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Effect of Nutrient Levels and Weed Management on Weed Control Efficiency, Grain Yield and Economics of Mustard

Shashank Tyagi [a*], Arun Kumar [b], S. S. Acharya [a] and S. C. Paul [c]

[a] Department of Agronomy, Bihar Agricultural College, Sabour, Bhagalpur, Bihar, India.
[b] Director Planning, Bihar Agricultural University, Sabour, Bhagalpur, Bihar, India.
[c] Department of Soil Science & Agricultural Chemistry, Bihar Agricultural College, Sabour, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A field experiment was conducted in *rabi* season 2018-19 and 2019-20 at Research farm of Bihar Agricultural College, Sabour with the aim to find out the effect of nutrient and weed management on grain yield, WCE and economics of mustard. This experiment consisted of three nutrient levels (N_1-soil test-based, N_2-100 % RDF, N_3-125 % RDF) in main plot while eight weed management practices (W_1-Weedy, W_2-HW, W_3-pendimethalin, W_4-pendimethalin *fb* quizalofop, W_5-pendimethalin *fb* clodinafop, W_6-oxyflourfen, W_7-oxyflourfen *fb* quizalofop, W_8-oxyflourfen *fb* clodinafop) in sub plots, laid out in split plot design replicated thrice. Results indicated that pendimethalin 30 EC 1.0 kg a.i. ha^{-1} PE *fb* quizalofop 5 EC 60 g a.i. ha^{-1} PoE + 125% RDF (N_3W_4) exhibited highest WCE (85.66 and 88.83 %) in 2018-19 and 2019-20, respectively being at par with N_3W_5 (81.84 %) in 2018-19 only. Though HW at 25 and 50 DAS + 125% RDF (N_3W_2) recorded highest WCE (100 %) than weedy. Grain yield was maximum (18.63 and 17.78 q ha^{-1}) under N_3W_4 being at par with N_3W_7 in 2018-19; while in 2019-20, it was at par with rest of the treatments except N_3W_1 and N_3W_6. In 2018-19, N_3W_4 noted highest net return (Rs. 59068 ha^{-1}) being at par with N_3W_2 and N_3W_7. While in 2019-20, same treatment exhibited highest net return (Rs. 58279 ha^{-1}) being at par with rest of the treatments except N_3W_6 and N_3W_1. In 2018-19, N_3W_4 recorded highest B: C ratio (2.78) being at par with rest of the treatments except N_3W_2 and N_3W_1. In 2019-20, N_3W_7 exhibited highest B: C ratio (2.80) being at par with rest of the treatments except N_3W_6 and N_3W_1.

**Corresponding author: E-mail: drshashank_tyagi@rediffmail.com;*

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1. INTRODUCTION

Oilseeds occupy 27.5 M ha which account for 14% of total cropped area in the country with production 24.7 M tonnes, accounts for nearly 5% of gross national product. Mustard rank third in area and production after groundnut and soybean. It is mainly used for its oil for human consumption. Mustard is potential crop in *rabi* season due to its wider adaptability and suitability to exploit residual moisture in North part of India [1]. Per hectare productivity of mustard in country is quite low (11.5 q ha^{-1}) [2]. To increase the productivity, some constraints of low productivity like nutrient and weed management may be taken under consideration.

Yield depression in mustard due to weed infestation varied from 20-70% depending on the density of weed flora and time of their occurrence [3]. In the past, farmers were bound to follow traditional weed control *viz*., hand-pulling, hand- or mechanical hoeing. These practices apart from labour, energy intensive, weather dependent, are very difficult to apply due to scarcity and high wages of labour. In the past, a few emphasis has been given to improve mustard productivity through weed management. Competition by weeds at initial stage is a major limiting factor for its low productivity. Manual weeding at 3-4 weeks after sowing is the most common practice to control weeds in mustard. But increasing wages and unavailability of labour, they compel for alternative option over manual weeding; which seems as herbicidal weed control. Pre-emergence herbicides are used in mustard to control weeds, however, not all weeds are controlled effectively by these herbicides and left over weeds create more serious problem during active growth period. So there is a possibility to explore the use of post emergence herbicides in mustard.

Application of adequate fertilizer to plant crop increased their leaf growth, which facilitates earlier shading of the soil surface and thus reduces weed seed germination [4]. Mustard responds well to N and P fertilizer depending upon initial soil fertility status and moisture availability. Soil test based fertilizer can be effective tool in boosting yield of mustard [5]. Keeping these in view, an experiment on effect of nutrient and weed management strategies on weed control efficiency and profitable productivity of mustard was conducted.

2. MATERIALS AND METHODS

A field experiment was carried out in *rabi* season of 2018-19 and 2019-20 at Research Farm of Bihar Agricultural College, Sabour, Bhagalpur situated at latitude 25°15' 40" N and longitude 87°2' 42" E with an altitude of 37.46 meters above mean sea level with the aim to assess the impact of nutrient levels and weed management on grain yield, WCE and economics of mustard. The soil of experiment was sandy loam, pH 7.2, organic carbon 0.48 %, available N 123.47 kg ha^{-1}, available P 26.19 kg ha^{-1} and K 168.51 kg ha^{-1}. The experiment was laid out in split plot design with three nutrient levels *viz*., N_1-soil test-based RDF (100:40:40:20:6.25 kg ha^{-1} N P K S Zn), N_2-100 % RDF (80:40:40:20:5 kg ha^{-1} N P K S Zn), N_3-125 % RDF (100:50:50:25:6.25 kg ha^{-1} N P K S Zn) in main plot and eight weed management practices *viz*. W_1-Weedy, W_2-HW at 25 & 50 DAS, W_3-pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} as pre emergence, W_4-pendimethalin 30 EC @ 1.0 kg a.i.ha^{-1} as pre emergence *fb* quizalofop 5 EC @ 60 g a.i. ha^{-1} as post emergence, W_5-pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} as pre emergence *fb* clodinafop 15 WP @ 60 g a.i. ha^{-1} as post emergence , W_6-oxyflourfen 23.5 EC @ 150 g a.i. ha^{-1} as pre emergence, W_7-oxyflourfen 23.5 EC @ 150 g a.i. ha^{-1} as pre emergence *fb* quizalofop 5 EC @ 60 g a.i. ha^{-1} as post emergence, W_8-oxyflourfen 23.5 EC @ 150 g a.i. ha^{-1} as pre emergence *fb* clodinafop 15 WP @ 60 g a.i. ha^{-1} as post emergence in sub plots, replicated thrice. Pendimethalin and oxyflourfen were applied at three days after sowing. Quizalofop and clodinafop were applied at 25 days after sowing. Herbicides were applied through a manually operated knapsack sprayer with flat fan nozzle using 500 liter water ha^{-1}. Hand weeding was done manually with the help of hand tool 'Khunti'.

