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RESEARCH ARTICLE

Productivity of sesame as affected by herbicides and nitrogen levels and their residual effects on subsequent chickpea

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ABSTRACT

A field experiment was conducted with an objective to identify effective herbicides and optimum nitrogen level for managing weeds and enhance productivity of sesame (*Sesamum indicum* L.) and to study their residual effects on succeeding chickpea (*Cicer arietinum* L.). The study was carried at the Instructional Farm of the College of Agriculture, Swami Keshwanand Rajasthan Agricultural University, situated in Bikaner, during the *Kharif* seasons of 2022 and 2023 and the *Rabi* seasons of 2022-23 and 2023-24. There were 20 treatments combinations, with four nitrogen levels (control, 20, 40, and 60 kg/ha) assigned to the main plots and five weed control treatments: weed-free, pre-emergence application (PE) of pendimethalin 750 g/ha, flumioxazin 75 g/ha PE, post-emergence application (PoE) of imazethapyr 50 g/ha PoE and weedy check, designated to the subplots. The highest weed biomass was observed with 60 kg N/ha. Among the herbicidal treatments, pendimethalin 750 g/ha PE, flumioxazin 75 g/ha PE, and imazethapyr 50 g/ha PoE resulted in the lowest density and biomass of grassy weeds, broad-leaved weeds, and sedges. The highest uptake of nitrogen, phosphorus, and potassium by weeds was recorded in the weedy check. The maximum sesame seed yield (770 kg/ha), net return (67,609 ₹/ha), and benefit-cost ratio of 3.28 were recorded with pendimethalin 750 g/ha PE compared to flumioxazin at 75 g/ha and imazethapyr at 50 g/ ha. No statistically significant interaction effects were observed between nitrogen levels and weed control measures during both years and in the pooled analysis. Additionally, there was no residual effect of the applied nitrogen and herbicides on the subsequent chickpea crop.

Keywords: Chickpea, Flumioxazin, Imazethapyr, Nitrogen levels, Pendimethalin, Residual effect, Sesame, Weed management

INTRODUCTION

Sesame (*Sesamum indicum* L.) is a vital oilseed crop in India, frequently referred to as the "Queen of oilseeds" because of its remarkable quality of polyunsaturated stable fatty acids. These seeds serve as a valuable source of consumable oil, comprising 48-55% of their content, but also pack a significant protein punch, with 20-28% protein enriched with vitamins like niacin and minerals such as calcium and phosphorus (Kamani *et al*. 2022). The principal protein in sesame seeds, globulin, is abundant in sulfur-containing amino acids, particularly methionine and tryptophan, which are crucial for protein biosynthesis. Often dubbed as the poor man's substitute for ghee, sesame seeds offer a substantial amount of oil, making them an affordable and nutritious option. A100 grams of sesame seeds provide approximately 592 calories of energy. One of the remarkable qualities of sesame oil is its resistance to oxidative rancidity, allowing it to be stored for extended periods due to its stability. The primary fatty acids in sesame include palmitic, stearic, oleic, and linoleic acids. Moreover, sesame oil has 17 aroma components, with acetyl pyrazine being particularly notable for imparting a strong, popcorn-like aroma. Sesame oil is predominantly used for edible purposes, accounting for approximately 73% of its total usage. It is also utilized for hydrogenation (around 8.3%) and various industrial applications (about 4.2%), including the manufacturing of insecticides, perfumed oils, paints, and pharmaceuticals. Additionally, sesame cake, a byproduct of oil extraction, serves as an excellent manure, containing significant amounts of nitrogen (6-6.2%), phosphorus (2-2.2%), and potassium (1-1.2%) (Dhaka *et al.* 2013).

