
CD ($p=0.05$)	0.43	0.34	0.50	0.25	0.35	NS	0.39	0.42	0.69

Figures in parentheses are the original value and outside values are transformed values. NS, Non-significant. Treatment details are given under Materials and Methods.

protein synthesis and enzymatic activity in plants.

Wheat yield attributing parameters, grain and straw yield: Yield parameters such as spike length, grains/spike, spike weight and test weight (Table 3) as well as wheat grain and straw yield (Table 4) varied significantly across treatments. Treatment T₆ resulted in significantly higher numbers of wheat tillers, longer spikes and greater grain numbers/spike, wheat grain yield and straw yield compared to other treatments. This improvement can be attributed to effective weed control during the crop's critical growth stages, which created a favourable environment for optimal crop development and yield formation.

These outcomes were mainly due to promoting efficient nutrient partitioning and corroborate the findings of Abbas *et al.* (2015) and Patel *et al.* (2020). In contrast, T₉ had the lowest harvest index (43.0%) due to intense weed competition. Weed pressure in unweeded control caused the highest loss in wheat grain yield (56.8%). Treatment T₆ effectively minimised yield losses to 2.8–5.2% and was

comparable to hand weeding due to effective control of all major weed species.

Correlation between weed biomass, NDVI and grain yield: A strong negative quadratic relationship with a coefficient of determination (R^2) of 0.87 was observed between weed biomass and grain yield (Fig. 1A), indicating that increased weed growth significantly reduces yield by intensifying competition for light, nutrients, water and space. This finding was consistent with the earlier work of Mitra *et al.* (2019). In contrast, a strong positive linear relationship with a R^2 of 0.91 was found between weed biomass and NDVI (Fig. 1B), suggesting that NDVI values rise with greater weed presence, making it a promising proxy for estimating weed density in crop fields. However, its broader applicability requires validation across diverse crop and weed species. Similarly, NDVI exhibited a logarithmic relationship with grain yield having R^2 of 0.77, indicating that higher NDVI values driven by weed proliferation or excessive vegetative growth are associated with reduced

Table 3 Effect of herbicides and nano-fertilisers treatments on NDVI, plant growth and yield attributing parameters of wheat (two years pooled data)

Treatments	NDVI	Phytotoxicity rating	Plant height (cm)	Tillers/ m ²	Plant biomass (g/m ²)	Leaf area index	Crop growth rate (g/m ² /day)	Relative growth rate (g/g/day)	Net assimilation rate (g/m ² /day)	Spike length (cm)	Grains/ ear	Spike weight (g)	Test weight (g)
		7 DAHA											
T ₁	0.468	0	81.3	384.3	1,128.3	3.08	5.11	0.056	0.018	11.6	71.1	3.20	38.8
T ₂	0.431	0	84.5	416.9	1,278.1	3.50	6.91	0.061	0.023	12.2	77.2	3.67	39.7
T ₃	0.457	0	82.9	392.9	1,188.4	3.37	5.72	0.058	0.020	11.8	72.3	3.34	39.3
T ₄	0.439	0	83.4	405.7	1,233.1	3.46	6.15	0.058	0.020	11.9	73.2	3.49	39.3
T ₅	0.429	0	84.7	418.1	1,324.0	3.77	6.90	0.059	0.022	12.3	77.9	3.79	40.1
T ₆	0.377	0	85.7	438.7	1,391.3	4.22	7.25	0.062	0.022	12.7	82.4	3.88	40.6
T ₇	0.427	0	84.7	425.0	1,325.8	3.88	6.89	0.059	0.021	12.5	77.6	3.77	39.8
T ₈	0.384	0	85.6	427.1	1,360.8	3.98	7.14	0.062	0.022	12.5	79.7	3.88	40.3
T ₉	0.460	3	79.6	390.3	1,154.2	3.14	5.77	0.060	0.022	11.6	71.3	3.33	38.7
T ₁₀	0.443	2	84.1	413.9	1,277.6	3.49	6.20	0.058	0.021	12.1	75.0	3.57	39.6
T ₁₁	0.453	3	82.7	398.5	1,197.2	3.36	6.04	0.060	0.022	11.9	73.1	3.47	38.7
T ₁₂	0.448	2	82.9	406.6	1,213.4	3.44	6.19	0.059	0.022	12.1	74.7	3.51	39.3
T ₁₃	0.704	0	76.4	304.7	826.6	2.73	4.15	0.050	0.017	11.6	65.78	2.62	38.1
CD (p=0.05)	0.082	-	3.92	40.07	13.98	0.54	0.48	0.005	0.003	0.96	5.20	0.65	NS

NDVI, Normalised difference vegetation index; NS, Non-significant; DAHA, Days after herbicide application. Treatment details are given under Materials and Methods.