To carry out the experiment, land preparation operations *viz*., pre sowing irrigation, ploughing and levelling were done. Mustard variety, Pusa bold was sown with seed rate 5 kg ha^{-1} on 22th November, 2018 and on 20th November, 2019 and harvested on 11th March, 2019 and 08th March, 2020 in Ist and IInd year, respectively. The dose of nitrogen, phosphorus, potash, zinc and sulphur was applied *viz*., soil test based, 100 and 125 % RDF in furrows as basal and N was top dressed into splits. Other weed management practices i.e. hand weeding at 25 and 50 DAS, pre emergence alone and/ or with post

emergence herbicide spray was practiced as per treatment in the experimental plots.

The data on density and dry weight of weeds was recorded by randomly placing two quadrates (0.25 x 0.25 m) per plot and converted into m^2. The dry weight of weeds was recorded by drying the weeds in hot air oven at 70^o C ± 1^0 C for 72 hours or till constant weight was achieved. Grain yield was measured from net plot area. Net return of the treatments was calculated by subtracting cost of cultivation from gross return. B: C ratio was calculated by dividing net return with cost of cultivation. WCE of the treatments was calculated as per standard formula. The data were analyzed using analysis of variance (ANOVA) technique [6].

3. RESULTS AND DISCUSSION

3.1 Weed Density and Weed Dry Weight

The data depicted in Table 1 & Table 2 on weed density and dry weight of broad leaved, sedges and grassy weeds in mustard under the influence of nutrient levels and weed management practices revealed that application of 125% RDF (100:50:50:25:6.25 kg NPKS Zn ha^{-1}) exhibited minimum density and dry weight of broad leaved, sedges and grassy weeds as compared to 100% RDF (80:40:40:20:5 kg NPKSZn ha^{-1}) during both the years 2018-19 and 2019-20. Among weed management practices, weedy treatment (W_1) was considered as before treatment of herbicides and rests of the treatments were considered as after treatment of herbicides.

Two hand weeding at 25 and 50 DAS (W_2) exhibited zero value of weed density and dry weight which was significantly inferior over weedy treatment (W_1). Among herbicide treatments, Pendimethalin 30 EC 1.0 kg a.i. ha^{-1} PE *fb* Quizalofop 5 EC @ 60 g a.i. ha^{-1} PoE (W_4) recorded significantly lowest weed density and dry weight in comparison to rest of the herbicide treatments during both the years 2018-19 and 2019-20.

Maximum density and dry weight of total weeds was found as sequence in terms of sedges, followed by broad leaved weeds and then grasses during both the years 2018-19 and 2019-20.

3.2 Weed Control Efficiency

The data depicted in Table 3, Table 4 & Table 5 on weed control efficiency of mustard under the influence of nutrient levels and weed management practices revealed that among herbicides, application of pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} PE *fb* quizalofop 5 EC @ 60 g a.i. ha^{-1} PoE along with 125% RDF (N_3W_4) exhibited significantly highest weed control efficiency (85.66 and 88.83 %) during 2018-19 and 2019-20, respectively which was found statistically at par with pendimethalin 1.0 kg a.i. ha^{-1} PE *fb* clodinafop 60 a.i. ha^{-1} PoE along with 125% RDF (N_3W_5) (81.84 %) in 2018-19 only. Though hand weeding at 25 and 50 DAS along with 125% RDF (N_3W_2) recorded significantly highest weed control efficiency (100 %) as compared to weedy along with 125% RDF (N_3W_1) which recorded zero value during both the years.

Application of herbicide alone or in combination with other herbicides and two hand weeding exhibited maximum WCE due to their lowest weed dry weight and weed population that might the fact that they would influence directly on weed germination and also controls late flushes of weeds due to its long persistency resulting to be more effective against weeds.

These results are in conformity by Singh et al. [7] and Chaudhary et al. [8]. Amongst fertility levels, maximum WCE was recorded with 125 % RDF due to lower weed density that might be due to better growth of crop over weeds and smothering effect of crop vegetative growth over the weeds leading to suppression of weeds population greatly. Effective control of broad-leaved weeds due to combined activity of pre- and post-emergence herbicides has also been reported by Sharma et al. [9].

3.3 Growth and Yield Components of Mustard

The data depicted in Table 6, Table 7 & Table 8 on growth and yield components of mustard under the influence of nutrient levels and weed management practices revealed that among herbicides, application of pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} PE *fb* quizalofop 5 EC @ 60 g a.i. ha^{-1} PoE (W_4) exhibited significantly highest growth (plant height) and yield components (siliqua $plant^{-1}$, siliqua length, seeds $siliqua^{-1}$, test weight) during 2018-19 and 2019-20, respectively.