Sesame is cultivated during the rainy season and its slow initial growth creates favorable conditions for weed proliferation. The sesame is highly sensitive to weed competition, especially when compared to C_4

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plants. Without effective weed management, sesame yields can be reduced by 50 to 75% (Lins *et al.* 2019). Major weeds found during sesame cultivation include: *Cynodon dactylon*, *Dactyloctenium aegyptium*, *Cyperus rotundus*, *Amaranthus spinosus*, *Eleusine indica*, *Digera arvensis*, *Physalis minima*, *Trianthema portulaca*, *Leucas aspera*, *Digitaria sanguinalis* and *Cenchrus biflorus*. Weed management poses a considerable challenge, as weeds vie with sesame plants for essential resources such as water, light, space, and nutrients, ultimately resulting in diminished yields and financial returns. Improving the use efficiency of nitrogen, phosphorus, and potassium (NPK) fertilizers can also be achieved through effective weed management practices. Hand weeding, although common, is labor-intensive, expensive, and strenuous, particularly during peak agricultural periods when labor is scarce and wages are high. Herbicides usage is viable, time-saving, easier, economical, and timely solution for weed control with greater efficacy than manual weeding, especially where labor shortages exist during crucial field operations. Herbicides allow for consistent and extended weed control, improving overall crop health and yield (Bhadauria *et al.* 2012). Hence, this experiment was undertaken with an objective to identify effective herbicides and optimum nitrogen level for managing weeds to enhance the productivity of sesame and to study herbicides residual effects on succeeding chickpea (*Cicer arietinum* L.).

MATERIALS AND METHOD

The study was conducted at the Instructional Farm of the College of Agriculture, Swami Keshwanand Rajasthan Agricultural University, Bikaner, during the kharif seasons of 2022 and 2023, and the rabi seasons of 2022-23 and 2023-24. The farm is located on Sri Ganganagar Road at a latitude of 28.100° N and a longitude of 73.350° E, with an elevation of 234.7 meters above mean sea level. According to the 'Agro-ecological Region Map' by the National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), Bikaner falls under Agro-ecological Region No. 2 (M9E1) within the Hot Arid Eco-region, characterized by deep, sandy, coarse loamy desert soils with low water retention and a hot, arid climate. The annual rainfall ranges from 350 to 600 mm. Based on the NARP classification, Bikaner is categorized in Agro-climatic Zone I C (Hyper Arid Partially Irrigated Western Plain Zone) of Rajasthan, and as part of Agro-climatic Zone XIV (Western Dry Region) of India by the National Planning Commission. A split-plot design with three replications was used. There were 20 treatments combinations, with four nitrogen levels (control, 20, 40, and 60 kg/ha) assigned to the main plots and five weed control treatments: weed-free; pre-emergence application (PE) of pendimethalin at 750 g/ha; flumioxazin at 75 g/ha PE; post-emergence application (PoE) of imazethapyr 50 g/ha PoE and weedy check, designated to the subplots. The sesame variety RT-351 was planted at a row and plant spacing of 30 x 10 cm, utilizing a seed rate of 2.5 kg/ha. Following the sesame harvest, chickpea was seeded as a test crop during the rabi seasons to evaluate the residual effects of the treatments applied to sesame. Chickpea (GNG-1581) was sown at a row spacing of 30 x 10 cm, with a seed rate of 60 kg/ha.

The herbicides were applied using a knapsack sprayer with 500 liters of water per hectare. Weed density and weed dry weight (biomass) were recorded at 30, 60 days after seeding (DAS) by placing a quadrat of 0.5 m^2 randomly placed at two spots in each plot. Data on weed density and biomass were subjected to square root transformation before statistical analysis. Weed control efficiency (WCE) was estimated by using the formula: biomass of weeds in control plot- weeds biomass in treated plot/ weeds biomass in control plot. The effectiveness of weed control was assessed based on weed biomass and the sesame yield measured in kilograms per plot was adjusted to a moisture content of 12-14%. Subsequently, the weight was converted to kg/ha. The weed index was determined by comparing the grain yield from treatment plots with that from control plots. The uptake of nitrogen, phosphorus and potassium by weed at harvest was computed using the formula: Nutrient content in weed (%) x dry weight of weed (kg/ha) /100. To compute the net returns for each treatment, the total cultivation costs were deducted from the gross returns. Mean analysis was conducted employing Fisher's method of analysis of variance, as outlined by Gomez and Gomez (1984). The identification of mean differences was performed through Duncan's univariate test at a significance level of p 0.05.

