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Effect of nitrogen and weed management on weed dynamics, and mustard yield and profitability in semi-arid Afghanistan

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Abstract

An experiment was conducted at the experimental farm of Afghanistan National Agricultural Sciences and Technology University (ANASTU), Kandahar during spring 2020 to study the effect on nitrogen and weed management practices in mustard under semi-arid region. Experimental treatments comprised four weed management practices (WMPs) in main-plot [viz. Weedy-check (WC), Weed-free check (WFC), Pendimethalin pre-emergence @ 1.0 kg ha^{-1} and Pendimethalin @ 0.75 kg ha^{-1} pre-emergence followed by one hand-weeding at 30 DAS and four N levels [120, 80, 40 and 0 kg ha^{-1}] as sub-plot treatments. The experiment was laid-out in a split-plot design with three replications. Among WMPs, the WFC recorded zero population of weeds, while significantly lower number of weeds (NLWs + BLWs) was recorded with WMPs, Pendimethalin 0.75 kg ha^{-1} (PE) followed by (fb) hand-weeding at 30 DAS (51.9 m^{-2}). The highest number of weeds (NLWs + BLWs) was recorded with WFC (76.2 m^{-2}). Among N management practices (NMPs), the significantly lower ($p<0.05$) number of weeds (NLWs+ BLWs) was recorded with 0 kg N ha^{-1} (36.5 m^{-2}) followed by 40 kg N ha^{-1} (41.5 m^{-2}) and 80 kg N ha^{-1} (47.0 m^{-2}). The significantly lower dry weight of weed was observed with 0.75 kg ha^{-1} Pendimethalin (PE) followed by (fb) hand-weeding at 30 DAS (15.63 g m^{-2}) fb Pendimethalin 1 kg ha^{-1} PE (16.88 g m^{-2}) and higher weed dry weight (NLWs + BLWs) was observed with treatment, WC (20.91 g m^{-2}). The results showed that significantly higher weed control efficiency was recorded with WMPs, 0.75 kg ha^{-1} Pendimethalin (PE) herbicide fb hand-weeding at 30 DAS (23.6 %), followed by Pendimethalin 1 kg ha^{-1} PE (14.1%). The higher WCE was recorded with NMPs, 0 kg N ha^{-1} followed by 40 kg N ha^{-1}. The significantly higher plant height, leaf area index, dry matter accumulation, seed yield of mustard was recorded with WFC, then 0.75 kg ha^{-1} Pendimethalin (PE) herbicide followed by hand-weeding at 30 DAS. In among the NMPs significantly higher plant height, leaf area index, dry matter accumulation, seed yield and net returns of mustard was recorded with application of 120 kg N ha^{-1} followed by 80 kg N ha^{-1} and 40 kg N ha^{-1}. Based on the experimental results, it is inferred that weed free-check and pre- emergence application of Pendimethalin 0.75 kg ha^{-1} fb hand-weeding at 30 DAS along with 120 kg N ha^{-1} resulted in higher crop growth, productivity and profitability of mustard crop in semi- arid region of Kandahar, Afghanistan.

Key words: Mustard, nitrogen, weed, growth, yield.

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Introduction

Rapeseed-mustard is the 3rd most important oilseed crop in the world after soybean and palm oil (Choudhary *et al*., 2015). Rapeseed-mustard is globally cultivated in area of 34.7 million ha (m ha) with production of 76.23 million tonnes (mt). Similarly, in India the crop occupies ~6 m ha with total production of 7.91 mt (FAOSTAT, 2017). But the information for crop area and total production for Afghanistan is not available. Rapeseed-mustard comprising eight different species are widely cultivated in about 53 countries. Amongst different species; Indian mustard (*Brassica juncea*) is one of the most important species (Lakhana, 2007). Mustard is having a wider adaptability and economic viability (Rana *et al.,* 2018), it is considered as an important rainfed crop preferably grown on marginal and sub-marginal lands (Singh *et al*., 1997). Mustard crop requires higher amount of nitrogen fertilizer (Kumar *et al.*, 2002). Generally, increase in N level results in higher seed and oil yield of mustard (Kumar *et al*., 2002; Choudhary *et al*., 2003, 2004). The improved varieties of mustard respond markedly to N application. The productivity of rapeseed and mustard in Afghanistan is far below the world average productivity because of numerous production constraints like poor irrigation infrastructure, low rainfall, less availability of improved variety seeds, imbalanced nutrition and sub-optimal fertilizer-use specially nitrogen (N), poor crop stand, poor weed management and plant protection measures, etc. (Ehsan *et al*., 2017a; Ibrahimi *et al*., 2017; Noori *et al*., 2019; Hamim and Choudhary, 2019; Kohistani and Choudhary, 2019). Above all, the efficient fertilizer N management is the important factor that greatly affects the growth attributes and yield of this crop (Choudhary and Suri, 2014a, 2014b). Moreover, most of the soils in semi-arid region of Afghanistan are low in soil fertility where proper N management may enhance the mustard productivity (Ehsan *et al*., 2017a, 2017b; Ibrahimi *et al*., 2017; Jahish *et al*., 2017; Noorzai and Choudhary, 2017; Choudhary *et al*., 2020).

The full benefit from inputs like fertilizer and irrigation cannot be derived without adequate weed control (Choudhary *et al*., 2020, 2021). Mustard being a slow growing crop especially during its initial stage it is adversely affected by weeds (Paul *et al.,* 2011; Rana *et al.,* 2018). Mustard faces severe competition with weeds and results in yield loses up to 15-30% from potential yield of mustard (Gill *et al.,* 1984). Afghanistan has a total usable land area of 65.2 m ha and about 9.6 m ha area is arable. Out of total arable land area, 24% area account for irrigated conditions whereas 8% area account for cultivated rainfed situation (Anonymous, 2018). Major oilseed crops grown in Afghanistan are cotton, sunflower, groundnut, flax, soybean, sesame and mustard occupying total land area 73,880 ha. Mustard is grown as a major source of edible oil, vegetable, condiments, cakes and for animal fodder in spring and winter season in eastern most and northern most part of Afghanistan (Ningarahar, Kuner, Laghman, Badghese and Jawzjan). However, acreage of mustard in Afghanistan is fluctuating every year. During 2015-16, the area under mustard was 3891 ha and whereas in year 2017-18 it was reduced to 586 ha (Anonymous, 2018). The large decline in acreage under mustard crop in recent years (2015-16 and 2017-18), indicates the influence of the wide variability in the climatic conditions like rainfall and low productivity due to poor fertilizer management (Anonymous, 2018). Moreover, the use of local varieties, traditional cultivation methods and poor weed and nutrient management practices are the main reasons for low productivity which in turn caused large reduction in land area under mustard crop. With an aim to increase and stabilize the acreage of mustard crop in Afghanistan, its productivity needs to be improved which are largely dependent on fertilization N management and improved methods of weed control.