Table 1. Effect of nutrient levels and weed management on weed density (No. m^{-2}) and weed dry weight (g m^{-2}) of mustard at 60 DAS during 2018-19

Treatments	Weed density (No.m^{-2})				Weed dry weight (g m^{-2})			
	BLWs	Sedges	Grasses	Total	BLWs	Sedges	Grasses	Total
Nutrient levels								
N_1-Soil test-based fertilizer application	50.19	53.51	18.60	122.30	34.25	36.59	13.10	83.94
N_2-100% RDF(80:40:40:20:5 kg NPKSZn ha^{-1})	54.57	57.55	21.97	134.10	36.77	39.20	15.27	91.24
N_3-125%RDF (100:50:50:25:6.25 kg NPKS Zn ha^{-1})	48.67	51.57	15.48	115.72	34.14	35.54	10.79	80.47
SEm±	0.15	0.71	0.78	1.35	0.13	0.47	0.54	0.91
CD (P=0.05)	0.60	2.77	3.06	5.29	0.52	1.86	2.13	3.57
Weed management								
W_1- Weedy	109.83	117.63	50.08	277.54	88.59	93.29	39.57	221.45
W_2- Two hand weeding at 25 and 50 DAS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
W_3- Pendimethalin 30 EC 1.0 kg a.i. ha^{-1} PE	61.05	62.10	23.28	146.43	34.75	35.03	13.64	83.42
W_4- Pendimethalin 30 EC 1.0 kg a.i. ha^{-1} PE *fb* Quizalofop 5 EC @ 60 g a.i. ha^{-1} PoE	30.03	48.35	10.99	89.37	18.56	31.29	7.18	57.03
W_5- Pendimethalin 30 EC 1.0 kg a.i. ha^{-1} PE *fb* Clodinafop 15 WP @ 60 g a.i. ha^{-1} PoE	37.83	48.59	13.23	99.65	25.15	30.89	8.76	64.80
W_6- Oxyflourfen 23.5 EC @ 150 g a.i. ha^{-1} PE	71.50	61.51	23.05	156.06	45.54	40.41	14.91	100.86
W_7- Oxyflourfen 23.5 EC @ 150 g a.i. ha^{-1} PE *fb* Quizalofop 5 EC @ 60 g a.i. ha^{-1} PoE	48.18	45.20	13.92	107.30	32.07	30.45	9.65	72.16
W_8-Oxyflourfen 23.5 EC @ 150 g a.i. ha^{-1} PE *fb* Clodinafop 15 WP @ 60 g a.i. ha^{-1} PoE	50.70	50.33	14.94	115.97	35.74	35.53	10.72	81.99
SEm±	1.67	1.60	1.16	3.06	1.08	1.09	0.82	2.04
CD (P=0.05)	4.77	4.56	3.32	8.73	3.09	3.10	2.34	5.83

Table 2. Effect of nutrient levels and weed management on weed density (No. m^{-2}) and weed dry weight (g m^{-2}) of mustard at 60 DAS during 2019-20

Treatments	Weed density (No.m^{-2})				Weed dry weight (g m^{-2})			
	BLWs	Sedges	Grasses	Total	BLWs	Sedges	Grasses	Total
Nutrient levels								
N_1-Soil test-based fertilizer application	52.37	55.73	18.98	127.08	35.79	38.15	13.20	87.15
N_2-100% RDF(80:40:40:20:5 kg NPKSZn ha^{-1})	56.68	59.97	23.04	139.68	37.96	40.88	16.09	94.94
N_3-125%RDF (100:50:50:25:6.25 kg NPKS Zn ha^{-1})	49.20	52.07	15.70	116.97	34.51	35.81	10.76	81.08
SEm±	0.13	0.70	0.81	1.40	0.10	0.46	0.56	0.93
CD (P=0.05)	0.51	2.73	3.18	5.49	0.41	1.79	2.19	3.67
Weed management								
W_1- Weedy	113.78	119.71	50.98	284.47	92.49	95.78	40.15	228.42
W_2- Two hand weeding at 25 and 50 DAS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
W_3- Pendimethalin 30 EC 1.0 kg a.i. ha^{-1} PE	61.71	63.61	23.85	149.17	34.28	35.84	13.80	83.91
W_4- Pendimethalin 30 EC 1.0 kg a.i. ha^{-1} PE *fb* Quizalofop 5 EC @ 60 g a.i. ha^{-1} PoE	30.39	50.40	11.39	92.18	18.94	31.77	7.19	57.91
W_5- Pendimethalin 30 EC 1.0 kg a.i. ha^{-1} PE *fb* Clodinafop 15 WP @ 60 g a.i. ha^{-1} PoE	39.03	51.92	13.38	104.33	25.89	33.55	9.02	68.47
W_6- Oxyflourfen 23.5 EC @ 150 g a.i. ha^{-1} PE	75.79	63.74	24.57	164.10	47.46	41.43	15.47	104.37
W_7- Oxyflourfen 23.5 EC @ 150 g a.i. ha^{-1} PE *fb* Quizalofop 5 EC @ 60 g a.i. ha^{-1} PoE	49.66	47.62	14.20	111.48	33.56	32.39	9.85	75.80
W_8-Oxyflourfen 23.5 EC @ 150 g a.i. ha^{-1} PE *fb* Clodinafop 15 WP @ 60 g a.i. ha^{-1} PoE	51.62	50.37	15.57	117.56	36.07	35.51	11.32	82.91
SEm±	1.74	1.60	1.18	3.14	1.11	1.09	0.83	2.08
CD (P=0.05)	4.96	4.58	3.37	8.95	3.17	3.11	2.36	5.93

Table 3. Effect of nutrient levels and weed management on weed control efficiency (%) and grain yield (q ha^{-1}) of mustard during 2018-19 and 2019-20