RESULTS AND DISCUSSION

The nitrogen levels did not significantly affect the density of grassy, broad-leaved, or sedge weeds at 30, 60 DAS, or at harvest (**Table 1**) confirming the findings of Fazil *et al.* (2022). However, increasing nitrogen levels led to a significant rise in weed biomass. The highest biomass of grassy, broad-leaved, and sedge weeds was recorded with nitrogen 40 kg/ha, which was statistically comparable to the

60 kg N/ha. This increase in weed biomass can be attributed to the greater availability of nitrogen, which created a more favorable nutritional environment for weed growth as reported by Kumar *et al*. (2020). The total weeds biomass throughout the sesame growth period was significantly affected by nitrogen levels, with the highest weed biomass observed with 40 kg/ha N which was significantly higher than weedy check and 20 kg/ha N, but statistically similar with 60 kg/ha N. The nitrogen content and uptake by weeds increased with higher nitrogen levels as observed by Upasani *et al*. (2013). However, phosphorus and potassium content did not change significantly but their uptake did increase with nitrogen levels. Ihsanullah *et al*. (2023) also reported significant sesame seed yield improvement with increasing nitrogen levels, with the highest seed yield recorded at 40 kg N/ha, comparable to the yield at 60 N kg /ha.

All weed control treatments significantly reduced weed density and biomass at all stages of crop growth, minimizing nutrient depletion by weeds at harvest, compared to the heavily weed infested weedy check (**Tables 1** to **4**). The observed increase in both weed density and biomass in the weedy check was due to the continuous unchecked weed growth throughout the crop season and usage of available resources (Kakabouki *et al*. 2022). In plots treated with herbicides, weed density and biomass increased at successive stages due to the regeneration of existing weeds and the emergence of new seedlings later in the crop cycle as observed earlier by Dubey *et al*. (2010). Flumioxazin 75 g/ha PoE recorded the lowest weed density and the highest reduction in biomass of broad-leaved weeds at all growth stages. Flumioxazin was effective in controlling most of the weed species including grassy, broad-leaved, and sedges. Weed control treatments significantly reduced weed density and biomass at 30 and 60 DAS, and at harvest. Imazethapyr 50 g/ha was more effective than pendimethalin at 750 g /ha PE in managing weeds confirming the findings of Das (2015). The effectiveness of imazethapyr at 50 g/ha PoE in controlling weeds was due to its inhibition of acetolactate synthase (ALS), an enzyme necessary for the synthesis of the branched-chain amino acids valine, leucine, and isoleucine, which are essential for protein synthesis and plant growth. ALS inhibitors block cell division and reduce carbohydrate translocation in susceptible plants. Imazethapyr is absorbed through both roots and shoots, leading to a rapid decrease in weed populations. The post-emergence application of imazethapyr was the most effective strategy for managing broad-leaved, narrow-leaved, and overall weed growth. Symptoms such as plant stunting, chlorosis, and tissue necrosis appeared within 1 to 4 weeks after herbicide application.

The significant reduction in weed density and biomass at harvest, particularly with pendimethalin at 750 g/ha PE, may be due to prevented weed seed

Table 1. Effect of nitrogen levels and weed management treatments on weed density (no./m^2) in sesame

