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Weed flora dynamics, weed control efficiency and nutrient uptake as influenced by integrated weed management in green gram (*Vigna radiata* L.)

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Abstract

A two-year field experiment was conducted during the 2025 and 2026 kharif seasons at the Agriculture Research Farm, Faculty of Agriculture, Rabindranath Tagore University, Raisen, Madhya Pradesh, to study weed flora dynamics, weed control efficiency and nutrient uptake as influenced by ten weed management treatments in green gram (*Vigna radiata* L.) cv. PDM 139, laid out in a Randomized Block Design with three replications. Ten weed species, two grasses (*Echinochloa colona*, *Digitaria sanguinalis*), one sedge (*Cyperus rotundus*) and seven broad-leaved species, were recorded at the experimental site. Pooled analysis of two years' data showed that treatment T8 (pendimethalin 1.0 kg/ha as pre-emergence followed by imazamox 75 g/ha at 30 days after sowing followed by mechanical hoeing at 45 days after sowing) recorded the lowest total weed count (3.49/m²) and lowest total weed dry weight (2.21 g/m²) at harvest, a reduction of 98.2 and 96.5 per cent respectively relative to the unweeded control (197.17/m²; 62.43 g/m²), and the highest weed control efficiency (89.16% at harvest). Treatment T9 (pyroxasulfone 0.75 kg/ha followed by halosulfuron-methyl 75 g/ha at 25 days after sowing followed by hand weeding at 45 days after sowing) ranked a close second (weed control efficiency 88.55% at harvest). Weed index, weed persistence index and herbicide efficiency index were all highest under T8 and T9 among the active treatments, consistent with their superior and sustained weed suppression, and were zero, by construction, under the unweeded control. Nitrogen, phosphorus and potassium uptake by the crop was highest, and by weeds lowest, under T8 and T9, while available soil nitrogen, phosphorus and potassium after harvest were correspondingly higher under these treatments than under the control, reflecting reduced nutrient diversion to weed biomass. Soil pH, electrical conductivity and organic carbon remained broadly stable across treatments. Treatments relying on a single herbicide application without a complementary post-emergence or mechanical/manual follow-up (T4, T6 and T7) showed substantially higher weed density, dry weight and nutrient removal by weeds, and correspondingly lower weed control efficiency, than the integrated treatments. The study concludes that integrated weed management combining a pre-emergence herbicide, a post-emergence herbicide and a mechanical or manual follow-up operation achieves broad-spectrum, season-long suppression of a diverse weed flora and minimises nutrient diversion to weeds in green gram, with the pendimethalin-imazamox-mechanical hoeing (T8) and pyroxasulfone-halosulfuron-methyl-hand weeding (T9) sequences the most effective among the treatments evaluated.

Keywords: Green gram, weed flora, weed control efficiency, weed index, nutrient uptake, integrated weed management

Introduction

Weeds are among the most persistent biotic constraints in green gram (*Vigna radiata* L.) cultivation, competing with the crop for light, moisture, space and nutrients throughout its short growth cycle and disrupting the nutrient dynamics that underpin its growth and productivity [1]. A typical rainfed or irrigated green gram field supports a diverse weed flora spanning grasses, sedges and broad-leaved species, several of which, such as *Parthenium hysterophorus*, also carry allelopathic and human-health implications beyond their direct crop-competitive effect [2]. Because different weed species emerge and peak at different times through the crop's growth cycle, and pre-emergence herbicide efficacy itself varies spatially with soil moisture and organic matter, a single weed management intervention often leaves a significant fraction of the weed flora, and in particular later-emerging or escaping cohorts, uncontrolled [3].

The residual weed seed bank further ensures that incomplete control in one season carries a legacy into subsequent seasons^[4]. Weed control efficiency, weed index, weed persistence index and herbicide efficiency index are widely used composite measures for comparing the season-long performance of weed management treatments beyond simple weed counts, since they express weed suppression relative to the unweeded control and relative to yield loss, and so provide a more complete picture of a treatment's practical value than density or dry weight data alone. Non-chemical components, mechanical hoeing and hand weeding, remain an important complement to herbicide use in integrated programmes, both to control weeds that escape herbicide activity and to reduce the cumulative reliance on chemical inputs^[5], a consideration of growing importance given increasing attention to the environmental fate and non-target effects of repeated herbicide use^[6]. Combining tactics with complementary modes of action and timing, the central principle of Integrated Weed Management, has therefore been proposed as the most reliable route to season-long, broad-spectrum weed suppression across a diverse weed flora^[7] and^[8].