Treatments	Weed control efficiency (%)		Grain yield (q ha^{-1})	
	2018-19	2019-20	2018-19	2019-20
Nutrient levels				
N_1- Soil test-based fertilizer application	63.90	67.17	14.71	14.64
N_2-100% RDF (80:40:40:20:5 kg NPKSZn ha^{-1})	60.92	61.60	13.40	13.60
N_3-125% RDF (100:50:50:25:6.25 kg NPKS Zn ha^{-1})	67.01	70.13	15.87	15.80
SEm±	0.59	0.34	0.37	0.26
CD (P=0.05)	2.30	1.33	1.44	1.02
Weed management				
W_1- Weedy	0.00	0.00	9.38	8.49
W_2- Two hand weeding at 25 and 50 DAS	100.0	100.0	17.46	17.92
W_3- Pendimethalin 30 EC 1.0 kg a.i. ha^{-1} PE	52.48	63.50	14.08	14.48
W_4- Pendimethalin 30 EC 1.0 kg a.i. ha^{-1} PE *fb* Quizalofop 5 EC @ 60 g a.i. ha^{-1} PoE	82.24	84.23	16.47	16.05
W_5- Pendimethalin 30 EC 1.0 kg a.i. ha^{-1} PE *fb* Clodinafop 15 WP @ 60 g a.i. ha^{-1} PoE	77.90	79.47	15.42	15.54
W_6- Oxyflourfen 23.5 EC @ 150 g a.i. ha^{-1} PE	54.19	54.58	13.83	14.07
W_7- Oxyflourfen 23.5 EC @ 150 g a.i. ha^{-1} PE *fb* Quizalofop 5 EC @ 60 g a.i. ha^{-1} PoE	74.62	75.90	15.49	15.67
W_8-Oxyflourfen 23.5 EC @ 150 g a.i. ha^{-1} PE *fb* Clodinafop 15 WP @ 60 g a.i. ha^{-1} PoE	70.10	72.72	15.18	15.20
SEm±	0.86	0.74	0.38	0.37
CD (P=0.05)	2.45	2.10	1.09	1.04

Table 4. Interaction effect of nutrient levels and weed management on weed control efficiency (%) of mustard during 2018-19

Weed management **Nutrient Levels**	**W_1- Weedy**	**W_2- Two HW at 25 & 50 DAS**	**W_3- Pendi methalin 1.0 kg a.i. ha^{-1}**	**W_4-Pendi methalin 1.0 kg a.i. ha^{-1} PE + Quizalofop 60 g a.i. ha^{-1} PoE**	**W_5- Pendi methalin 1.0 kg a.i. ha^{-1} PE + Clodinafop 60 a.i. ha^{-1} PoE**	**W_6- Oxyflourfen 150 g a.i. ha^{-1}**	**W_7- Oxyflourfen 150 g a.i. ha^{-1} + Quizalofop 60 g a.i. ha^{-1} PoE**	**W_8- Oxyflourfen 150 g a.i. ha^{-1} + Clodinafop 60 g a.i. ha^{-1} PoE**
N_1-Soil test 100:40:40:20:6.25 kg NPKSZn ha^{-1}	0.00	100.0	52.54	82.58	78.40	54.14	74.40	69.13
N_2-100% RDF 80:40:40:20:5 kg NPKSZn ha^{-1}	0.00	100.0	48.90	78.49	73.47	48.39	71.35	66.73
N_3-125% RDF 100:50:50:25:6.25 kg NPKSZn ha^{-1}	0.00	100.0	56.00	85.66	81.84	60.04	78.10	74.45
SEm (±)	1.49					1.51		
CD (P=0.05)	4.25 (Levels of W at same level of N)					4.56 (Levels of N at same level of W)		

Table 5. Interaction effect of nutrient levels and weed management on weed control efficiency (%) of mustard during 2019-20

Weed management Nutrient Levels	W_1- Weedy	W_2- Two HW at 25 & 50 DAS	W_3- Pendi methalin 1.0 kg a.i. ha^{-1}	W_4-Pendi methalin 1.0 kg a.i. ha^{-1} PE + Quizalofop 60 g a.i. ha^{-1} PoE	W_5- Pendi methalin 1.0 kg a.i. ha^{-1} PE + Clodinafop 60 a.i. ha^{-1} PoE	W_6- Oxyflourfen 150 g a.i. ha^{-1}	W_7- Oxyflourfen 150 g a.i. ha^{-1}+ Quizalofop 60 g a.i. ha^{-1} PoE	W_8- Oxyflourfen 150 g a.i. ha^{-1} + Clodinafop 60 g a.i. ha^{-1} PoE
N_1-Soil test 100:40:40:20:6.25 kg NPKSZn ha^{-1}	0.00	100.0	63.89	85.82	80.80	55.61	76.35	74.93
N_2-100% RDF 80:40:40:20:5 kg NPKSZn ha^{-1}	0.00	100.0	56.80	78.04	73.22	48.69	70.03	66.03
N_3-125% RDF 100:50:50:25:6.25 kg NPKSZn ha^{-1}	0.00	100.0	69.81	88.83	84.39	59.46	81.32	77.21
SEm (±)	1.27					1.24		
CD (P=0.05)	3.82 (Levels of W at same level of N)					3.72 (Levels of N at same level of W)		

Table 6. Effect of nutrient levels and weed management on plant height and yield attributes of mustard during 2018-19

