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Effect of nitrogen levels and herbicides on productivity and economics of sesame (*Sesamum indicum*) and residual effects on succeeding chickpea (*Cicer arietinum*)

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ABSTRACT

A field experiment was carried out to investigate the effect of nitrogen levels and different herbicides on weed dynamics, growth and productivity of sesame (*Sesamum indicum* L.) and their residual effects on succeeding chickpea (*Cicer arietinum* L.). It was conducted during the 2022–23 and 2023–24 at the Instructional Farm, College of Agriculture, Swami Keshwanand Rajasthan Agricultural University, Bikaner, Rajasthan. Twenty different treatment combinations were tested with main-plots assigned four different nitrogen levels (control, 20, 40 and 60 kg/ha) and the sub-plots were divided into five different weed control methods (weed-free treatment, pendimethalin @750 g/ha pre-emergence (PE), flumioxazin @75 g/ha PE, imazethapyr @50 g/ha applied 25 days after sowing, and weedy check). The results demonstrated that applying 40 kg N/ha significantly enhanced multiple growth metrics. These metrics included plant height, dry matter accumulation, crop growth rate, relative growth rate, seed yield, stalk yield and oil content of sesame but it was at par with 60 kg N/ha. The seed yield percentage increase by 68.4 and 18.5%, net return registered 216.5 and 35.9% increase over control and 20 kg N/ha, respectively. A maximum benefit-cost ratio (2.39) was recorded with the application of nitrogen 60 kg/ha, which was at par with 40 kg N/ha (2.29). Among herbicide treatments, pendimethalin at 750 g/ha, showed a significant improvement in plant height, dry matter accumulation, crop growth rate, relative growth rate, seed yield, stalk yield, net return and benefit-cost ratio of sesame over flumioxazin, weedy check and imazethapyr, whereas it was at par with weed free treatment. Maximum partial factor productivity, agronomic efficiency and physiological efficiency was observed in 20 kg N/ha followed by 40 kg N/ha and 60 kg N/ha. Lowest weed index was reported under pendimethalin (5.18%), however highest weed control efficiency (88.50%) was observed under imazethapyr. Furthermore, the succeeding chickpea crop was unaffected by the nitrogen and herbicide that had been sprayed in pervious chickpea crop. It was concluded that the application of nitrogen at 40 kg/ha along with pendimethalin at 750 g/ha as a PE treatment is recommended for reduce weed dynamics and achieving higher productivity, along with improved quality and profitability, in the hyper-arid regions of Rajasthan, considering its economic importance.

Keywords: Flumioxazin, Imazethapyr, Nitrogen levels, Pendimethalin, Residual effect

Oilseeds play a major role in India's agricultural economy, second only in terms of area farmed to food grains and output levels. Domestic edible oil output reached 12.18 mt in the 2023–24 fiscal year, with consumption reaching 15.66 mt (NITI Aayog 2024). Various indigenous and naturalised annual oilseed crops can be grown in India due to the country's diverse agro-ecological characteristics. Because of its abundance of high-quality polyunsaturated stable fatty acids, sesame (*Sesamum indicum* L.) is often called the 'Queen of Oilseeds' and is an essential oilseed crop. Edible oil makes up 48–55% of the seeds, which are also rich in protein (20–28%), niacin, calcium, and phosphorus, among other minerals and vitamins (Kamani *et al.* 2022).

Soils in India, especially those with a lighter texture, which are common in areas where sesame is grown, tend to be nitrogen deficient. Sesame yields might drop by 50–75% due to inefficient weed control. Effective weed management measures can also increase the efficiency of NPK fertilisers. Instead of spending time and energy weeding by hand, use a chemical weed killer. Herbicides improve crop health and yield by controlling weeds consistently and for an extended period. Soil residual effects of pre-emergence (PE) herbicides can control weeds in their early phases of growth and reduce the need for post-emergence (PoE) treatments. There is a lack of data on the selectivity and efficacy of PE

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herbicides for sesame crops, which limits their use in sesame production. Therefore, it is crucial to control the weeds that are unaffected, such as sedges, grasses, and broadleaf weeds with PoE herbicides like imazethapyr. To help reduce yield losses, field studies are made to determine key weed-free intervals by evaluating the stages of both crops and weeds. The persistence of herbicides applied in preceding crops can have prolonged effects on soil, resulting in reduced weed infestation in succeeding crops within the system. To assess the residual effects of pre- and post-emergence herbicide applications in succeeding crops such as chickpea, various growth parameters including germination count, plant height, and dry matter accumulation were recorded.