Nitrogen (N) plays a vital role in crop growth, seed yield and oil yield of mustard (Choudhary *et al.*, 2001a, 2001b, 2001c; Rana *et al.,* 2018). In view to derive full advantage of applied nitrogen fertilizer in mustard, timely weed management is utmost important which otherwise may reduce the seed yield of mustard to an extent of 10-70% depending upon the composition and intensity of weed flora (Singh *et al*., 2002). The effect of weed removal by manual method is costly and cumbersome (Choudhary *et al*., 2020, 2021; Rajpoot *et al*., 2021). Herbicides namely Pendimethalin (1.0

kg a.i. ha^{-1}) and Isoproturon (0.5 kg a.i. ha^{-1}) are reported to be effective and economical for weed control in mustard in India. Considering the above facts and non-availability of information pertaining to the optimum nitrogen levels and weed control options in mustard in Afghanistan, the current study aimed at assessing the influence of nitrogen and weed management practices on weed dynamics, and growth, yield and profitability of mustard in semi-arid Afghanistan.

Materials and Methods

Experimental site and climate

Current study was laid-out at Tarnak farm of Afghanistan National Agricultural Sciences and Technology University (ANASTU), Kandahar, Afghanistan during spring and summer season of 2020. Experimental plot was located at 31^{0}45′ N latitude and 65^{0}58′ E longitude with an altitude of 986 m. Major constraints of the region are soil alkalinity and receding water table. Major crops grown in this region are wheat, barley, maize, groundnut, cotton, gram and mungbean. The region falls under dry southern agro-ecological zone (dry and hot summer) of Kandahar, Afghanistan. Experimental site was under maize-wheat cropping system before this crop was sown. The climate of Kandahar is semi-arid to subtropical with extreme cold and hot situations. June-July are hottest months with mean temperature 31.9^{0}C. Whereas, January is coldest month with minimum temperature is 5.1^{0}C. The average monthly variation in mean temperature is 16.7^{0}C. The average annual relative humidity is 38% and average monthly relative humidity ranges from 23% in June to 59% in February. Average normal annual rainfall of Kandahar is about 190.6 mm. On an average, there are 29 days per year receive more than 0.1 mm of rainfall or 2.4 days with a quantity of rain, snow etc. per month. The no rainfall received in the month June. January is the wettest month of the year with an average rainfall of 54 mm (Fig. 1). The soil of experimental field belongs to the desert under Agro-ecological Zone classification with sandy-loam and alkaline reaction. The initial physical and chemical characteristics of soil of the experimental field are presented in Table 1.

Treatment details and crop management

The experiment comprising of main and sub-plots with 16 treatment combinations having with four levels of weed management imposed on main plots (W_1: Weedy check, W_2: Weed free check, W_3: Pendimethalin @ 1.0 kg ha^{-1} (Pre emergence) and W_4: Pendimethalin @ 0.75 kg ha^{-1} (pre emergence) follow by hand-weeding at 30 DAS) and four levels of nitrogen (0, 40, 80 and 120 kg ha^{-1}) in sub-plots. The experiment was carried out in split-plot design with three replications. Plot size was 3 m

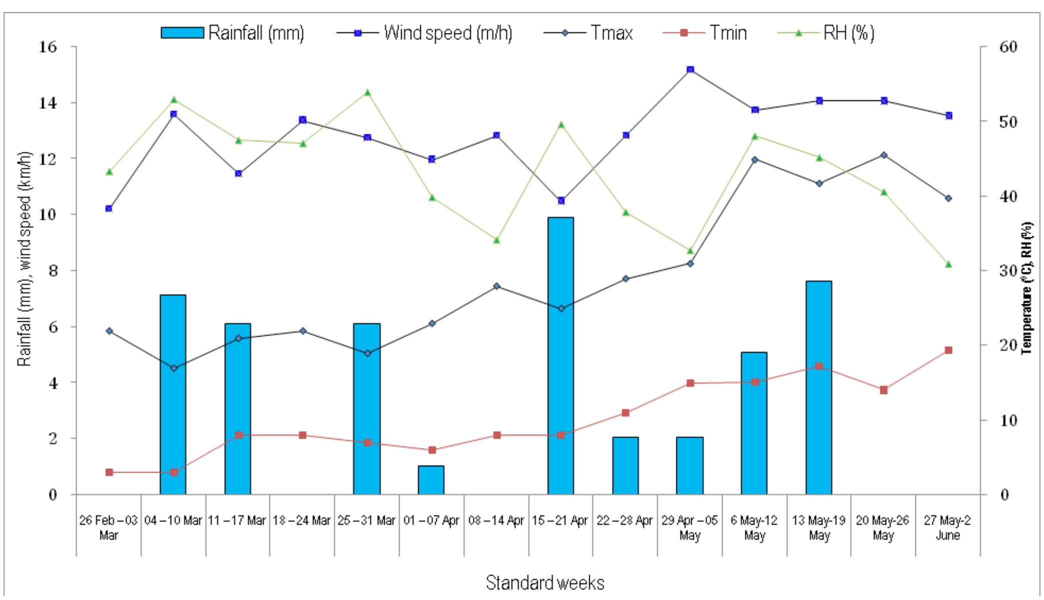

Fig. 1. Mean weekly meteorological data of experimental period.

× 4 m. Experimental field was cultivated with tractor drawn plough and land was prepared by harrowing, planking, lesser leveler and rotovator. Mustard variety 'Madrid-1' was sown using 5 kg seed ha^{-1} on March 1, 2020 while maintaining plant spacing of 50 cm × 15 cm after thinning at 20 DAS. For gap filling, mustard seedlings were also grown simultaneously in polybags (0.2 kg capacity) and then 20-days old seedlings were transplanted in main field at 20 DAS. Herbicides were applied using knapsack sprayer fitted with flat-fan nozzle as pre-emergence with respective doses as per the treatments. Crop was fertilized as per recommended doses except the treatments through different sources like urea, triple super phosphate and MOP. 50% N and full dose of P and K were applied as basal. Rest 50% N was applied as top dressing. Recommended P and K were applied @ 40 and 30 kg ha^{-1}. To maintain optimum moisture during entire growth duration, first irrigation was given at 11 DAS and the second at 20 DAS, and other three additional irrigations were given at pre-flowering, full bloom and at pod-formation stages to fulfil crop requirement with 10-12 DAS interval.