Treatments	Plant height (cm)	Siliqua plant^{-1}	Length of siliqua	Seeds siliqua^{-1}	Test weight (g)
Nutrient levels					
N_1- Soil test-based fertilizer application	163.0	266.3	4.83	12.24	4.74
N_2-100% RDF (80:40:40:20:5 kg NPKSZn ha^{-1})	157.3	256.3	4.42	11.06	4.53
N_3-125% RDF (100:50:50:25:6.25 kg NPKS Zn ha^{-1})	164.5	269.1	5.13	12.85	4.82
SEm±	2.5	3.8	0.11	0.59	0.02
CD (P=0.05)	NS	NS	0.45	NS	0.09
Weed management					
W_1- Weedy	132.4	173.1	3.83	8.33	3.90
W_2- Two hand weeding at 25 and 50 DAS	172.9	293.1	5.24	12.85	5.03
W_3- Pendimethalin 30 EC 1.0 kg a.i. ha^{-1} PE	163.6	268.8	4.82	12.45	4.67
W_4- Pendimethalin 30 EC 1.0 kg a.i. ha^{-1} PE *fb* Quizalofop 5 EC @ 60 g a.i. ha^{-1} PoE	169.0	285.3	5.10	12.72	4.91
W_5- Pendimethalin 30 EC 1.0 kg a.i. ha^{-1} PE *fb* Clodinafop 15 WP @ 60 g a.i. ha^{-1} PoE	165.7	280.7	4.92	12.66	4.88
W_6- Oxyflourfen 23.5 EC @ 150 g a.i. ha^{-1} PE	159.5	263.9	4.73	12.36	4.60
W_7- Oxyflourfen 23.5 EC @ 150 g a.i. ha^{-1} PE *fb* Quizalofop 5 EC @ 60 g a.i. ha^{-1} PoE	167.3	274.6	4.90	12.55	4.81
W_8-Oxyflourfen 23.5 EC @ 150 g a.i. ha^{-1} PE *fb* Clodinafop 15 WP @ 60 g a.i. ha^{-1} PoE	162.2	271.7	4.81	12.47	4.74
SEm±	2.5	1.1	0.06	0.81	0.03
CD (P=0.05)	7.1	3.0	0.17	2.32	0.09

Table 7. Effect of nutrient levels and weed management on plant height and yield attributes of mustard during 2019-20

Treatments	Plant height (cm)	Siliqua plant^{-1}	Length of siliqua	Seeds siliqua^{-1}	Test weight (g)
Nutrient levels					
N_1- Soil test-based fertilizer application	169.1	270.8	4.98	12.59	4.74
N_2-100% RDF (80:40:40:20:5 kg NPKSZn ha^{-1})	154.5	262.2	4.58	11.38	4.64
N_3-125% RDF (100:50:50:25:6.25 kg NPKS Zn ha^{-1})	168.2	282.9	5.30	13.16	4.91
SEm±	2.6	3.9	0.12	0.61	0.03
CD (P=0.05)	10.4	15.3	0.47	NS	0.10
Weed management					
W_1- Weedy	134.7	185.3	3.92	8.55	3.95
W_2- Two hand weeding at 25 and 50 DAS	174.7	302.9	5.41	13.15	5.10
W_3- Pendimethalin 30 EC 1.0 kg a.i. ha^{-1} PE	163.7	277.8	5.03	12.95	4.64
W_4- Pendimethalin 30 EC 1.0 kg a.i. ha^{-1} PE *fb* Quizalofop 5 EC @ 60 g a.i. ha^{-1} PoE	169.7	289.2	5.24	12.93	5.01
W_5- Pendimethalin 30 EC 1.0 kg a.i. ha^{-1} PE *fb* Clodinafop 15 WP @ 60 g a.i. ha^{-1} PoE	170.1	293.1	5.03	12.91	4.94
W_6- Oxyflourfen 23.5 EC @ 150 g a.i. ha^{-1} PE	160.7	263.0	4.90	12.74	4.76
W_7- Oxyflourfen 23.5 EC @ 150 g a.i. ha^{-1} PE *fb* Quizalofop 5 EC @ 60 g a.i. ha^{-1} PoE	174.1	282.9	5.13	12.85	4.89
W_8-Oxyflourfen 23.5 EC @ 150 g a.i. ha^{-1} PE *fb* Clodinafop 15 WP @ 60 g a.i. ha^{-1} PoE	164.0	281.7	4.98	12.91	4.80
SEm±	2.5	1.1	0.06	0.84	0.03
CD (P=0.05)	7.2	3.2	0.17	2.38	0.10

Table 8. Interaction effect of nutrient levels and weed management on siliqua plant^{-1} of mustard during 2019-20

Weed management Nutrient Levels	W_1- Weedy	W_2- Two HW at 25 & 50 DAS	W_3- Pendi methalin 1.0 kg a.i. ha^{-1}	W_4-Pendi methalin 1.0 kg a.i. ha^{-1} PE + Quizalofop 60 g a.i. ha^{-1} PoE	W_5- Pendi methalin 1.0 kg a.i. ha^{-1} PE + Clodinafop 60 a.i. ha^{-1} PoE	W_6- Oxyflourfen 150 g a.i. ha^{-1}	W_7- Oxyflourfen 150 g a.i. ha^{-1} + Quizalofop 60 g a.i. ha^{-1} PoE	W_8- Oxyflourfen 150 g a.i. ha^{-1} + Clodinafop 60 g a.i. ha^{-1} PoE
N_1-Soil test 100:40:40:20:6.25 kg NPKSZn ha^{-1}	186.1	298.2	273.1	290.3	293.8	273.1	282.9	269.1
N_2-100% RDF 80:40:40:20:5 kg NPKSZn ha^{-1}	176.0	288.7	272.0	281.4	276.2	251.9	274.7	276.5
N_3-125% RDF 100:50:50:25:6.25 kg NPKSZn ha^{-1}	193.7	321.9	288.2	295.8	309.2	264.0	291.0	299.4
SEm (±)	1.9					4.3		
CD (P=0.05)	5.5 (Levels of W at same level of N)					16.1 (Levels of N at same level of W)		

Though hand weeding at 25 and 50 DAS (W_2) recorded significantly highest growth (plant height) and yield components (siliqua plant^{-1}, siliqua length, seeds siliqua^{-1}, test weight) as compared to weedy (W_1) during both the years. Maximum growth and yield components were recorded with 125% RDF which did not differ significantly due to nutrient levels except, siliqua length and test weight during 2018-19 whereas in 2019-20, all the growth and yield components of the crop were significantly affected by nutrient levels except seeds siliqua^{-1} which was obviously due to higher seed yield obtained with these treatments.

Higher fertilizer dose might have enhanced the availability of both native and added nutrients in soil as a result of improved growth, yield attributes and yield of the crop significantly [10] and [11].