Weeds do not merely occupy space and compete for light; they also directly remove nitrogen, phosphorus and potassium from the soil that would otherwise be available to the crop, so that the nutrient uptake and nutrient-use efficiency of a cropping system depend directly on how effectively its weed flora is suppressed^[9]. Since the cost of nutrient loss to weeds is rarely quantified alongside herbicide and labour costs in on-farm decision-making^[10], a treatment's effect on crop and weed nutrient uptake, and on the associated soil available-nutrient status, is an important complement to weed density and yield data in evaluating a weed management package.

Against this background, the present two-year field investigation was undertaken to characterise the weed flora at the experimental site and to evaluate the effect of nine integrated pre-emergence, post-emergence and mechanical/manual weed management combinations, together with an unweeded control, on weed density and dry weight dynamics, weed control efficiency and related indices, and nitrogen, phosphorus and potassium uptake by the crop, by weeds, and in the soil, in green gram cv. PDM 139.

Materials and Methods

A field experiment was conducted over two consecutive kharif seasons (2025 and 2026) at the Agriculture Research Farm, Faculty of Agriculture, Rabindranath Tagore University (RNTU), Raisen, Madhya Pradesh, India, on a medium-to-deep black (Vertisol) soil, near-neutral in reaction (pH 7.23) and low in organic carbon (0.38%) before sowing. The experiment was laid out in a Randomized Block Design with ten treatments (Table 1) and three replications, on plots of 5.00 m x 4.00 m. Green gram variety PDM 139 was sown at 30 cm x 10 cm spacing on 20 June in both years and fertilized uniformly at 20:40:20 kg N:P2O5:K2O per ha.

Weed count (species-wise, No./m²) and weed dry weight (species-wise and total, g/m²) were recorded from randomly placed 1 m² quadrats at 20, 40 and 60 days after sowing (DAS) and at harvest, excluding border rows, and weed species present at the experimental site were identified to family and, where possible, common name. Weed count and weed dry weight data were subjected to a square-root ($\sqrt{x+1}$) transformation before analysis of variance, in line with standard practice for count-type

data, and back-transformed means are reported. Weed control efficiency (WCE, %) was calculated as $WCE = [(DWC - DWT) / DWC] \times 100$, where DWC and DWT are the total weed dry weight in the unweeded control and the treated plot respectively^[11]. Weed index (WI, %) was calculated relative to the highest-yielding treatment as $WI = [(Y_{max} - Y_t) / Y_{max}] \times 100$ ^[12]. Herbicide efficiency index (HEI) was calculated as $HEI = [(Y_t - Y_c) / Y_t \times 100] \div [(WDM_t / WDM_c) \times 100]$ ^[13], and weed persistence index (WPI) as $WPI = (W_{Pt} / W_{Pc}) \times (WDM_t / WDM_c)$ ^[14], where Y_t , Y_c , WDM_t , WDM_c , W_{Pt} and W_{Pc} denote seed yield and weed dry matter/population in the treated and control plots respectively.

Soil pH and electrical conductivity were determined by the glass electrode method^[15], organic carbon by the Walkley and Black rapid titration method^[16], available nitrogen by the alkaline potassium permanganate method^[17], available phosphorus by the Olsen sodium bicarbonate extraction method^[18], and available potassium by the neutral normal ammonium acetate extraction method^[19]. Nitrogen, phosphorus and potassium uptake by the crop (grain and stover) and by weed biomass were computed as the product of nutrient concentration and dry matter yield, summed across plant parts. All data were subjected to analysis of variance appropriate to a Randomized Block Design, following Panse and Sukhatme^[20]; where the error variances of the two years were homogeneous, a pooled analysis across years was carried out, and pooled means, SEM $\pm$, CD (P=0.05) and CV% are reported.