Treatment	Grassy weeds			Sedges			Broad-leaved weeds		
	At 30 DAS	At 60 DAS	At harvest	At 30 DAS	At 60 DAS	At harvest	At 30 DAS	At 60 DAS	At harvest
Nitrogen levels									
Control	*1.27 (**1.70)	2.28 (6.11)	1.94 (4.08)	1.69 (4.09)	1.88 (5.38)	1.72 (4.44)	2.10 (6.73)	2.45 (8.48)	2.28 (7.62)
20 kg/ha	1.39 (2.06)	2.42 (6.89)	2.04 (4.57)	1.76 (4.40)	2.01 (5.80)	1.82 (4.83)	2.23 (7.42)	2.70 (10.04)	2.41 (8.25)
40 kg/ha	1.51 (2.57)	2.58 (7.73)	2.19 (5.29)	1.89 (4.96)	2.19 (6.55)	2.05 (5.83)	2.31 (7.92)	2.83 (10.76)	2.53 (8.77)
60 kg/ha	1.60 (3.07)	2.70 (8.55)	2.26 (5.68)	1.97 (5.25)	2.33 (7.36)	2.16 (6.39)	2.35 (8.15)	2.96 (11.54)	2.61 (9.23)
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Weed management treatment									
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)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
Pendimethalin 750 g/ha PE	0.71 (0.00)	2.22 (4.58)	1.93 (3.27)	1.38 (1.43)	1.59 (2.12)	1.47 (1.75)	2.66 (6.71)	2.94 (8.26)	2.90 (8.01)
Flumioxazin 75 g/ha PE	1.84 (3.03)	2.67 (6.79)	2.27 (4.75)	1.44 (1.65)	1.74 (2.62)	1.56 (2.03)	1.07 (0.65)	2.02 (3.79)	1.51 (1.93)
Imazethapyr 50 g/ha PoE at 25 DAS	1.20 (1.06)	2.39 (5.38)	2.10 (4.05)	1.25 (1.12)	1.57 (2.07)	1.30 (1.34)	1.43 (1.66)	2.06 (3.89)	1.71 (2.48)
Weedy check	2.77 (7.67)	4.50 (19.92)	3.52 (12.44)	4.35 (19.17)	4.92 (24.54)	4.63 (21.73)	5.37 (28.75)	5.93 (35.08)	5.48 (30.00)
LSD (p=0.05)	0.24	0.20	0.23	0.27	0.29	0.28	0.23	0.23	0.24

*Transformed to $\sqrt{x+0.5}$, ** Original values; PE = pre-emergence application; PoE = post-emergence application; DAS =days after seeding germination and controlled the growth of those already germinated (Sujithra *et al.* 2020). Pendimethalin was reported to control both grassy and small-seeded dicot weed species (Singh *et al.* 2018). It forms a thin layer on the soil surface, inhibiting weed seed germination. The pre-emergence application of pendimethalin disrupts microtubule formation in susceptible weed cells, essential for cell division, which reduces cell division, restricts weed emergence, and ultimately leads to weed death due to

Table 2. Effect of nitrogen levels and weed management treatments on weed biomass (g/m^2) in sesame

Treatment	Grassy weeds			Sedges			Broad-leaved weeds		
	At 30 DAS	At 60 DAS	At harvest	At 30 DAS	At 60 DAS	At harvest	At 30 DAS	At 60 DAS	At harvest
Nitrogen levels									
Control	*0.98 (**0.60)	3.22 (13.06)	2.58 (8.14)	1.47 (2.94)	2.72 (12.45)	2.39 (11.49)	1.70 (4.17)	4.87 (37.87)	4.85 (39.67)
20 kg/ha	1.17 (1.14)	3.38 (14.43)	3.09 (11.49)	1.70 (4.01)	2.91 (13.18)	2.79 (13.88)	2.07 (5.81)	5.35 (43.84)	5.18 (43.12)
40 kg/ha	1.27 (1.46)	3.69 (16.74)	3.48 (14.30)	1.81 (4.47)	3.18 (14.59)	3.55 (18.51)	2.16 (6.36)	5.71 (47.70)	5.67 (48.02)
60 kg/ha	1.30 (1.50)	3.86 (18.47)	3.78 (16.99)	1.89 (4.85)	3.42 (16.97)	3.80 (20.85)	2.21 (6.75)	5.99 (51.58)	6.03 (52.71)
LSD (p=0.05)	0.134	0.26	0.14	0.151	0.22	0.28	0.202	0.40	0.25
Weed management treatment									
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)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
Pendimethalin 750 g/ha PE	0.71 (0.00)	3.12 (9.52)	2.99 (8.67)	1.13 (0.85)	2.22 (4.67)	2.21 (5.04)	2.42 (5.66)	6.08 (36.94)	6.60 (43.69)
Flumioxazin 75 g/ha PE	1.39 (1.54)	3.88 (14.83)	3.64 (13.25)	1.31 (1.28)	2.54 (6.20)	2.62 (7.27)	1.05 (0.66)	4.05 (16.87)	3.45 (12.96)
Imazethapyr 50 g/ha PoE at 25 DAS	1.09 (0.75)	3.46 (11.83)	3.26 (10.93)	1.28 (1.18)	2.27 (4.92)	2.18 (5.28)	1.37 (1.48)	4.09 (17.00)	3.77 (14.18)
Weedy check	2.00 (3.60)	6.53 (42.21)	5.57 (30.79)	4.16 (17.02)	7.45 (55.18)	7.95 (63.32)	4.62 (21.07)	12.48 (155.43)	12.60 (158.58)
LSD (p=0.05)	0.113	0.22	0.17	0.13	0.26	0.28	0.181	0.34	0.31