MATERIALS AND METHODS

The present experiment was conducted during two consecutive years 2022–23 and 2023–24 at the Instructional Farm of the College of Agriculture, Swami Keshwanand Rajasthan Agricultural University, Bikaner (28.10° N, 73.35° E; at an elevation of 234.7 m amsl), Rajasthan. The 'Agro-ecological region map' from the NBSS&LUP places Bikaner in the Hot Arid Eco-region, specifically Agro-ecological region No. 2 (M_9E_1). This region is defined by low water retention capacity soils deep, coarse sandy loam texture and a hot, dry environment. The area receives 350–600 mm of rainfall every year. Bikaner comes under the Hyper Arid Partially Irrigated Western Plain zone and in India's Agro-climate zone XIV, which is the Western Dry Region, as stated by the National Planning Commission (Planning commission 1989).

The layout was based on a split-plot design (SPD) with three replications. The main plots were assigned four nitrogen levels (control, 20, 40, and 60 kg/ha) and the sub-plots were designated five weed control methods [weed-free, pendimethalin @750 g/ha (PE), flumioxazin @75 g/ha (PE), imazethapyr @50 g/ha applied 25 days after sowing (DAS), and a weedy check]. The sesame variety ‘RT-351’ was sown @2.5 kg/ha with a geometry of 30 cm × 10 cm. The experiment was conducted in plot sizes of 5 m × 4.5 m. Nitrogen was applied according to specific treatment levels, while phosphorus and potash were applied at a basal rate of 32 kg/ha and 20 kg/ha, respectively, following the recommended package of practices. The crop received three irrigations via the sprinkler method. Sowing was performed on 6 July 2022 and 15 July 2023 for the respective experimental years. Following the sesame harvest, the residual effects of the treatments were evaluated using chickpea (cv. ‘GNG-1581’) as a test crop during the *rabi* seasons of 2022–23 and 2023–24. Chickpea was sown in the same experimental plots on 1 November 2022 and 29 October 2023 @60 kg/ha. A uniform geometry of 30 cm × 10 cm was maintained using a mechanical seed drill. A basal fertiliser dose of 20:32:20 kg/ha ($N:P_2O_5:K_2O$) was applied, and the crop was supported by two supplemental irrigations throughout the growing period.

Five samples were chosen at random within each treatment's net plot to collect biometric data. Using Brown's (1984) formula, the crop growth rate (CGR) was determined, and is represented in g/m^2/day. Radford's (1967) formula was used to calculate the relative growth rate (RGR), and expressed as g/g/day. Oil content in kernel was determined by Soxhlet apparatus using petroleum ether (60–800°C) as an extractant (AOAC 1990). Following formulae were used to calculate nutrient use efficiency:

$$\text{Agronomic efficiency (AUE) (kg/kg)} = \frac{\text{Grain yield of fertilised plot (kg/ha)} - \text{Grain yield of unfertilised plot (kg/ha)}}{\text{Quantity of applied nutrient (kg/ha)}}$$

$$\text{Physiological efficiency (PE) (kg/kg)} = \frac{\text{Biological yield of fertilised plot (kg/ha)} - \text{Biological yield of unfertilised plot (kg/ha)}}{\text{Nutrient uptake from fertilised plot (kg/ha)} - \text{Nutrient uptake unfertilised plot (kg/ha)}}$$

$$\text{Partial factor productivity (PFP) (kg/kg)} = \frac{\text{Yield (kg/ha)}}{\text{Amount of nutrient applied (kg/ha)}}$$

To test for the significance of experimental variance, we used the data obtained for different treatment effects and followed the procedure of split-plot design described by Panse and Sukhatme (1985) for statistical analysis. The critical differences were calculated to assess the significance of treatment means wherever, the ‘F’ test was found significant at 5% level of significance.