Weed studies

The quadrant method was used to determine weed density by species and total weed density (No. m^2). At 20, 40, 60 DAS and at harvest, weed density was measured in quadrants (0.50 m^2) chosen at random in each plot and data were expressed per m^2. Weeds were uprooted at random in one location to determine weed dry weight by species and total weed dry weight at 30, 60, and at harvest by a quadrant of one m^2 in each plot with the help of *khurpi*. These were sun-dried and then oven-dried for 24 hours at 65°C and their weight was noted in grams.

Weed control efficiency: Weed control efficiency (WCE) was calculated to judge the efficiency of weed control treatments at 30, 60 DAS and at harvest using the formula below (Das *et al.,* 2017):

$$WCE(\%) = \frac{WPc - WPt}{WPc} \times 100$$

Where, WPc is the weed population in weedy check plot and WPt is the weed population in the treated plot (Das *et al.,* 2017).

Weed control index: To compare the different treatments of weed control on the basis of dry weight, weed control index (WCI) was calculated at 30 DAS, 60 DAS and harvest stageas follows (Das *et al.*, 2018).:

$$WCI(\%) = \frac{WDc - WDt}{WDc} \times 100$$

Where, WDc is the weed dry weight (g m^{-2}) in weedy check plot and WDt is the weed dry weight (g m^{-2}) in the treated plot (Das *et al.,* 2017).

Weed index: The following formula was used to determine the weed index:

$$WI = \frac{\text{Yield from weed free plots} - \text{yield from treated plots}}{\text{Yield from weed free plots}}$$

Mustard growth parameters

Plant height was measured from randomly

Table 1. Physico-chemical characteristics of the soil of experimental field (0-20 cm depth).

S. No.	Particulars	Values	Method employed
Physical properties			
1	Fine sand (%)	73.10	Hydrometer method (Bouyoucos, 1962)
2	Silt (%)	17.85	
3	Clay (%)	9.06	
4	Textural Class	Sandy loam	
Chemical properties			
1	pH	8.2	BuckmoricHmeter (Piper,1950)
2	EC (dS m^{-1})	2.1	Jackson (1973)
3	Organic carbon (%)	0.5	Walkley and Black method (Walkley and Black, 1934)
Available nutrient status			
1	Available N (kg ha^{-1})	156.8	Alkaline potassium permanganate method (Subbiah and Asija,1 956)
2	Available P (kg ha^{-1})	37.8	Olsen's method (Olsen et al., 1954)
3	Available K (kg ha^{-1})	89.712	Flame photometer method (Hanway and Heidal, 1952)

selected plants in the net plot area of each plot from ground level to tip of the fully opened leaf at 30, 60 DAS and at harvest. The mean height was expressed in cm. The leaf area was measured from the leaves of random selected plants by using the leaf area meter (Model LI-COR-3100). Leaf area index was calculated as ratio of total leaf area to the total ground area in which the crop is grown. Five plants were sampled at different stages of development (30 and 60 DAS and at harvest) for dry matter accumulation (DMA). After sun drying, the plants were oven dried for 24 hours at 65°C. The weight was recorded using pan balance. The DMA was measured in gm^{-2}.

Yield attributes and yield

The number of siliqua was counted for each of the 10 mustard plants that were sampled and then the number of siliqua per plant was calculated and expressed in number. The number of seeds per siliqua was calculated and expressed in number from 20 sampled siliqua. From each plot's seed lots, a random sample was collected for mustard test weight for 1,000 seed wt. (g). After crop harvest at maturity, mustard seed yield from each net plot was weighed and then calculated as t ha^{-1}. Stover was also weighed as t ha^{-1} after seed threshing. Seed and stover yield were added together to get the biological yield. The harvest index was calculated on the ratio of grain yield to biological yield and expressed into percentage (Rana *et al*., 2014).

Economic studies

In order to evaluate the different treatments, total cost of cultivation (COC), gross and net returns (including by product) were worked out. The benefit: cost ratio was also calculated on the basis of total COC. COC was worked out by using the prevailing input costs/prices incurred *viz*. seeds, fertilizers, pesticides, fungicide, herbicides etc. applied to each treatment for black-eyed bean production.Gross returns were calculated on the basis of seed, stover yield and their present prices in the market (mustard seed price = 80000 AFN t^{-1}, stover price = 4000 AFN t^{-1})

Net returns were calculated by using the following formula:

Net returns (AFN ha^{-1}) = Gross return (AFN ha^{-1}) – Total expenses or cost (AFN ha^{-1})

Benefit: cost ratio (BCR) was calculated using following formula.

$$BCR = \frac{\text{Gross returns}\left(\frac{At}{ha}\right)}{Totalcostofcultivation\left(\frac{Af}{\Box a}\right)}$$

Statistical analysis

For determining the statistical difference between the treatments and to draw conclusions, the data obtained during the course of investigation were subjected to statistical analysis as described by Gomez and Gomez (1984). The original data on weed density and their dry weight at all stages were subjected to square root transformation before statistical analysis to analyze the significant effects of different treatment on weed growth (Rana *et al*., 2014). The original values are given in parentheses. The significance of treatment effect was tested with the help of "F" (variance ratio) test. The critical difference was calculated at 5% level of significance in order of significance in order to compare treatments means.

Results and Discussion

Weed flora and distribution in mustard field

Major weed flora found in the experimental field were; narrow leaved weeds (NLWs) - *Eleusine indica, Setariaviridis, Digitariasanguinalis, Cyperus rotundus, Cynodondactylon, Dactyloctenium aegyptium, Cyperus iria,* and broad-leaved weeds (BLWs) - *Digera arvensis, Eclipta alba, Alhagi maurorum, Cirsium vulgare, Carlina vulgaris, Alternanthera sessilis, Bidens pilosa, Convolvulus arvensis and Chenopodium album* (Table 2). The same status was reported by Gogoi and Kalita (1995) and Choudhary *et al*. (2021).