*Transformed to $\sqrt{x+0.5}$, ** Original values; PE = pre-emergence application; PoE = post-emergence application; DAS =days after seeding

Table 3. Effect of weed management treatments on weed index and weed control efficiency (%) in sesame

Treatment	Weed index (%)			Weed control efficiency (%)		
	2022	2023	Pooled	2022	2023	Pooled
Weed free	0.00	0.00	0.00	100.00	100.00	100.00
Pendimethalin 750 g/ha PE	5.01	5.35	5.18	81.79	77.44	79.69
Flumioxazin 75 g/ha PE	96.89	97.14	97.01	86.39	85.13	85.78
Imazethapyr 50 g/ha PoE at 25 DAS	38.28	38.04	38.16	90.46	86.43	88.50
Weedy check	40.71	40.19	40.45	0.00	0.00	0.00

*PE = pre-emergence application; PoE = post-emergence application; DAS =days after seeding

Table 4. Effect of nitrogen levels and weed management treatments on nutrient content and uptake by weeds in sesame

Treatment	Nutrient content (%)			Nutrient uptake (kg/ha)		
	Nitrogen	Phosphorus	Potassium	Nitrogen	Phosphorus	Potassium
Nitrogen levels						
Control	0.83	0.258	0.538	6.59	2.14	4.35
20 kg/ha	1.01	0.272	0.564	9.00	2.60	5.09
40 kg/ha	1.16	0.284	0.582	12.24	3.19	6.18
60 kg/ha	1.17	0.291	0.595	13.83	3.61	7.13
LSD (p=0.05)	0.08	NS	NS	1.57	0.34	0.89
Weed management treatment						
Weed free	0.00	0.000	0.000	0.00	0.00	0.00
Pendimethalin 750 g/ha PE	1.29	0.348	0.677	7.84	2.08	4.01
Flumioxazin 75 g/ha PE	1.27	0.306	0.681	4.70	1.07	2.47
Imazethapyr 50 g/ha PoE at 25 DAS	1.26	0.320	0.707	3.88	0.95	2.08
Weedy check	1.39	0.407	0.784	35.65	10.33	19.88
LSD (p=0.05)	0.07	0.026	0.049	1.66	0.37	0.92

*PE = pre-emergence application; PoE = post-emergence application; DAS =days after seeding

Table 5. Effect of nitrogen levels and weed management treatments on sesame seed yield, net return, and B:C ratio of sesame

Treatment	Sesame seed yield (kg /ha)			Net return (₹/ha)			B:C ratio		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
Nitrogen levels									
Control	350	355	353	12968	13902	13435	1.40	1.42	1.41
20 kg/ha	498	504	501	30494	32073	31283	1.94	1.97	1.96
40 kg/ha	590	597	594	41604	43463	42533	2.27	2.30	2.29
60 kg/ha	621	629	625	45224	47307	46265	2.37	2.40	2.39
LSD (p=0.05)	60	56	37	7462	7105	4587	0.20	0.22	0.13
Weed management treatment									
Weed free	807	817	812	55995	58926	57461	2.25	2.30	2.27
Pendimethalin 750 g/ha PE	766	773	770	66416	68802	67609	3.27	3.29	3.28
Flumioxazin 75 g/ha PE	25	23	24	-25535	-26469	-26002	0.11	0.10	0.10
Imazethapyr 50 g/ha PoE at 25 DAS	498	506	502	33126	34863	33994	2.14	2.17	2.15
Weedy check	478	488	483	32859	34808	33833	2.22	2.25	2.24
LSD (p=0.05)	44	45	31	5472	5631	3850	0.18	0.19	0.13

*PE = pre-emergence application; PoE = post-emergence application; DAS =days after seeding

insufficient food reserves, thus lowering weed biomass (Joshi *et al.* 2022). This timely intervention resulted in a significant reduction in weed biomass, maintaining a weed-free environment and minimizing competition (Manasa *et al.* 2022).