3.4 Grain Yield

The data (Table 9 & Table 10) on grain yield of mustard under the influence of nutrient levels and weed management practices revealed that among herbicides, grain yield of mustard was observed significantly maximum (18.63 and 17.78 q ha^{-1}) during 2018-19 and 2019-20, respectively under pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} PE *fb* quizalofop 5 EC @ 60 g a.i. ha^{-1} PoE along with 125% RDF (N_3W_4) which was found at par with N_3W_7 in 2018-19; while in 2019-20, it was at par with rest of the treatments except weedy along with 125% RDF (N_3W_1) and oxyflourfen 23.5 EC @ 150 g a.i. ha^{-1} along with 125% RDF **(**N_3W_6). Though hand weeding at 25 and 50 DAS along with 125% RDF (N_3W_2) recorded significantly highest grain yield (19.44 q ha^{-1}) which was at par with N_3W_4 in 2018-19 only. However, in 2019-20, hand weeding at 25 and 50 DAS along with 125% RDF (N_3W_2) recorded significantly highest grain yield (19.94 q ha^{-1}) of mustard over rest of the treatments. The lowest value of yield attributes and yield may be due to severe competition by weeds for resources, which made the crop plant incompetent to take up more moisture and nutrients, consequently growth was adversely affected.

Higher grain yield owing to 125% RDF was because of better growth and more photosynthate translocation from source to sink [12,13]. Greater grain yield at high fertility was attributed to increased growth [14]. This might be due to efficient weed control. This was in conformity with the finding of O'-Donovan et al. [3]. Due to adequate nutrient supply under increase in nutrient doses which resulted in higher seed yield. These findings were reported by Roul et al. [15] and Kumar and Yadav [16]. Dubey et al. [17].

Grain yield varied in herbicide treatment was due to the fact that crop has least competition for nutrient, moisture and space, provides opportunity for proper growth than weedy. Similar results were reported by Nagar et al. [18]. Hand weeding at 25 and 50 DAS conceded with critical growth stages resulted in higher yield. Similar finding were reported by Chauhan et al. [19]. These treatments kept the crop almost weed free upto 40-50 DAS as a consequence of which reduction in weed dry matter and less competition thus saved a substantial amount of nutrients for crop that led to profuse growth enabling the crop to utilize more soil moisture and nutrients from deeper soil layers.

Two hand weeding at 25 and 50 DAS produced maximum grain yield as they provide long time weed control. These favourable effects in rhizosphere were more conspicuous in HW as this improved soil tilth by making it loose and porous, vulnerable for crop to utilize water and air. Under the weedy condition, although vegetative growth reached up to a level but the sink was not sufficient

to accumulate meaningful photosynthate translocation towards seed formation. Similar results were also reported by Degra et al. [20] and Yadav et al. [21].

The lowest yield was recorded in weedy that might be due to severe competition by weeds, which made the crop incompetent to take up more moisture and nutrients, consequently growth was adversely affected. Similar results were also reported by Sharma and Jain [22] and Yadav [23].

3.5 Net Return

The data presented in Table 11, Table 12 & Table 13 on net return of mustard under the influence of nutrient levels and weed management practices revealed that among herbicides, in 2018-19, application of pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} PE *fb* quizalofop 5 EC @ 60 g a.i. ha^{-1} PoE along with 125% RDF (N_3W_4) recorded significantly highest net return (Rs. 59068 ha^{-1}) of mustard which was

Table 9. Interaction effect of nutrient levels and weed management on grain yield (q ha^{-1}) of mustard during 2018-19

Weed management **Nutrient Levels**	**W_1- Weedy**	**W_2- Two HW at 25 & DAS**	**W_3- Pendi methalin 1.0 kg a.i. ha^{-1}**	**W_4-Pendi methalin 1.0 kg a.i. ha^{-1} PE + Quizalofop 60 g a.i. ha^{-1} PoE**	**W_5- Pendi methalin 1.0 kg a.i. ha^{-1} PE + Clodinafop 60 a.i. ha^{-1} PoE**	**W_6- Oxyflourfen 150 g a.i. ha^{-1}**	**W_7- Oxyflourfen 150 g a.i. ha^{-1} + Quizalofop 60 g a.i. ha^{-1} PoE**	**W_8- Oxyflourfen 150 g a.i. ha^{-1} + Clodinafop 60 g a.i. ha^{-1} PoE**
N_1-Soil test 100:40:40:20:6.25 kg NPKSZn ha^{-1}	8.94	17.64	14.12	15.86	15.53	14.95	15.39	15.25
N_2-100% RDF 80:40:40:20:5 kg NPKSZn ha^{-1}	10.12	15.31	13.16	14.93	14.37	10.80	14.29	14.24
N_3-125% RDF 100:50:50:25:6.25 kg NPKSZn ha^{-1}	9.07	19.44	14.94	18.63	16.34	15.74	16.78	16.05
SEm (±)	0.66					0.72		
CD (P=0.05)	1.89 (Levels of W at same level of N)					2.25 (Levels of N at same level of W)		

Table 10. Interaction effect of nutrient levels and weed management on grain yield (q ha^{-1}) of mustard during 2019-20

Weed management **Nutrient Levels**	**W_1- Weedy**	**W_2- Two HW at 25 & 50 DAS**	**W_3- Pendi methalin .0 kg a.i. ha^{-1}**	**W_4-Pendi methalin 1.0 kg a.i. ha^{-1} PE + Quizalofop 60 g a.i. ha^{-1} PoE**	**W_5- Pendi methalin 1.0 kg a.i. ha^{-1} PE + Clodinafop 60 a.i. ha^{-1} PoE**	**W_6- Oxyflourfen 150 g a.i. ha^{-1}**	**W_7- Oxyflourfen 150 g a.i. ha^{-1} + Quizalofop 60 g a.i. ha^{-1} PoE**	**W_8- Oxyflourfen 150 g a.i. ha^{-1} + Clodinafop 60 g a.i. ha^{-1} PoE**
N_1-Soil test 100:40:40:20:6.25 kg NPKSZn ha^{-1}	8.94	17.64	14.12	15.39	15.53	14.95	15.59	14.92
N_2-100% RDF 80:40:40:20:5 kg NPKSZn ha^{-1}	7.12	16.17	13.36	14.99	14.74	14.17	14.80	13.44
N_3-125% RDF 100:50:50:25:6.25 kg NPKSZn ha^{-1}	9.41	19.94	15.94	17.78	16.34	13.08	16.63	17.25
SEm (±)	0.63					0.65		
CD (P=0.05)	2.00 (Levels of W at same level of N)					2.04 (Levels of N at same level of W)		