Weed population and total weed dry weight

The weed management practices (WMPs) and nutrient management practices (NMPs) had a significant (p<0.05) effect on weed population (NLWs and WLWs) of mustard at 30 and 60 DAS and at harvest (Table 3). Population density and dry matter of BLWs) and NLWs were recorded at 30, 60 DAS and harvest. The results showed that BLWs were more in field than NLWs at different stages of crop growth (Tables3&4). The lesser weed population and dry matter accumulation of NLWs and WLWs at 30 DAS, 60 DAS and at harveststage of mustard were recorded under weed management practice W_4:0.75 kg ha^{-1} (PE) Pendimethalin followed by (fb) hand-weeding (HW) at 30 DAS and followed by W_3 – 1.0 kg ha^{-1} (PE) Pendimethalin. The weed free check (WFC) was superior with no-weeds. Lesser weed population and weed dry matter accumulation at 30 DAS, 60 DAS and at harvest in W_4: 0.75 kg ha^{-1} Pendimethalin(PE)fb HW at 30 DAS might be due to better weed management by the Pendimethalin fb HW (Kour *et al*., 2014; Mukherjee, 2014).

Among NMPs, the significantly (p<0.05) lesser

Table 2. Different weed flora in mustard field cultivation at ANASTU farm, Afghanistan.

Common name	Botanical name	Family	Habit and characteristics
Narrow-leaved weeds (NLWs)			
Bermuda grass	*Cynodon Dactylon*	Poaceae	Perennial grass
Purple nutsedge	*Cyperus rotundus*	Cyperaceae	Perennial, erect
Large crab grass	*Digitariasanguinalis*	Poaceae	Semi-spreading herb
Umbrella/rice flat sedge	*Cyperus iria*	Cyperaceae	Perennial, erect
Yellow foxtail	*Setariaviridis*	Poaceae	Annual grass herb
Goose grass	*Eleusine indica*	Poaceae	Erect, tufted annual
Broad leaved weeds (BLWs)			
Persian manna plant	*Alhagi maurorum*	Fabaceae	Edges of ditches, waste and often saline places, Grows in dry barren places
White amaranth	*Amaranthus albus*	Amaranthaceae	Annual weed
Carline thistle	*Carlina vulgaris*	Asteraceae	mostly biennial, without latex
Prickly lettuce or milk thistle	*Lactuca serriola*	Asteraceae	Annual or biennial broad leaves
Field bindweed	*Convolvulus arvensis*	Convolvulaceae	Perennial broad leaved, above ground, the stems trail or climb by twining.
Wild spinach and fat-hen	*Chenopodium album*	Amaranthaceae	Mostly herbs, rarely shrubs or under shrubs (Deeringia), annual or perennial

Table 3. Effect of different WMPs and NMPs on weed population in mustard.

Treatments	Weed population at 30 DAS (Number m^{-2})			Weed population at 60 DAS (Number m^{-2})			Weed population at harvest (Number m^{-2})		
	NLWs	BLWs	Total weeds	NLWs	BLWs	Total weeds	NLWs	BLWs	Total weeds
Weed management practices (WMPs)									
W_1	2.9 (8.4)	3.6 (12.5)	4.6 (21.0)	3.2 (9.9)	3.7 (13.6)	4.9 (23.5)	3.1 (9.6)	3.7 (13.1)	4.8 (22.7)
W_2	0.7 (0.0)	0.7 (0.0)	0.70 (0.0)	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)
W_3	2.7 (7.6)	3.2 (10.0)	4.2 (17.6)	3.0 (8.5)	3.4 (11.5)	4.5 (20.0)	3.0 (8.6)	3.5 (11.8)	4.5 (20.4)
W_4	2.6 (6.6)	3.1 (9.0)	4.0 (15.6)	2.8 (7.5)	3.3 (10.5)	4.3 (18.0)	2.8 (7.5)	3.3 (10.8)	4.3 (18.3)
SE(m)±	0.11	0.11	0.14	0.10	0.08	0.12	0.10	0.09	0.13
CD (P=0.05)	0.37	0.40	0.50	0.37	0.30	0.43	0.36	0.33	0.46
Nitrogen management practices (NMPs)									
N_1	2.0 (4.3)	2.4 (6.5)	3.0 (10.8)	2.2 (5.3)	2.6 (7.7)	3.3(12.9)	2.2 (5.3)	2.6 (7.5)	3.3 (12.8)
N_2	2.2 (5.2)	2.6 (7.7)	3.3 (12.8)	2.3 (6.0)	2.7 (8.4)	3.5 (14.4)	2.3 (6.0)	2.7 (8.3)	3.5 (14.3)
N_3	2.4 (6.2)	2.7 (8.2)	3.5 (14.3)	2.5 (7.1)	2.9 (9.3)	3.7 (16.4)	2.5 (6.8)	2.9 (9.6)	3.7 (16.3)
N_4	2.5 (6.9)	2.9 (9.3)	3.7 (16.2)	2.6 (7.6)	3.0 (10.2)	3.8 (17.8)	2.6 (7.7)	3.0 (10.3)	3.9 (18.0)
SE(m)±	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
CD (P=0.05)	0.05	0.05	0.05	0.04	0.03	0.04	0.04	0.04	0.03

Values of weed population are transformed to square root ("x +0.5), while those in parentheses are the original values. **Note**: **NLWs**: Narrow leaved weed; **BLWs**: Broad leave weeds; $\mathbf{W_1}$: Weedy-check; $\mathbf{W_2}$: Weed-free check; $\mathbf{W_3}$; Pendimethalin @ 1.0 kg ha^{-1} (PE); $\mathbf{W_4}$: Pendimethalin @ 0.75 kg/ha (PE) followed by hand-weeding at 30 DAS; $\mathbf{N_1}$: Control (0 kg N ha^{-1}); $\mathbf{N_2}$: 40 kg N ha^{-1}; $\mathbf{N_3}$: 80 kg N ha^{-1} and $\mathbf{N_4}$: 120 kg N ha^{-1}

number of NLWs and WLWs and lower weed dry matter accumulation of NLWs and WLWsat 30 DAS, 60 DAS and at harvest of mustard was recorded with 0 kg N ha^{-1} (Tables3& 4). Increase in the weed population and dry matter accumulation of BLWs, NLWs and total weeds were noted with increase in N doses from 0 to 120 kg N ha^{-1} at 30 DAS, 60 DAS and at harvest. The highest weed population and dry matter accumulation of BLWs, NLWs and total weeds at 30 DAS, 60 DAS and at harvest of mustard were recorded with by applying120 kg N ha^{-1}. The significantly higher weed population and dry matter accumulation of weeds under120 kg N ha^{-1} might be due to better plant nutrition leading to improved weed growth (Choudhary *et al*., 2021;Bhupenchandra *et al*., 2022a).