Results

Table 1: Treatment details

Treatment	Details
T1	Pendimethalin 1.0 kg/ha (PE) + Hand weeding (20 DAS) + Quizalofop-P-ethyl 75 g/ha (35 DAS) + Mechanical hoeing (50 DAS)
T2	Flumioxazin 0.6 kg/ha (PE) + Hand weeding (20 DAS) + Propaquizafop 100 g/ha (40 DAS)
T3	Pyroxasulfone 0.75 kg/ha (PE) + Imazamox 75 g/ha (25 DAS) + Hand weeding (40 DAS)
T4	Pendimethalin 1.0 kg/ha (PE) + Quizalofop-P-ethyl 75 g/ha (30 DAS)
T5	Pendimethalin 1.0 kg/ha (PE) + Quizalofop-P-ethyl 75 g/ha (25 DAS) + Halosulfuron-methyl 75 g/ha (40 DAS)
T6	Flumioxazin 0.6 kg/ha (PE) + Propaquizafop 100 g/ha (30 DAS)
T7	Pyroxasulfone 0.75 kg/ha (PE) + Imazamox 75 g/ha (35 DAS)
T8	Pendimethalin 1.0 kg/ha (PE) + Imazamox 75 g/ha (30 DAS) + Mechanical hoeing (45 DAS)
T9	Pyroxasulfone 0.75 kg/ha (PE) + Halosulfuron-methyl 75 g/ha (25 DAS) + Hand weeding (45 DAS)
T10	Unweeded control

Weed flora composition: Ten weed species were recorded at the experimental site (Table 2), comprising two grasses (*Echinochloa colona*, *Digitaria sanguinalis*), one sedge (*Cyperus rotundus*) and seven broad-leaved species (*Commelina benghalensis*, *Phyllanthus niruri*, *Parthenium hysterophorus*, *Amaranthus viridis*, *Euphorbia hirta*, *Chenopodium album* and *Trianthema portulacastrum*), confirming a mixed, multi-family weed flora typical of green gram fields in central India.

Table 2: Weed flora recorded at the experimental site

Botanical name	English name	Local name	Family	Type
Echinochloa colona	Jungle rice	Jangli Jhangora	Poaceae	Grasses
Digitaria sanguinalis	Large crabgrass	Summer Grass	Poaceae	Grasses
Cyperus rotundus	Nut grass	Nagarmotha	Cyperaceae	Sedges
Commelina benghalensis	Benghal dayflower	Kanchara	Commelinaceae	Broadleaf
Phyllanthus niruri	Stonebreaker	Bhumi Amla	Phyllanthaceae	Broadleaf
Parthenium hysterophorus	Congress weed	Gajar Ghas	Asteraceae	Broadleaf
Amaranthus viridis	Green Amaranth	Jangali Chaulai	Amaranthaceae	Broadleaf
Euphorbia hirta	Snakeweed	Bara Dudhi	Euphorbiaceae	Broadleaf
Chenopodium album	White Goosefoot	Bathua	Amaranthaceae	Broadleaf
Trianthema portulacastrum	Horse Purslane	Sabuni	Aizoaceae	Broadleaf

Total weed count and total weed dry weight: Data on total weed count and total weed dry weight at 20, 40 and 60 DAS and at harvest, pooled over two years, are presented in Table 3. Weed density and dry weight declined progressively through the season under all treatments as the crop canopy closed, but far more sharply under the integrated treatments than under the control. Treatment T8 recorded the lowest total weed count at every observation stage, reaching 3.49/m² at harvest against 197.17/m² in the unweeded control, a 98.2 per cent reduction; treatment T9

was a close second (5.51/m² at harvest). Total weed dry weight followed the same pattern, with T8 recording 2.21 g/m² and T9 3.60 g/m² at harvest against 62.43 g/m² in the control, reductions of 96.5 and 94.2 per cent respectively. Treatments relying on a single herbicide application without a complementary follow-up (T4, T6 and T7) recorded substantially higher weed count and dry weight than the integrated treatments throughout the season, only modestly below the control.