RESULTS AND DISCUSSION

The experimental field was mainly infested by weeds, namely *Digera arvensis*, *Portulaca oleracea*, *Eragrostis tennela*, *Cenchrus biflorus* and *Gisekia poiedious.* Total weed density (No./m^2) was negligibly affected at 30, 60 DAS and harvest on pooled basis (Table 1). Since, total weed dry weight (g/m^2) was increased in all the three stages due to enhanced nitrogen dose. The minimum and maximum weed dry weight (7.71, 63.38 and 59.03 g/m^2 and 13.11, 87.03 and 91.75 g/m^2) was recorded under control and 60 kg N/ha at 30, 60 DAS and harvest, respectively (Table 1). Increase in dry matter of weeds might be due to the availability of nitrogen in ample amount to leading better nutritional environment for sustained growth and development (Kumar *et al.* 2020). All the herbicides significantly reduced the weed density and weed dry weight to compared weed check. Among the herbicides, imazethapyr has shown promise in effectively preventing both weed density and the buildup of dry matter (Das 2015).

Highest weed control efficiency was observed in weed free followed by imazethapyr @50 g/ha, flumioxazin @75 g/ha and pendimethalin @750 g/ha in terms of 100, 88.5, 85.8 and 79.7%, respectively (Fig. 1). Weed index indicated the loss of yield caused by weed under applied treatment as compared to weed free plot. Among herbicides, the minimum losses in yield were under pendimethalin (5.18%) followed by imazethapyr and flumioxazin during both the years. The loss of yield as measured in terms of weed index was noticed highest under weedy check due to heavy infestation of weeds, while in herbicide applied treatments, lesser yield

Table 1 Effect of nitrogen levels and weed management on weed parameters and growth attributes of sesame on pooled basis

Treatments	Total weed density (No./m²)			Total weed dry weight (g/m²)			Plant height (cm)			Dry matter accumulation (g/plant)		
	30 DAS	60 DAS	At harvest	30 DAS	60 DAS	At harvest	25 DAS	60 DAS	At harvest	30 DAS	60 DAS	At harvest
Nitrogen levels												
Control	2.80 (12.52)	3.69 (19.99)	3.29 (16.13)	2.20 (7.71)	6.37 (63.38)	5.92 (59.03)	21.32	111.05	132.74	1.56	7.61	9.73
20 kg/ha	3.03 (13.95)	4.01 (22.76)	3.51 (17.65)	2.75 (10.96)	6.92 (71.45)	6.67 (68.56)	24.76	118.53	145.48	1.73	9.07	11.25
40 kg/ha	3.23 (15.47)	4.26 (25.03)	3.80 (19.88)	2.93 (12.28)	7.42 (79.03)	7.51 (81.10)	27.63	124.46	154.41	1.84	9.48	11.77
60 kg/ha	3.36 (16.49)	4.49 (27.45)	3.95 (21.30)	3.04 (13.11)	7.82 (87.03)	8.11 (91.75)	28.16	127.35	159.82	1.89	9.52	11.89
SEm±	0.09	0.13	0.13	0.06	0.14	0.08	0.92	1.10	1.65	0.038	0.15	0.11
CD (*p*=0.05)	NS	NS	NS	0.18	0.42	0.24	2.83	3.38	5.08	0.12	0.47	0.36
Weed management												
Weed free	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	26.65	130.01	163.68	1.83	9.66	12.46
Pendimethalin 30% EC @750 g/ha (PE)	2.93 (8.20)	3.90 (14.97)	3.66 (13.04)	2.59 (6.51)	7.17 (51.63)	7.64 (58.90)	26.28	128.80	162.19	1.80	9.51	12.07
Flumioxazin 50% SC @75 g/ha (PE)	2.38 (5.38)	3.66 (13.21)	3.06 (9.13)	1.95 (3.47)	6.12 (37.90)	5.76 (34.99)	25.59	127.08	159.58	1.75	9.11	12.02
Imazethapyr 10% SL @50 g/ha (PoE)	2.05 (3.87)	3.39 (11.33)	2.76 (7.38)	1.93 (3.41)	5.77 (33.75)	5.26 (28.97)	24.53	96.53	106.79	1.72	7.99	9.70
Weedy check	7.46 (55.58)	8.91 (79.54)	7.99 (64.17)	6.47 (41.69)	15.90 (252.82)	15.89 (252.69)	24.28	119.31	148.33	1.69	8.33	9.55
SEm±	0.08	0.10	0.10	0.06	0.10	0.10	0.72	0.86	1.61	0.037	0.15	0.14
CD (*p*=0.05)	0.22	0.27	0.29	0.18	0.29	0.27	NS	2.42	4.56	NS	0.41	0.39