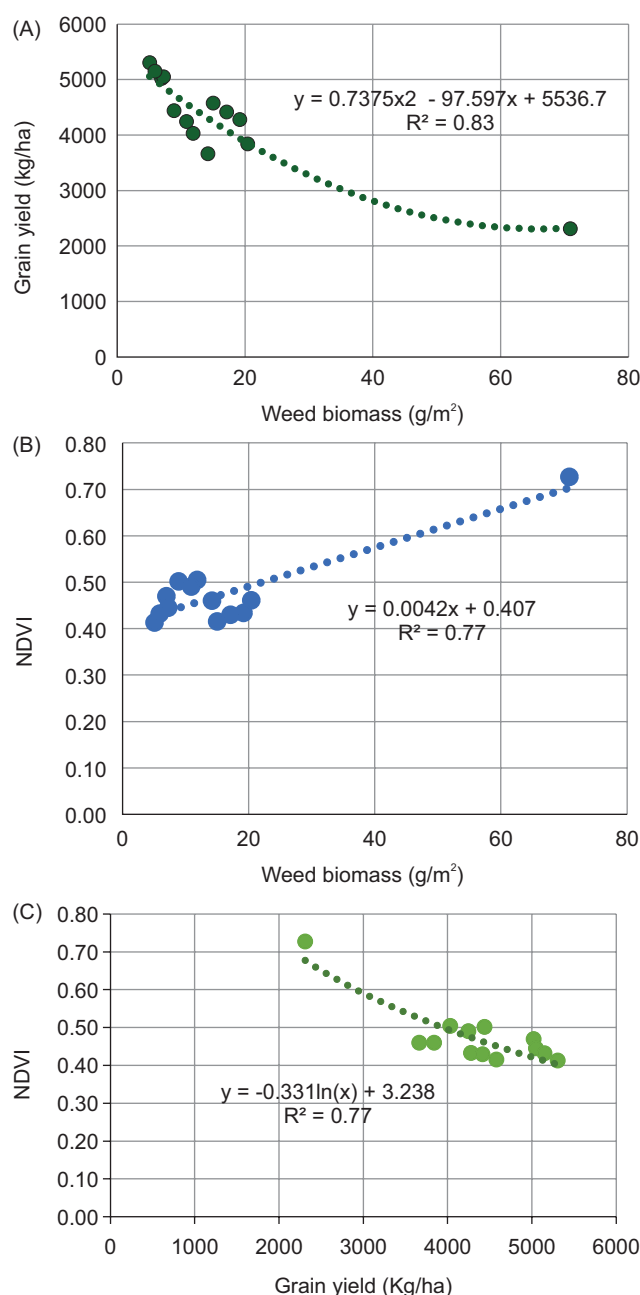


Fig. 1 Effect of herbicides and nano-fertiliser treatments on relationship between (A) weed biomass and wheat grain yield; (B) weed biomass and NDVI and (C) NDVI and wheat grain yield (two years pooled data). NDVI, Normalised difference vegetation index.

yields due to heightened competition (Fig. 1C). These results highlight NDVI as a valuable tool for predicting yield losses and informing timely weed management decisions. Nevertheless, further research is needed to account for environmental variability and differing crop management practices to ensure its robustness across agro-ecological contexts.

Economics: Amongst the tested treatments, T₆ recorded the highest economic gains, with net return of ₹99,623/ha and a benefit cost ratio of 3.57. These results underscore the synergy between nano-fertilisers and herbicides,

Table 4 Effect of herbicides and nano fertilisers treatments on wheat yield, weed indices and economics (two years pooled data)

Treatments	Grain yield (kg/ha)		Straw yield (kg/ha)		Harvest index (%)	WCE (%)	Weed index (%)	Cost of cultivation (₹/ha)	Net returns (₹/ha)	B:C ratio
	2023–24	2024–25	2023–24	2024–25						
T ₁	3,862	3,813	4,817	4,836	44.3	62.7	27.2	36,810	64,482	2.75
T ₂	4,115	5,037	5,196	5,618	45.7	73.0	13.9	37,485	82,349	3.20
T ₃	3,903	4,649	4,969	5,281	45.4	65.8	19.4	38,610	73,885	2.93
T ₄	3,994	4,836	5,112	5,562	45.2	68.9	16.9	38,048	77,689	3.03
T ₅	4,748	5,288	5,982	5,832	45.9	81.5	5.2	38,072	93,240	3.45
T ₆	4,910	5,697	6,088	6,150	46.4	85.5	0.0	38,747	99,623	3.57
T ₇	4,785	5,312	6,039	5,920	45.8	81.6	4.6	39,872	92,634	3.34
T ₈	4,857	5,441	6,085	6,011	45.7	83.6	2.8	39,310	95,296	3.41
T ₉	3,896	3,425	4,922	4,766	43.0	65.6	30.3	38,052	59,302	2.56
T ₁₀	4,105	4,773	5,158	5,446	45.5	76.0	16.3	38,727	77,097	2.96
T ₁₁	3,954	4,107	4,917	5,015	44.8	71.1	23.7	39,852	66,803	2.70
T ₁₂	4,042	4,447	5,162	5,136	45.2	73.3	19.8	39,290	72,270	2.84
T ₁₃	1,871	2,750	2,410	3,251	45.5	0	56.8	35,972	24,619	1.68
CD (<i>p</i> =0.05)	713.36	441.10	874.88	476	NS					

NS, Non-significant; WCE, Weed control efficiency; B:C ratio, Benefit-cost ratio. Treatment details are given under Materials and Methods.

demonstrating their effectiveness in weed control with enhanced profitability and sustainability, confirming the results reported by Asif *et al.* (2023), Deshmukh *et al.* (2023), Sarita *et al.* (2022) and Sarkar *et al.* (2023). Overall, the results reinforce the effectiveness of integrating herbicides with nano-fertilisers as a synergistic strategy to boost wheat productivity in an economical manner.

It can be concluded that the tested herbicides and nano-fertilisers were compatible and effective when applied together and clodinafop + metsulfuron (60 + 4 g/ha) along with nano-urea (4 mL/L) was most effective in managing weeds and improving wheat growth, yield attributes and higher grain and straw yield.

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