Table 3: Effect of weed management treatments on total weed count and total weed dry weight of green gram at different growth stages (pooled data of two years)

Treatment	Total weed count (No./m ²)				Total weed dry weight (g/m ²)			
	20 DAS	40 DAS	60 DAS	Harvest	20 DAS	40 DAS	60 DAS	Harvest
T1	7.12 (49.65)	5.94 (34.27)	5.32 (27.29)	4.33 (17.78)	3.42 (10.68)	2.87 (7.22)	2.69 (6.25)	2.28 (4.20)
T2	9.30 (85.50)	8.13 (65.09)	7.48 (54.92)	6.51 (41.39)	3.95 (14.59)	3.34 (10.16)	3.32 (9.99)	2.88 (7.28)
T3	8.29 (67.68)	7.20 (50.78)	6.31 (38.76)	5.32 (27.25)	3.71 (12.75)	3.12 (8.74)	3.05 (8.31)	2.63 (5.92)
T4	12.91 (165.57)	11.44 (129.79)	10.71 (113.64)	9.74 (93.79)	4.89 (22.95)	4.36 (18.00)	4.21 (16.75)	3.81 (13.55)
T5	7.69 (58.11)	6.62 (42.83)	6.16 (36.92)	5.19 (25.91)	3.70 (12.66)	3.08 (8.47)	3.10 (8.59)	2.67 (6.12)
T6	12.36 (151.89)	10.60 (111.26)	10.22 (103.50)	9.22 (84.06)	4.79 (21.97)	4.24 (17.01)	4.07 (15.59)	3.72 (12.81)
T7	9.78 (94.69)	8.67 (74.24)	7.96 (62.39)	7.13 (49.77)	4.17 (16.38)	3.60 (11.97)	3.53 (11.43)	3.13 (8.81)
T8	4.61 (20.29)	2.80 (6.83)	3.56 (11.66)	2.12 (3.49)	3.22 (9.38)	2.53 (5.42)	2.43 (4.90)	1.79 (2.21)
T9	7.12 (49.66)	5.58 (30.15)	5.19 (25.94)	4.30 (17.47)	3.37 (10.36)	2.75 (6.55)	2.65 (6.00)	2.14 (3.60)
T10	18.02 (323.61)	17.25 (296.41)	15.13 (227.92)	14.08 (197.17)	9.44 (88.20)	8.88 (77.85)	8.25 (66.99)	7.96 (62.43)
SE (m+)	0.26	0.33	0.37	0.30	1.10	0.09	0.07	0.08
CD (P=0.05)	0.79	0.99	1.11	0.91	0.31	0.28	0.22	0.25
CV %	2.37	2.86	3.17	2.68	0.91	0.86	0.69	0.77

Weed control efficiency: Weed control efficiency (WCE), pooled over two years, is presented in Table 4. WCE exceeded 88 per cent at harvest under both T8 (89.16%) and T9 (88.55%), and remained above 88 per cent from the earliest (20 DAS) observation onward for these two treatments, indicating sustained, season-long control rather than early control that faded

as the pre-emergence herbicide's soil residual activity declined. By contrast, single-application treatments T4, T6 and T7 showed WCE in the 73-85 per cent range at harvest, a gap of 4-16 percentage points that, compounded over the season, produced the substantially larger weed biomass documented in Table 3.

Table 4: Effect of weed management treatments on weed control efficiency (%) of green gram at different growth stages (pooled data of two years)

Treatment	20 DAS	40 DAS	60 DAS	At harvest
T1	92.30	90.19	89.40	88.15
T2	87.90	86.36	85.51	84.28
T3	89.02	87.60	86.78	85.58
T4	76.05	75.87	75.12	73.70
T5	90.84	89.43	88.63	87.12
T6	77.98	77.15	76.31	75.05
T7	85.63	84.15	83.29	82.25
T8	95.96	91.55	90.64	89.16
T9	92.71	90.68	89.83	88.55
T10	0.00	0.00	0.00	0.00

Weed index, weed persistence index and herbicide efficiency index: Data on these three derived indices, pooled over two years, are presented in Table 5. All three indices followed the same treatment ranking as weed control efficiency, with T8 (weed

index 40.21%; weed persistence index 96.33; herbicide efficiency index 377.22) and T9 (36.51%; 83.52; 366.72) recording the highest values among the nine active treatments, and the unweeded control recording zero on all three indices by

construction. Treatment T4, the weakest of the single-tactic treatments, recorded the lowest values among the active treatments (1.39%; 8.83; 5.50), closely followed by T6 (8.88%; 9.73; 37.38). This ranking is consistent with the weed density, dry

weight and weed control efficiency results in Tables 3 and 4, where T8 and T9 were likewise the best-performing treatments and T4 and T6 among the weakest.