DAS, Days after sowing; PE, Pre-emergence; PoE, Post-emergence; NS, Non-significant.

loss in PoE herbicide as compared to PE because PoE herbicide efficiently controls the weed at early stage and provide the favourable environment to good establishment of crop and proper growth of crop. The similar findings were also reported by Singh *et al.* (2014) and Yadav *et al.* (2018).

The study revealed the growth attributes, growth indices, nutrient use efficiency, yields, quality and economics of sesame were significantly affected by enhanced nitrogen levels. Application of 40 kg N/ha resulted significantly tallest plant height of 124.46 cm and 154.41 cm and higher dry matter accumulation of 9.48 and 11.77 g/plant were recorded at 60 DAS and harvest, respectively over

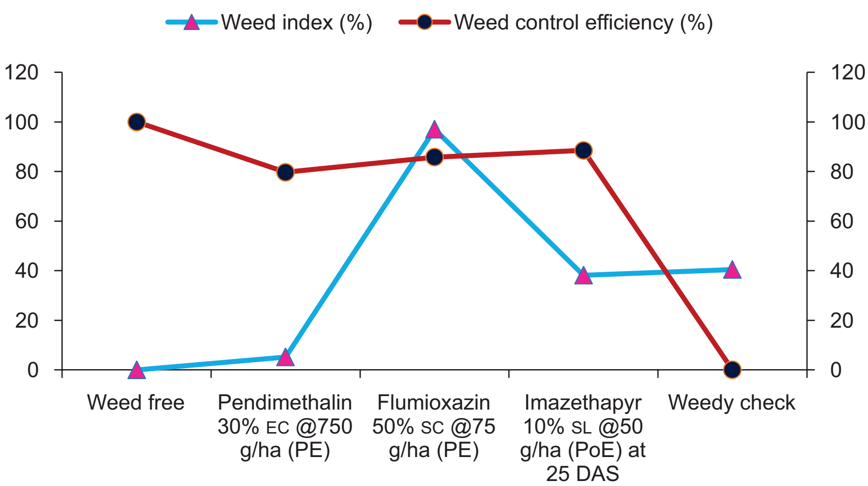

Fig. 1 Effect of weed control treatments on weed index and weed control efficiency. DAS, Days after sowing; PE, Pre-emergence; PoE, Post-emergence.

control and 20 kg N/ha, whereas it was at par with 60 kg N/ha on pooled mean basis (Table 2). The increase in plant height with higher nitrogen levels may be attributed to enhanced cell division, elongation and increased chlorophyll content, leading to improved photosynthetic activity and biomass accumulation (Salam *et al.* 2020, Reddy *et al.* 2022). The data also showed that increasing nitrogen levels up to 40 kg/ha significantly increased the crop growth rate (8.47 g/m^2/day) during 30–60 DAS compared with control and 20 kg N/ha which was on par with 60 kg N/ha. However, the crop growth rate at 40 kg N/ha was statistically at par with 60 kg N/ha. Similarly, this might be due to nitrogen, present in protoplasts, amino acids, proteins, and chlorophyll, which is recognised as to improve growth and production by encouraging the efficient use of photosynthates (Reddy *et al.* 2022).