Weed indices

The different weed management practices (WMPs) and nitrogen management practices (NMPs) had a significant (p<0.05) effect on weed control efficiency (WCE) and weed control index (WCI) at 30 DAS, 60 DAS and harvest stage of mustard (Table 5). Significantly higher WCE and WCI at 30 DAS, 60 DAS and harvest stage of mustard was found under W_4, 0.75 kg ha^{-1} (PE) Pendimethalin fb HW at 30 DAS followed by W_3, 1.0 kg ha^{-1} (PE) Pendimethalin (Table 4). Higher WCE and WCI in W_4, 0.75 kg ha^{-1} (PE) Pendimethalin fb HW at 30 DAS might be due to better weed management by the Pendimethalin fb HW (W_4). A similar type of results has been reported by Kour *et al*. (2014). The higher weed index (WI) was recorded in W_1, Weedy check plot followed by 1.0 kg ha^{-1} (PE) Pendimethalin (W_3). The lowest weed index was recorded with W_4, 0.75 kg ha^{-1} (PE) Pendimethalin fb HW at 30 DAS due to better weed management by the Pendimethalin fb HW (Table4).The same type of results has been reported by Sarkar *et al*. (2005). The higher WCE and WCI at 30 DAS were recorded with 0 and 80 kg N ha^{-1}, while higher WCE and WCI at 60 DAS were recorded by applying 120 kg N ha^{-1} followed by 0 and 80 kg N ha^{-1}. The lowest weed WCE and WCI wererecorded with 40 and 0 kg N ha^{-1}. A similar type of results has been reported by Patel *et al*. (2013). The NMPs had a significant effect on weed index. The highest weed index was reported under40 kg N ha^{-1} followed by 120 kg N ha^{-1}. The lowest weed index was reported under80 kg N ha^{-1}. Similar kinds of results were reported by Kumar *et al.* (2017, 2020) and Choudhary *et al*. (2021).

Table 4. Effect of different WMPs and NMPs on total weed dry weight in mustard.

Treatments	TWDW at 30 DAS (g m^{-2})			TWDW at 60 DAS (g m^{-2})			TWDW at harvest(g m^{-2})		
	NLWs	BLWs	Total weeds	NLWs	BLWs	Total weeds	NLWs	BLWs	Total weeds
Weed management practices (WMPs)									
W_1	1.3 (1.12)	1.5 (1.89)	1.9 (3.06)	1.6 (2.13)	2.1 (3.83)	2.5 (5.96)	2.1 (4.02)	2.9 (7.88)	3.5 (11.89)
W_2	0.7 (0.00)	0.7 (0.00)	0.7 (0.00)	0.7 (0.00)	0.7 (0.00)	0.7 (0.00)	0.7 (0.00)	0.7 (0.00)	0.7 (0.00)
W_3	1.1 (0.85)	1.4 (1.59)	1.7 (2.44)	1.4 (1.62)	1.8 (2.93)	2.2 (4.54)	1.9 (3.35)	2.6 (6.53	3.2 (9.90)
W_4	1.1 (0.73)	1.3 (1.37)	1.6 (2.10)	1.4 (1.56)	1.8 (2.72)	2.2 (4.28)	1.9 (3.00)	2.6 (6.25)	3.1 (9.25)
SE(m)±	0.03	0.04	0.05	0.04	0.04	0.06	0.05	0.06	0.08
CD (P=0.05)	0.12	0.13	0.17	0.13	0.16	0.21	0.19	0.21	0.28
Nitrogen management practices (NMPs)									
N_1	0.9 (0.36)	1.2 (0.98)	1.3 (1.34)	1.2 (1.03)	1.4 (1.83)	1.7 (2.87)	1.6 (2.20)	2.2 (4.85)	2.6 (7.20)
N_2	1.0 (0.56)	1.2 (1.16)	1.4 (1.72)	1.3 (1.21)	1.5 (2.07)	1.8 (3.28)	1.6 (2.49)	2.2 (5.00)	2.6 (7.52)
N_3	1.1 (0.76)	1.3 (1.30)	1.5 (2.06)	1.3 (1.46)	1.6 (2.53)	2.0 (3.99)	1.7 (2.76)	2.2 (5.15)	2.7 (7.91)
N_4	1.2 (1.08)	1.3 (1.41)	1.6 (2.48)	1.4 (1.61)	1.8 (3.03)	2.1(4.64)	1.7 (2.94)	2.3 (5.49)	2.7 (8.43)
SE(m)±	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.02
CD (P=0.05)	0.02	0.04	0.03	0.02	0.05	0.04	0.05	0.05	0.06

Values of total dry weight of weeds are transformed to square root (√x +0.5), while those in parentheses are the original values**.**

Note: **NLWs**: Narrow leaved weeds; **BLWs**: Broad leave weeds; $\mathbf{W_1}$: Weedy-check; $\mathbf{W_2}$: Weed free check; $\mathbf{W_3}$; Pendimethalin @ 1.0 kg ha^{-1} (PE); $\mathbf{W_4}$: Pendimethalin @ 0.75 kg/ha (PE) followed by hand-weeding at 30 DAS; $\mathbf{N_1}$: Control (0 kg N ha^{-1}); $\mathbf{N_2}$: 40 kg N ha^{-1}; $\mathbf{N_3}$: 80 kg N ha^{-1} and $\mathbf{N_4}$: 120 kg N ha^{-1}

Growth parameters of mustard

Crop growth parameters like plant height, leaf area index (LAI) and dry matter accumulation (DMA) varied with different weed and nitrogen management practices at different crop growth stages of mustard (Table 6). The significantly higher plant height, leaf area index and dry matter accumulation of mustard was recorded with WMPs, weed free check followed by WMPs, 0.75kgha^{-1} (PE) Pendimethalin fb hand-weeding at 30 DAS and WMPs, 1.0 kg ha^{-1} (PE) Pendimethalin (Table 5). The lowest plant height, leaf area index and dry matter accumulation were observed with WMPs, Weedy-checkplots at 30 DAS and 60 DAS.Dry matter accumulation (DMA) at 30 and 60 DAS was significantly higher in WPMs, weed free check, followed by 0.75 kg ha^{-1} (PE) Pendimethalin fb hand-weeding at 30 DAS due to better weed management by the

Table 5. Effect of different WMPs and NMPs on weed indices in mustard.