Table 5: Effect of weed management treatments on weed index, weed persistence index and herbicide efficiency index of green gram (pooled data of two years)

Treatment	Weed index (%)	Weed persistence index	Herbicide efficiency index
T1	32.60	73.73	314.16
T2	17.65	29.47	122.07
T3	27.70	39.04	210.49
T4	1.39	8.83	5.50
T5	30.41	56.56	265.68
T6	8.88	9.73	37.38
T7	13.75	21.84	82.79
T8	40.21	96.33	377.22
T9	36.51	83.52	366.72
T10	0.00	0.00	0.00

Soil properties and available nutrient status: Data on soil pH, electrical conductivity (EC), organic carbon (OC) and available nitrogen, phosphorus and potassium after harvest, pooled over two years, are presented in Table 6. Soil pH, EC and OC remained close to their pre-sowing values (7.23, 0.20 dS/m and 0.38% respectively) across all treatments, with only modest and

agronomically minor differences among treatments. Available nitrogen, phosphorus and potassium after harvest were consistently highest under T8 and T9 and lowest under the unweeded control, reflecting reduced nutrient removal by weed biomass under the better-performing treatments.

Table 6: Effect of weed management treatments on soil pH, electrical conductivity, organic carbon and available nutrient status of green gram field after harvest (pooled data of two years)

Treatment	pH	EC (dS/m)	OC (%)	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)
T1	7.37	0.26	0.63	284.58	24.77	182.57
T2	7.25	0.22	0.51	282.13	22.30	179.26
T3	7.30	0.23	0.57	282.54	23.05	180.89
T4	7.16	0.17	0.38	278.06	19.23	176.63
T5	7.36	0.25	0.61	283.93	24.33	182.24
T6	7.20	0.19	0.44	278.95	20.19	177.27
T7	7.22	0.21	0.48	280.86	21.18	178.05
T8	7.47	0.29	0.70	287.33	26.56	188.62
T9	7.41	0.27	0.67	286.94	24.93	185.14
T10	7.14	0.16	0.36	275.56	18.59	176.01
SE (m+)	0.03	0.03	0.05	0.33	0.17	1.05
CD (P=0.05)	0.09	0.07	0.09	0.94	0.43	2.98
CV %	0.17	0.14	0.19	0.96	1.02	2.55

Nutrient uptake by crop and weeds: Data on nitrogen, phosphorus and potassium uptake by the crop and by weed biomass, pooled over two years, are presented in Table 7. Nutrient uptake by the crop was highest under T8 (62.86 kg N, 18.13 kg P and 51.74 kg K/ha) and T9 (60.42 kg N, 17.39 kg P and 51.10 kg K/ha), and lowest under the unweeded control. Conversely, nutrient uptake

by weed biomass was lowest under T8 and T9 and highest under the control, confirming that the higher crop nutrient uptake recorded under the better-performing treatments came at the direct expense of nutrient removal by weeds rather than any difference in soil nutrient supply.

Table 7: Effect of weed management treatments on nitrogen, phosphorus and potassium uptake by crop and by weeds of green gram (pooled data of two years)

Treatment	Nutrient uptake by crop (kg/ha)			Nutrient uptake by weeds (kg/ha)		
	N	P	K	N	P	K
T1	59.94	17.03	50.75	3.25	1.09	6.79
T2	54.70	14.89	46.63	4.24	1.45	8.10
T3	56.00	15.22	47.99	3.81	1.36	7.69
T4	50.73	10.31	43.69	5.51	2.25	11.02
T5	57.51	16.31	49.90	3.54	1.20	7.48
T6	51.96	12.18	44.86	5.13	1.89	9.77
T7	53.55	14.73	45.90	4.64	1.62	8.61
T8	62.86	18.13	51.74	2.69	0.77	5.02
T9	60.42	17.39	51.10	3.18	0.88	6.54
T10	48.11	9.39	42.51	7.35	2.69	12.27
SE (m+)	0.06	0.05	0.04	0.07	0.07	0.05
CD (P=0.05)	0.15	0.12	0.12	0.25	0.16	0.12
CV %	0.20	0.33	0.16	3.13	4.00	0.63