Among herbicidal treatments, when compared to imazethapyr @50 g/ha and weedy check, the herbicide pendimethalin @750 g/ha produced noticeably superior plant height of 162.19 cm at harvest on a pooled basis, which increased 51.9 and 9.2%, respectively. However, this treatment was at par with weed free and flumioxazin @75 g/ha. Dry matter accumulation also recorded in same trend which increased in tune of 26.38 and 24.43% under PE pendimethalin @750 g/ha compared to weedy check and imazethapyr @50 g/ha, respectively. Pre-emergence application of pendimethalin improved sesame growth parameters by reducing weed density and biomass, which in turn lowered competition for light, space, nutrients, and water. According to Bijarnia *et al.* (2023), crop-weed competition was low and the plant had enough of what it needed light, space, moisture, and nutrients its morphology and physiological traits improved, leading to better photosynthesis and more efficient dry matter accumulation. At 30–60 DAS and 60 DAS to harvest stages, weed free treatment outperformed over weedy check and imazethapyr in terms of CGR (8.70 and 3.72 g/m^2/day) and RGR (55.60 and 10.23 mg/g/day), respectively on pooled basis, whereas pendimenthalin and flumioxazin trailed closely behind to weed free (Table 2). This might be due to reduce weed density, improve optimal environmental conditions as well as nutrient availability which is directly correlated to active physiological process of crops.

Significantly, higher seed yield (594 kg/ha) and stalk yield (2,262 kg/ha) were found under 40 kg N/ha compared to control and 20 kg N/ha, which on was par with 60 kg N/ha (625 and 2,384 kg/ha). Percentage increase in seed yield tune of 68.3 and 18.6% under 40 kg N/ha over control and 20 kg N/ha, respectively (Table 2). This might be because increasing the nitrogen levels in a sequential fashion causes plants to grow taller, produces more branches per plant, produce more capsules per plant, and increase the number

Table 2 Effect of nitrogen levels and weed management on growth indices, yields and oil content of sesame on pooled basis

Treatments	Crop growth rate ($g/m^2/day$)		Relative growth rate (mg/g/day)		Seed yield (kg/ha)	Stalk yield (kg/ha)	Oil content (%)
	30–60 DAS	60 DAS–harvest	30–60 DAS	60 DAS–harvest			
Nitrogen levels							
Control	6.71	2.82	52.60	9.73	353	1352	41.88
20 kg/ha	8.15	2.90	55.15	8.56	501	1907	45.12
40 kg/ha	8.47	3.04	54.65	8.48	594	2262	46.78
60 kg/ha	8.48	3.16	53.83	8.77	625	2384	47.43
SEM±	0.18	0.22	1.06	0.78	12	41	0.78
CD (*p*=0.05)	0.57	NS	NS	NS	37	125	2.40
Weed management							
Weed free	8.70	3.72	55.60	10.23	812	3083	47.82
Pendimethalin 30% EC @750 g/ha (PE)	8.56	3.41	55.51	9.62	770	2931	45.99
Flumioxazin 50% SC @75 g/ha (PE)	8.17	3.88	54.89	11.27	24	91	45.20
Imazethapyr 10% SL @50 g/ha (PoE) at 25 DAS	6.96	2.27	51.24	7.73	502	1923	44.15
Weedy check	7.38	1.62	53.07	5.57	483	1852	43.36
SEM±	0.16	0.27	0.88	0.88	11	38	0.64
CD (*p*=0.05)	0.46	0.77	NS	2.48	31	108	1.80

DAS, Days after sowing; PE, Pre-emergence; PoE, Post-emergence.

of seeds per capsule, all of which are directly correlated with crop yields. Salam *et al.* (2020) and Ihsanullah *et al.* (2023) both indicated that increasing nitrogen levels significantly improved the growth and yield attributes of sesame.

Seed and stalk yield was significantly superior under pendimethalin (770 and 2,931 kg/ha), statistically similar to weed-free treatment (812 and 3083 kg/ha), which was 59.4 and 58.7% higher than weedy check and 53.4 and 52.4% than imazethapyr at 50 g/ha, respectively (Table 2). Pendimethalin showed superiority because it effectively controls weeds during early crop growth stages and persists in soil much longer as another pre-emergence herbicide, thus enabling longer protection for crop-weed competition that reflected in growth, yield attributes and yields. Rajpurohit *et al.* (2017) and Patel *et al.* (2023) also reported lower weed density and dry weight of weeds and increased yields under application of pendimethalin. In contrast, imazethapyr resulted in lower yield due to possible phytotoxic effects on sesame, affecting plant growth and yield attributes (Jursik *et al.* 2011). Flumioxazin also showed poor performance due to adverse effects on crop establishment.