Table 11. Effect of nutrient levels and weed management on net return (Rs. ha^{-1}) and B:C ratio of mustard during 2018-19 and 2019-20

Treatments	Net return (Rs. ha^{-1})		B:C ratio	
	2018-19	2019-20	2018-19	2019-20
Nutrient levels				
N_1- Soil test-based fertilizer application	44380	46033	2.30	2.23
N_2-100% RDF (80:40:40:20:5 kg NPKSZn ha^{-1})	39344	41885	2.11	2.08
N_3-125% RDF (100:50:50:25:6.25 kg NPKS Zn ha^{-1})	48452	50321	2.39	2.31
SEm±	1570	1185	0.09	0.06
CD (P=0.05)	6165	4651	NS	NS
Weed management				
W_1- Weedy	23578	20504	1.40	1.13
W_2- Two hand weeding at 25 and 50 DAS	50949	55615	2.06	2.14
W_3- Pendimethalin 30 EC 1.0 kg a.i. ha^{-1} PE	42580	46276	2.33	2.36
W_4- Pendimethalin 30 EC 1.0 kg a.i. ha^{-1} PE *fb* Quizalofop 5 EC @ 60 g a.i. ha^{-1} PoE	50747	51311	2.48	2.36
W_5- Pendimethalin 30 EC 1.0 kg a.i. ha^{-1} PE *fb* Clodinafop 15 WP @ 60 g a.i. ha^{-1} PoE	47741	50353	2.52	2.47
W_6- Oxyflourfen 23.5 EC @ 150 g a.i. ha^{-1} PE	42203	44997	2.38	2.37
W_7- Oxyflourfen 23.5 EC @ 150 g a.i. ha^{-1} PE *fb* Quizalofop 5 EC @ 60 g a.i. ha^{-1} PoE	47230	50144	2.38	2.36
W_8-Oxyflourfen 23.5 EC @ 150 g a.i. ha^{-1} PE *fb* Clodinafop 15 WP @ 60 g a.i. ha^{-1} PoE	47443	49437	2.58	2.48
SEm±	1637	1663	0.09	0.08
CD (P=0.05)	4671	4747	0.25	0.23

Table 12. Interaction effect of nutrient levels and weed management on net return (Rs. ha^{-1}) of mustard during 2018-19

Weed management **Nutrient Levels**	**W_1- Weedy**	**W_2- Two HW at 25 & 50 DAS**	**W_3- Pendi methalin 1.0 kg a.i. ha^{-1}**	**W_4-Pendi methalin 1.0 kg a.i. ha^{-1} PE + Quizalofop 60 g a.i. ha^{-1} PoE**	**W_5- Pendi methalin 1.0 kg a.i. ha^{-1} PE + Clodinafop 60 a.i. ha^{-1} PoE**	**W_6- Oxyflourfen 150 g a.i. ha^{-1}**	**W_7- Oxyflourfen 150 g a.i. ha^{-1} + Quizalofop 60 g a.i. ha^{-1} PoE**	**W_8- Oxyflourfen 150 g a.i. ha^{-1} + Clodinafop 60 g a.i. ha^{-1} PoE**
N_1-Soil test 100:40:40:20:6.25 kg NPKSZn ha^{-1}	21868	51865	42937	48322	48317	46979	46900	47851
N_2-100% RDF 80:40:40:20:5 kg NPKSZn ha^{-1}	27283	42385	39300	44851	43992	30122	42748	44075
N_3-125% RDF 100:50:50:25:6.25 kg NPKSZn ha^{-1}	21583	58598	45503	59068	50914	49509	52042	50402
SEm (±)	2835					3082		
CD (P=0.05)	8091 (Levels of W at same level of N)					9653 (Levels of N at same level of W)		

Table 13. Interaction effect of nutrient levels and weed management on net return (Rs. ha^{-1}) of mustard during 2019-20

Weed management Nutrient Levels	W_1- Weedy	W_2- Two HW at 25 & 50 DAS	W_3- Pendi methalin 1.0 kg a.i. ha^{-1}	W_4-Pendi methalin 1.0 kg a.i. ha^{-1} PE + Quizalofop 60 g a.i. ha^{-1} PoE	W_5- Pendi methalin 1.0 kg a.i. ha^{-1} PE + Clodinafop 60 a.i. ha^{-1} PoE	W_6- Oxyflourfen 150 g a.i. ha^{-1}	W_7- Oxyflourfen 150 g a.i. ha^{-1} + Quizalofop 60 g a.i. ha^{-1} PoE	W_8- Oxyflourfen 150 g a.i. ha^{-1} + Clodinafop 60 g a.i. ha^{-1} PoE
N_1-Soil test 100:40:40:20:6.25 kg NPKSZn ha^{-1}	22698	54528	44846	48486	50429	49113	49868	48296
N_2-100% RDF 80:40:40:20:5 kg NPKSZn ha^{-1}	14992	48296	41889	47167	47477	46241	46864	42150
N_3-125% RDF 100:50:50:25:6.25 kg NPKSZn ha^{-1}	23822	64020	52093	58279	53152	39638	53701	57865
SEm (±)	2881					2944		
CD (P=0.05)	9082 (Levels of W at same level of N)					9280 (Levels of N at same level of W)		