Discussion

The broad-spectrum, season-long weed suppression achieved under T8 and T9, evident in their consistently lowest weed count and dry weight across all four observation stages and all ten weed species, reflects the complementary mode-of-action structure of these treatments: an effective pre-emergence herbicide controlling the first flush of germinating weeds, a post-emergence herbicide with a distinct mode of action controlling weeds escaping the pre-emergence layer, and a physical (mechanical or manual) intervention removing any remaining flush ahead of the crop's critical growth stages. This is consistent with reports that a single weed management intervention typically leaves a fraction of a diverse weed flora uncontrolled, given differences in the timing of species-wise emergence and in pre-emergence herbicide efficacy across the field [3], and that integrated, multi-tactic regimens are correspondingly more effective across a broad weed spectrum than any single tactic [7] and [8].

The sustained, rather than merely early-season, weed control efficiency recorded under T8 and T9 (remaining above 88% from 20 DAS through harvest) is a particularly important practical finding, since it demonstrates that these treatments do not simply delay weed emergence but suppress it through to crop maturity, addressing the residual weed seed bank concern raised for single-pass interventions [4]. The correspondingly highest weed index, weed persistence index and herbicide efficiency index recorded under T8 and T9 among the active treatments (Table 5) corroborate this pattern of consistently superior, season-long weed suppression relative to the other integrated treatments evaluated. The consistently higher nutrient uptake by the crop, and correspondingly lower nutrient uptake by weeds, recorded under T8 and T9 provides direct, quantitative confirmation that weeds compete with green gram for available soil nitrogen, phosphorus and potassium, and that effective weed suppression redirects this nutrient pool towards the crop rather than increasing overall nutrient supply [9]. This nutrient-competition dimension of weed management is often under-quantified relative to its yield and cost implications [10], yet the present results show it to be a substantial and directly measurable component of the advantage integrated weed management confers, and one that plausibly also contributed to the higher seed protein content recorded under these treatments through improved nitrogen availability.

The broadly stable soil pH, EC and organic carbon across treatments indicates that none of the herbicide or non-chemical interventions evaluated had a detectable adverse effect on these basic soil properties over the two-year study period, addressing, at least for this duration and this specific set of active ingredients, one of the general environmental-fate concerns raised for repeated herbicide use⁶. Mechanical hoeing and hand weeding, the non-chemical components of the two best-performing treatments, further reduced reliance on repeated herbicide application⁵, consistent with the wider case for integrating non-chemical tactics into herbicide-based weed management programmes. Treatments relying on a single herbicide application without a complementary post-emergence or mechanical/manual follow-up (T4, T6 and T7) consistently showed higher weed density and dry weight, and lower weed control efficiency and weed index, than the integrated treatments throughout the season, only modestly ahead of the unweeded control. This confirms that a single herbicide application, however well chosen, is generally insufficient to suppress the diverse, sequentially emerging weed flora characteristic of green gram fields in this region, and that combining it with a second, differently timed or differently acting intervention is necessary for effective, season-long weed and nutrient management.

Conclusion

Integrated weed management combining a pre-emergence herbicide with a post-emergence herbicide and a mechanical or manual follow-up operation achieved broad-spectrum, season-long suppression of a diverse ten-species weed flora and minimised nutrient diversion to weeds in green gram. Pendimethalin 1.0 kg/ha (PE) followed by imazamox 75 g/ha (30 DAS) followed by mechanical hoeing (45 DAS) (T8) recorded the lowest total weed count and dry weight, the highest weed control efficiency (89.16% at harvest), and the highest crop nutrient uptake among all treatments evaluated, and is recommended as the most effective weed management package for green gram in the central Narmada valley agro-climatic zone of Madhya Pradesh and comparable regions. Pyroxasulfone 0.75 kg/ha (PE) followed by halosulfuron-methyl 75 g/ha (25 DAS) followed by hand weeding (45 DAS) (T9) is recommended as an equally effective alternative, and single-tactic herbicide treatments without a complementary follow-up intervention are not recommended for season-long weed and nutrient management in this crop.

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