Maximum oil content recorded at 60 kg N/ha (47.43%), which was significantly higher that control (41.88%) and 20 kg N/ha (45.21%), but remained statistically at par with 40 kg N/ha (46.78%). Nitrogen plays a crucial role in enzymatic activities and protein synthesis, which indirectly influences oil biosynthesis in oilseed crops (Reddy *et al.* 2022). Among weed management treatment, the highest oil content was recorded in weed free (47.82%) treatment followed by pendimethalin @750 g/ha (45.99%) and flumioxazin @75 g/ha (45.20%), however these were significantly superior to weedy check (43.36%) on pooled mean basis. This may be because weed free environment amble the nutrient availability, which syntheses oil in developing seed (Bijarnia *et al.* 2023).

Economic analysis revealed that 40 kg N/ha recorded higher net returns and B:C ratio (2.29), which was statistically similar with 60 kg N/ha (Fig. 2). It might be due to higher nutrient use efficiency resulted in increased seed and straw yield hence, ultimately increased the return. The higher profitability at this level may be due to optimum input-output balance (Sharongmangyang and Nongmaithem 2019). Pendimethalin @750 g/ha recorded the highest net returns (67,609 ₹/ha) and B:C ratio (3.28), outperforming all other treatments (Fig. 2). Although weed-free treatment produced higher yield, its higher cost of manual weeding reduced economic returns (Patel *et al.* 2023).

Nutrient use efficiency indices, viz. partial factor productivity (PFP), agronomic efficiency (AE) and physiological efficiency (PE) were markedly influenced by different nitrogen levels (Table 3). Among the treatments 20 kg N/ha recorded the highest PFP (25.05 kg/kg), AE (7.42 kg/kg) and PE (29.95 kg/kg). However, with further increase in nitrogen levels, these efficiency indices declined progressively, with lowest values recorded at 60 kg N/ha. The higher NUE at lower nitrogen levels may be attributed to efficient utilisation of applied nitrogen due to limited availability, resulting in better conversion of nutrients into economic yield. In contrast, the decline in NUE at higher nitrogen levels may be due to diminishing returns, nutrient losses through volatilisation or leaching, and reduced uptake efficiency. Similar trends of decreasing NUE with increasing nitrogen levels have been reported by Reddy *et al.* (2022) and Ihsanullah *et al.* (2023).

The residual effect of nitrogen levels and weed management practices applied to sesame did not significantly

Table 3 Effect of nitrogen levels and weed control measures on nutrient use efficiency of sesame on pooled basis

Treatments	Partial factor productivity (kg/kg)	Agronomic efficiency (kg/kg)	Physiological efficiency (kg/kg)
Nitrogen levels			
Control	-	-	-
20 kg/ha	25.05	7.42	29.95
40 kg/ha	14.84	6.03	27.38
60 kg/ha	10.42	4.54	27.36