Treatments	WCE (%)			WCI (%)			Weed index(%)
	30 DAS	60 DAS	Atharvest	30 DAS	60 DAS	At harvest	
Weed management practices (WMPs)							
W_1	-	-	-	-	-	-	50.6
W_2	100.0	100.0	100.0	100.0	100.0	100.0	-
W_3	17.1	15.0	10.3	20.4	21.2	16.3	24.7
W_4	27.1	23.8	19.8	32.1	26.7	21.9	15.2
SE(m)±	2.63	1.52	1.35	2.64	1.30	0.78	1.39
CD (P=0.05))	10.61	6.12	5.44	10.64	5.23	3.13	5.59
Nitrogen management practices (NMPs)							
N_1	50.5	46.2	44.2	48.8	45.1	45.2	29.1
N_2	48.5	45.0	44.0	51.3	46.0	46.3	34.3
N_3	46.9	45.9	42.9	52.2	51.3	45.3	26.4
N_4	46.4	48.0	42.5	50.9	54.7	47.4	30.8
SE(m)±	0.49	0.52	0.49	0.87	1.55	0.88	1.64
CD (P=0.05)	1.47	1.56	NS	NS	4.65	NS	4.92

Note: **NS**: Non-significant, **NLWs**: Narrow leaved weeds; **BLWs**: Broad leave weeds; $\mathbf{W_1}$: Weedy-check; $\mathbf{W_2}$: Weed free check; $\mathbf{W_3}$; Pendimethalin @ 1.0 kg ha^{-1} (PE); $\mathbf{W_4}$: Pendimethalin @ 0.75 kg/ha (PE) followed by hand-weeding at 30 DAS; $\mathbf{N_1}$: Control (0 kg N ha^{-1}); $\mathbf{N_2}$: 40 kg N ha^{-1}; $\mathbf{N_3}$: 80 kg N ha^{-1} and $\mathbf{N_4}$: 120 kg N ha^{-1}

Table 6. Effect of different weed WMPs and NMPs on growth parameters of mustard.

Treatments	Plant height (cm)			LAI		DMA (g m^{-2})	
	30 DAS	60 DAS	At harvest	30 DAS	60 DAS	30 DAS	60 DAS
Weed management practices (WMPs)							
W_1	12.5	57.4	62.7	0.17	0.86	3.9	119.6
W_2	17.4	65.8	69.9	0.25	1.16	4.6	157.2
W_3	14.1	59.4	64.7	0.19	0.97	3.7	127.6
W_4	14.9	60.6	67.3	0.24	1.05	3.8	135.7
SE(m)±	0.12	0.47	0.45	0.01	0.02	0.06	2.81
CD (P=0.05)	0.44	1.66	1.61	0.03	0.06	0.23	9.90
Nitrogen management practices (NMPs)							
N_1	11.5	55.5	59.9	0.15	0.84	2.9	97.4
N_2	13.7	57.8	64.9	0.20	0.94	3.5	119.8
N_3	15.9	62.5	68.2	0.23	1.06	4.0	144.4
N_4	17.7	67.3	71.5	0.27	1.19	4.6	178.5
SE(m)±	0.28	0.25	0.43	0.006	0.01	0.07	1.62
CD (P=0.05)	0.82	0.75	1.27	0.01	0.04	0.21	4.76

Note: DAS: Days after sowing, **NS**: Non-significant, $\mathbf{W_1}$: Weedy-check; $\mathbf{W_2}$: Weed free check; $\mathbf{W_3}$; Pendimethalin @ 1.0 kg ha^{-1} (PE); $\mathbf{W_4}$: Pendimethalin @ 0.75 kg/ha (PE) followed by hand-weeding at 30 DAS; $\mathbf{N_1}$: Control (0 kg N ha^{-1}); $\mathbf{N_2}$: 40 kg N ha^{-1}; $\mathbf{N_3}$: 80 kg N ha^{-1} and $\mathbf{N_4}$: 120 kg N ha^{-1}

Pendimethalin fb hand-weeding.The nutrient management practices had a significant effect on plant height, leaf area index and dry matter accumulation (Table 5). The significantly higher plant height, leaf area index and dry matter accumulation was recorded with NMPs, 120 kg N ha^{-1} followed by 80 and 40 kg N ha^{-1}. While the lowest plant height, LAI and DMA of mustard was recorded with NMPs, 0 kg N ha^{-1}. A similar type of results has been reported by Rahi and Choudhary (2014).

Yield attributes of mustard

The different weed management practices (WMPs) and nitrogen management practices (NMPs) had a significant (p<0.05) effect on yield attributes of mustard (Table 7). Significantly higher number of seed per silique, number of siliqua per plant, test weight of mustard were recorded under W_2, weed free check followed by W_4, 0.75 kg ha^{-1} (PE) Pendimethalin fb hand-weeding at 30 DAS and W_3, 1.0 kg ha^{-1} (PE) Pendimethalin. The improvement in yield attributes might be due to better weed management by WMPs (Rana, 2015; and Singh *et al*., 2020a). The significantly higher number of seed per silique, number of siliqua per plant, test weight of mustard (1000-seed weight) of mustard were recorded with NMPs,120 kg N ha^{-1} followed by 80 and 40 kg N ha^{-1}. The improvement in yield attributes might be due to better N management at 120 kg N ha^{-1}. Similar results were found by various researchers (Varatharajan *et al*., 2019a, 2019b, 2022; Faiz *et al*., 2022; Harish *et al*., 2022a, 2022b).