The least sesame yield loss due to weeds was recorded with pendimethalin at 750 g/ha PE, followed by flumioxazin at 75 g/ha PE and imazethapyr at 50 g/ha PoE at 25 DAS during both years. The weed index reflects the yield loss due to weeds under a given treatment compared to a weed-free plot. The highest yield loss, as indicated by the weed index, occurred in the weedy check due to severe weed infestation. In contrast, post-emergence herbicide treatments resulted in lesser yield compared to those applied pre-emergence, as the latter effectively controls weeds at an early stage, fostering a favorable environment for optimal crop establishment and growth as reported by (Yadav *et al.* 2018).

Nutrient concentrations and their depletion by weeds were significantly affected by the various weed control treatments applied. The weedy check recorded significantly higher uptake of nitrogen, phosphorus, and potassium compared to pendimethalin 750 g/ha PE, flumioxazin 75 g/ha PE, and imazethapyr 50 g/ha PoE at 25 days after sowing (DAS), as observed during both years and in pooled data. This can be attributed to the effectiveness of the herbicides in controlling weeds, allowing the crops to absorb more nutrients compared to the unchecked growth of weeds. Similar observations were reported by (Choudhary *et al.* 2017). In the weedy check plot, where weeds grew freely throughout the crop cycle and recorded maximum nutrient uptake by weeds (35.65 kg N, 10.33 kg P, and 19.18 kg K/ha), which was significantly higher than in other weed management treatments. On the contrary, the lowest nutrient uptake by weeds (3.88 kg N, 0.95 kg P, and 2.08 kg K/ha) was recorded with imazethapyr 50 g/ha PoE. Both imazethapyr 50 g/ha PoE and flumioxazin 75 g/ha PE proved equally effective in minimizing nitrogen, phosphorus, and potassium depletion by weeds, showing statistical parity with each other, while differing significantly from pendimethalin at 750 g/ha PE and the weedy check. The reduction in nutrient depletion by weeds under these treatments can be attributed to the corresponding decrease in weed biomass, due to effective weed control, and the competitive suppression exerted by the crop on weed growth. Similar findings were reported by Kumbar *et al*. (2014). The higher weed biomass in the weedy check plot is likely the primary cause of increased nutrient depletion by weeds as observed by Bhatia *et al.* (2012).

The improved yield with pendimethalin 750 g/ha PE can be attributed to recorded lower weed density and biomass and reduction in competition which ultimately promoted better crop growth and yield (Patel *et al*. 2023). Pendimethalin offers a distinct advantage due to its prolonged persistence in the soil compared to other pre-emergence herbicides. This extended duration of action provides sustained protection against weed competition, which positively affects growth, yield attributes, and overall yields.

Significantly maximum net returns and B:C ratio were observed with 40 kg/ha N (42533 ₹/ha and 2.29) over control and 20 kg/ha N, and this treatment was on par with 60 kg/ ha in this regard, on pooled mean basis (**Table 5**). The result is in conformity with findings of Kumar *et al.* (2009) and Sharongmangyang and Nongmaithem (2019). Pendimethalin 750 g/ha recorded highest net return (67,609 ₹/ha) and B:C ratio (3.28) than all other herbicidal treatments. The pendimethalin 750 g/ha increase additionally ₹/ha by 33776, 33615 and 10148 over weedy check, imazethapyr at 50 g/ha and weed free, respectively, on pooled data analysis. This might be due to low cost of pendimethalin coupled with good economic yield Weed free gave maximum gross return but has higher labor cost for weed management (Patel *et al*. 2023).

It may be concluded that the effective weed management and maximum sesame seed yield can be obtained with pendimethalin 750 g/ha PE, without any residual effect on the subsequent chickpea crop.

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