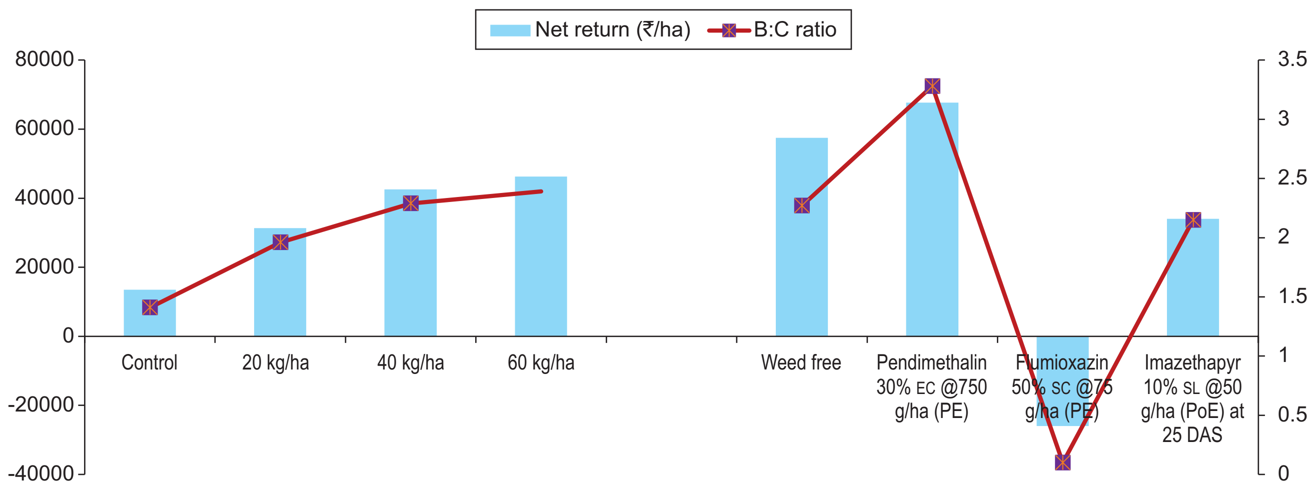

Fig. 2 Effect of nitrogen levels and weed management on net return and B:C ratio of sesame.
DAS, Days after sowing; PE, Pre-emergence; PoE, Post-emergence.

Table 4 Residual effect of previous crop applied treatment on growth attributes and yield of succeeding crop chickpea

Treatments	Plant population (000'/ha)		Plant height (cm)		Seed yield (kg/ha)	Straw yield (kg/ha)
	25 DAS	Harvest	25 DAS	Harvest		
Nitrogen levels						
Control	299.52	280.02	18.23	47.24	1102	1469
20 kg/ha	302.23	278.16	19.49	48.13	1167	1582
40 kg/ha	307.86	293.59	19.14	49.62	1162	1651
60 kg/ha	307.81	284.65	20.09	49.53	1165	1682
SEM±	5.53	5.50	0.47	0.68	35.85	65.59
CD (p=0.05)	NS	NS	NS	NS	NS	NS
Weed management						
Weed free	304.39	283.68	19.28	49.71	1728	1761
Pendimethalin 30% EC @750 g/ha (PE)	305.62	288.46	19.67	49.80	1677	1668
Flumioxazin 50% SC @ g/ha (PE)	304.53	286.75	19.19	48.86	1603	1611
Imazethapyr 10% SL @50 g/ha (PoE) at 25 DAS	302.34	277.87	18.83	47.53	1520	1526
Weedy check	304.88	283.77	19.21	47.24	1425	1441
SEM±	5.10	4.50	0.40	0.58	127.68	76.07
CD (p=0.05)	NS	NS	NS	NS	NS	NS

DAS, Days after sowing; PE, Pre-emergence; PoE, Post-emergence.

influence the growth and yield of succeeding crop chickpea (Table 4). Plant population, plant height, seed yield and straw yield of chickpea remained statistically non-significant across all treatments. This indicates that the applied nitrogen and herbicides did not persist at harmful levels in the soil. The absence of residual effect may be attributed to rapid degradation of herbicides under high temperature conditions of arid regions and adequate fertilisation of the succeeding crop. Similar findings were reported by Patel *et al.* (2016), and Saimaheswari *et al.* (2024). Higher temperature (35–45°C) accelerates degradation of imazethapyr, reducing its persistence in soil (Singh *et al.* 2010). Similarly, flumioxazin residues degrade rapidly below detectable levels (Li *et al.* 2013), which explains the absence of carryover effects.

Based on two years of experimentation, it can be concluded that application of 40 kg N/ha along with pendimethalin @750 g/ha (PE) proved to be the most effective combination for enhancing growth, yield and economic returns of sesame under hyper-arid condition of Rajasthan. Moreover, no adverse residual effects were observed on succeeding chickpea, indicating the sustainability of the treatment combination.

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