Yield of mustard

Different weed management practices (WMPs) and nitrogen management practices (NMPs) also exerted significant effect on grain, stalk and biological yield of mustard (Table 7). Significantly (p<0.05) higher grain yield was recorded with W_2, weed free check (995.4 kg ha^{-1}) followed by W_4, 0.75 kg ha^{-1} Pendimethalin (PE) herbicide fb HW at 30 DAS (837.2 kg ha^{-1}), and W_3, Pendimethalin 1 kg ha^{-1} PE (752.2 kg ha^{-1}). Lowest grain yield of mustard was recorded under weedy check plot (489.4 kg ha^{-1}). Likewise, significantly (p<0.05) higher stalk yield of mustard was recorded with weed free check (1490.2 kg ha^{-1}) followed by W_4, 0.75 kg ha^{-1} Pendimethalin (PE) fb HW at 30 DAS (1252.6 kg ha^{-1}), W_3, Pendimethalin 1 kg ha^{-1} PE (1197.4 kg ha^{-1}), and weedy check plot (1047.0 kg ha^{-1}). Significantly (p<0.05) higher biological yield of mustard was recorded under weed free check (2485.7 kg ha^{-1}) followed by W_4, 0.75 kg ha^{-1} Pendimethalin (PE) fb HW at 30 DAS (2089.7 kg ha^{-1}), W_3, Pendimethalin 1 kg ha^{-1} PE (1949.6 kg ha^{-1}), and

Table 7. Effect of different WMPs and NMPs on yield attributes and yield of mustard.

Treatments	Yield attributes			Yield (kg ha^{-1})			Harvest index (%)
	Seeds siliqua^{-1}	Siliqua plant^{-1}	Test-weight (g)	Grain yield	Stalk yield	Biological yield	
Weed management practices (WMPs)							
W_1	27.2	256.2	1.81	489.4	1047.0	1536.4	31.80
W_2	34.2	390.2	2.37	995.4	1490.2	2485.7	40.06
W_3	30.4	295.5	2.00	752.2	1197.4	1949.6	38.27
W_4	32.7	355.3	2.06	837.2	1252.6	2089.7	40.11
SE(m)±	0.40	3.63	0.03	27.37	11.17	32.16	0.53
CD (*P*=0.05)	1.4	12.8	0.12	96.6	39.4	113.5	1.88
Nitrogen management practices (NMPs)							
N_1	28.1	253.5	1.76	644.7	1112.3	1757.1	36.08
N_2	30.2	286.2	1.94	730.7	1165.2	1895.8	37.77
N_3	32.0	322.9	2.17	809.3	1303.6	2111.9	37.91
N_4	34.2	434.7	2.38	889.4	1407.2	2296.6	38.47
SE(m)±	0.21	3.03	0.03	11.87	13.05	19.21	0.35
CD (P=0.05)	0.62	8.9	0.09	34.9	38.3	56.4	1.04

Note:S: Significant, **W_1**: Weedy-check; **W_2**: Weed free check; **W_3**; Pendimethalin @ 1.0 kg ha^{-1} (PE); **W_4**: Pendimethalin @ 0.75 kg/ha (PE) followed by hand-weeding at 30 DAS; **N_1**: Control (0 kg N ha^{-1}); **N_2**: 40 kg N ha^{-1}; **N_3**: 80 kg N ha^{-1} and **N_4**: 120 kg N ha^{-1}

W_1, weedy check plot (1536.4 kg ha^{-1}). Overall, thre was an improvement in grain straw and biological yield of mustard due to better weed management under weed free check and 0.75 kg ha^{-1} Pendimethalin (PE) herbicide fb HW at 30 DAS (Rana, 2015; and Singh *et al*., 2020a).

Among NMPs, significantly higher (p<0.05) grain yield was recorded with 120 kg N ha^{-1} (889.4 kg ha^{-1}) followed by 80 kg N ha^{-1} (809.3 kg ha^{-1}), 40 kg N ha^{-1} (730 kg ha^{-1}) and 0 kg N ha^{-1} (644.7 kg ha^{-1}). Similarly, significantly higher (p<0.05) stalk yield was recorded with 120 kg N ha^{-1} (1407.2 kg ha^{-1}) followed by 80 kg N ha^{-1} (1303.6 kg ha^{-1}) and 40 kg N ha^{-1} (1165.2 kg ha^{-1}) and 0 kg N ha^{-1} (1112.3 kg ha^{-1}). Biological yield also followed the similar trend as that of grain and stalk yield for NMPs. Significantly (p<0.05) higher HI of mustard was recorded with W_4, 0.75 kg ha^{-1} Pendimethalin (PE) fb HW at 30 DAS (40.11%), followed by W_2, weed free check (40.06%), and W_3, Pendimethalin 1 kg ha^{-1} PE (38.27%) and W_1, weedy check plots (31.80%). Among NMPs, significantly higher HI was recorded 120 kg N ha^{-1} (38.47%) followed by 80 kg N ha^{-1} (37.91%), 40 kg N ha^{-1} (37.77%)and 0 kg N ha^{-1} (36.08%). On an average, better N management under 120 kg N ha^{-1} ledto higher grain, stalk and biological yield as well as harvest index of mustard under semi-arid Afghanistan (Kumar *et al*., 2015a, 2015b, 2016a, 2016b; Faiz *et al*., 2022).

The interaction effects between WMPs and NMPs for grain, stalk and biological yield of mustard were found significant (Table 8). It was revealed that increase in N levels from 0 to 120 kg N/ha had consistent and significant increase in the grain, stalk and biological yield of mustard at each weed management practice with highest magnitude under W_2, weed free check followed by W_4,

Table 9. Effect of WMPs and NMPs on economics of mustard crop.

Treatments	Cost of cultivation (10^3 × AFN /ha)	Gross returns (10^3 × AFN /ha)	Net returns (10^3 × AFN/ ha)	B: C ratio
Weed management practices (WMPs)				
W_1	20.89	44.38	22.12	1.99
W_2	24.51	87.08	64.82	3.91
W_3	21.51	66.16	43.89	2.97
W_4	22.29	73.23	50.97	3.28
SEm+	-	2.20	2.20	0.09
CD (P=0.05)	-	7.77	7.77	0.34
Nitrogen management practices (NMPs)				
N_1	17.97	57.14	34.87	2.56
N_2	21.18	64.27	42.01	2.88
N_3	24.39	71.25	48.99	3.20
N_4	27.60	78.18	55.92	3.51
SEm+	-	0.96	0.96	0.04
CD (P=0.05)	-	2.83	2.83	0.12

Note: $\mathbf{W_1}$: Weedy-check; $\mathbf{W_2}$: Weed free check; $\mathbf{W_3}$; Pendimethalin @ 1.0 kg ha^{-1} (PE); $\mathbf{W_4}$: Pendimethalin @ 0.75 kg/ha (PE) followed by hand-weeding at 30 DAS; $\mathbf{N_1}$: Control (0 kg N ha^{-1}); $\mathbf{N_2}$: 40 kg N ha^{-1}; $\mathbf{N_3}$: 80 kg N ha^{-1} and $\mathbf{N_4}$: 120 kg N ha^{-1}

Table 8. Interaction between WMPs and NMPs on grain, stalk and biological yield of mustard.