Table 14. Interaction effect of nutrient levels and weed management on B:C ratio of mustard during 2018-19

Weed management **Nutrient Levels**	**W_1- Weedy**	**W_2- Two HW at 25 & 50 DAS**	**W_3- Pendi methalin 1.0 kg a.i. ha^{-1}**	**W_4-Pendi methalin 1.0 kg a.i. ha^{-1} PE + Quizalofop 60 g a.i. ha^{-1} PoE**	**W_5- Pendi methalin 1.0 kg a.i. ha^{-1} PE + Clodinafop 60 a.i. ha^{-1} PoE**	**W_6- Oxyflourfen 150 g a.i. ha^{-1}**	**W_7- Oxyflourfen 150 g a.i. ha^{-1} + Quizalofop 60 g a.i. ha^{-1} PoE**	**W_8- Oxyflourfen 150 g a.i. ha^{-1} + Clodinafop 60 g a.i. ha^{-1} PoE**
N_1-Soil test 100:40:40:20:6.25 kg NPKSZn ha^{-1}	1.30	2.12	2.36	2.38	2.56	2.68	2.38	2.62
N_2-100% RDF 80:40:40:20:5 kg NPKSZn ha^{-1}	1.68	1.77	2.24	2.27	2.41	1.77	2.23	2.49
N_3-125% RDF 100:50:50:25:6.25 kg NPKSZn ha^{-1}	1.22	2.30	2.38	2.78	2.58	2.68	2.52	2.63
SEm (±)	0.15					0.17		
CD (P=0.05)	0.44 (Levels of W at same level of N)					0.52 (Levels of N at same level of W)		

Table 15. Interaction effect of nutrient levels and weed management on B:C ratio of mustard during 2019-20

Weed management **Nutrient Levels**	**W_1- Weedy**	**W_2- Two HW at 25 & 50 DAS**	**W_3- Pendi methalin 1.0 kg a.i. ha^{-1}**	**W_4-Pendi methalin 1.0 kg a.i. ha^{-1} PE + Quizalofop 60 g a.i. ha^{-1} PoE**	**W_5- Pendi methalin 1.0 kg a.i. ha^{-1} PE + Clodinafop 60 a.i. ha^{-1} PoE**	**W_6- Oxyflourfen 150 g a.i. ha^{-1}**	**W_7- Oxyflourfen 150 g a.i. ha^{-1} + Quizalofop 60 g a.i. ha^{-1} PoE**	**W_8- Oxyflourfen 150 g a.i. ha^{-1} + Clodinafop 60 g a.i. ha^{-1} PoE**
N_1-Soil test 100:40:40:20:6.25 kg NPKSZn ha^{-1}	1.26	2.11	2.31	2.24	2.49	2.60	2.36	2.45
N_2-100% RDF 80:40:40:20:5 kg NPKSZn ha^{-1}	0.86	1.91	2.22	2.24	2.42	2.52	2.28	2.20
N_3-125% RDF 100:50:50:25:6.25 kg NPKSZn ha^{-1}	1.26	2.39	2.55	2.58	2.51	1.99	2.43	2.80
SEm (±)	0.14					0.15		
CD (P=0.05)	0.45 (Levels of W at same level of N)					0.47 (Levels of N at same level of W)		

statistically at par with hand weeding at 25 and 50 DAS along with 125% RDF (N_3W_2) and oxyflourfen 23.5 EC @ 150 g a.i. ha^{-1} *fb* quizalofop 5 EC 60 g a.i. ha^{-1} PoE along with 125% RDF (N_3W_7). While in 2019-20, same treatment exhibited significantly highest net return (Rs. 58279 ha^{-1}) of mustard which was at par with rest of the treatments except oxyflourfen 23.5 EC @ 150 g a.i. ha^{-1} along with 125% RDF (N_3W_6) and weedy along with 125% RDF (N_3W_1).

Highest net return with 125% RDF was obviously due to higher grain yield because of low herbicide cost. These results corroborate with Nagar et al. [18] and Chaudhary et al. [8]. Roul et al. [15] reported higher monitory advantage in 125% RDF. Net return due to hand weeding was lower than herbicide dose.

3.6 B: C Ratio

The data (Table 14 & Table 15) on B: C ratio of mustard under the influence of nutrient levels and weed management practices revealed that among herbicides, in 2018-19, application of pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} PE *fb* quizalofop 5 EC @ 60 g a.i. ha^{-1} PoE + 125% RDF (N_3W_4) recorded significantly highest B: C ratio (2.78) of mustard which was statistically at par with rest of the treatments except hand weeding at 25 and 50 DAS along with 125% RDF (N_3W_2) and weedy along with 125% RDF (N_3W_1). While in 2019-20, oxyflourfen 23.5 EC @ 150 g a.i. ha^{-1} PE *fb* clodinafop 15 WP @ 60 g a.i. ha^{-1} PoE along with 125% RDF (N_3W_7) exhibited significantly highest B: C ratio (2.80) which was found at par with rest of the treatments except N_3W_6 and N_3W_1.

Maximum B: C ratio might be due to lower labour charges as compared to two hand weeding. which in turn gave minimum B: C ratio. These results are in conformity with the result of Yadav et al. [21]. Hand weeding was costly; therefore, all herbicidal treatments were superior to it.

4. CONCLUSION

Thus, it might be concluded that application of pendimethalin 30 EC 1.0 kg a.i. ha^{-1} PE *fb* quizalofop 5 EC 60 g a.i. ha^{-1} PoE along with 125% RDF (100:50:50:25:6.25 kg ha^{-1} N P K S Zn) exhibited significantly highest grain yield, net return and B:C ratio of mustard besides improvement in weed control efficiency of the applied herbicides.

FUTURE SCOPE OF RESEARCH

Based on the data achieved, the future research strategies must be focused on the practical feasibility of current research achievement on large scale particularly on farmers' field for achieving sustainable yield in mustard under predictable climate change of Bihar.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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