Treatments	Seed yield (kg ha^{-1})				Stalk yield (kg ha^{-1})				Biological yield (kg ha^{-1})			
	Nitrogen management practices				Nitrogen management practices				Nitrogen management practices			
WMPs	N_1	N_2	N_3	N_4	N_1	N_2	N_3	N_4	N_1	N_2	N_3	N_4
W_1	413.3	446.7	521.0	576.7	988.0	1019.7	1052.3	1128.0	1401.3	1466.3	1573.3	1704.7
W_2	823.3	985.0	1008.0	1,165.3	1237.7	1336.7	1526.0	1860.7	2061.0	2321.7	2534.0	3026.0
W_3	603.3	699.0	812.3	894.0	1090.3	1130.0	1286.3	1283.0	1693.7	1829.0	2098.7	2177.0
W_4	739.0	792.0	896.0	921.7	1133.3	1174.3	1345.7	1357.0	1872.3	1966.3	2241.7	2278.7
Nitrogen management level at the same level of weed management												
SE(m)±	54.8				22.4				64.3			
CD (P=0.05)	186.2				79.7				212.8			
Weed management level at the same/diff. level of nitrogen management												
SE(m)±	34.2				25.2				46.3			
CD (P=0.05)	113.5				83.2				160.9			

Note: W_1: Weedy-check; W_2: Weed free check; W_3; Pendimethalin @ 1.0 kg ha^{-1} (PE); W_4: Pendimethalin @ 0.75 kg/ha (PE) followed by hand-weeding at 30 DAS; N_1: Control (0 kg N ha^{-1}); N_2: 40 kg N ha^{-1}; N_3: 80 kg N ha^{-1} and N_4: 120 kg N ha^{-1}

0.75 kg ha^{-1} Pendimethalin PE fb HW at 30 DAS, and W_3, Pendimethalin 1 kg ha^{-1} PE, and W_1, weedy check plot, respectively. The significantly higher grain, stalk and biological yield of mustard were recorded with 120 kg N ha^{-1} along with weed-free check or 0.75 kg ha^{-1} Pendimethalin PE fb HW at 30 DAS due to better weed management and plant nutrition leading to improved growth, yield attributes and yield with these treatment combinations (Varatharajan *et al.*, 2019a, 2019b; Faiz *et al*., 2022; Bhupenchandra *et al.*, 2022b, 2022c; Gupta *et al.,* 2022).

Economics

In the study, it was found that cost of cultivation, gross and net returns and benefit: cost ratio in mustard varied with different weed and N management practices (Table 9). The highest cost of cultivation (COC) in WMPs was under weed free check (24510 AFN ha^{-1}) followed by W_4, 0.75 kg ha^{-1} Pendimethalin (PE) fb HW at 30 DAS (22290 AFN ha^{-1}), W_3, Pendimethalin 1 kg ha^{-1} PE (21510 AFN ha^{-1}) and weedy-check plot (20890 AFN ha^{-1}). The significantly higher gross and net returns and benefit: cost ratio were recorded with WMPs, weed free check followed by WMPs, 0.75 kg ha^{-1} (PE) Pendimethalin fb hand-weeding at 30 DAS and WMPs, 1.0 kg ha^{-1} (PE) Pendimethalin. Significantly higher net returns were calculated under weed free check (64821 AFN ha^{-1}) followed by W_4, 0.75 kg ha^{-1} Pendimethalin (PE) fb HW at 30 DAS (50972 AFN ha^{-1}) and lowest net returns in weedy check (22124 AFN ha^{-1}). Significantly higher B: C ratio was calculated in weed free check (3.91) followed by W_4, 0.75 kg ha^{-1} Pendimethalin (PE) fb HW at 30 DAS (3.28), W_3, Pendimethalin 1 kg ha^{-1} PE (2.97) and lowest in weedy check plot (1.99). The higher yield due to better weed management is the possible reason for higher gross and net returns among WMPs [0.75kgha^{-1} (PE) Pendimethalin fb hand-weeding at 30 DAS]. Lowest gross and net returns and benefit: cost ratio were recorded in weedy-check plots due to high weed competition (Choudhary *et al*., 2021). A similar type of results has been reported by Chaudhary *et al*. (2011) and Singh *et al*. (2020b). The highest cost of cultivation in NMPs was under 120 kg N ha^{-1} (27600 AFN ha^{-1}) followed by 80 kg N ha^{-1} (24390 AFN ha^{-1}) and 40 kg N ha^{-1} (21180 AFN ha^{-1}). Significantly higher gross returns were fetched with 120 kg N ha^{-1} followed by 80 and 40 kg N ha^{-1}. Among NMPs, the significantly higher net returns were fetched with 120 kg N ha^{-1} (55925 AFN ha^{-1}) followed by 80 kg N ha^{-1} (48996 AFN ha^{-1}) and 40 kg N ha^{-1} (42015 AFN ha^{-1}). The significantly higher B: C ratio was recorded with 120 kg N ha^{-1} (3.51) followed by 80 kg N ha^{-1} (3.20) and 40 kg N ha^{-1} (2.88). The significantly higher gross returns, net returns and benefit: cost ratio were calculated with 120 kg N ha^{-1} due to better plant nutrition leading to improved growth and yield (Choudhary *et al*., 2021).

Conclusion

Based on the experimental results, it is inferred that weed free-check and pre-emergence application of Pendimethalin 0.75 kg ha^{-1} fb hand-weeding at 30 DAS along with 120 kg N ha^{-1} resulted in higher crop growth, productivity and profitability of mustard crop in semi-arid region of Kandahar, Afghanistan. The interaction effects between weed management and N management practices on weed growth, weed indices, yield attributes, yield and economics of mustard were found significant in semi-arid region of Kandahar, Afghanistan. Hence, it can be concluded that pre-emergence application of Pendimethalin 0.75 kg ha^{-1} fb hand-weeding at 30 DAS along with 120 kg N ha^{-1} can be recommended for harnessing higher crop productivity and profitability in mustard crop in semi-arid region of Kandahar, Afghanistan.

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