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Influence of weed management and nitrogen fertilization on weed dynamics, nutrient depletion by weeds, productivity and profitability of barley (*Hordeum vulgare*) in hot semi–arid region of western India

M M PUNIYA[1], S S YADAV[2], D R BAJYA[3] and ARVIND KUMAR[4]

SKN Agricultural University, Jobner, Rajasthan 303 338

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ABSTRACT

Field experimentation was conducted during *rabi* 2012–13 and 2013–14 to assess the performance of weed management practices and nitrogen (N) fertilization on weed dynamics, productivity and profitability of barley (*Hordeum vulgare* L.). Results indicated that hand–weeding at 25 and 50 days after sowing (DAS), and metsulfuron methyl @ 4 g/ha resulted in significant reduction in weed infestation and weed biomass production at different growth stages. The highest weed control efficiency (WCE) was recorded with 2 HWs' at 25 and 50 DAS followed by metsulfuron methyl @ 4 g/ha with lowest NPK depletion by weeds than other treatments. Two HWs' also remained superiormost w.r.t. grain (5.21 tonnes/ha) and straw (7.13 tonnes/ha) yields. Application of metsulfuron methyl also exhibited higher grain yield with minimum weed competition index (8.57%). Among N levels, application of 90 kg N/ha to barley resulted in highest weed count, weed intensity, weed infestation and their dry weight at all the stages as well as higher NPK concentrations in weeds and NPK depletion by weeds at harvest stage. Application of 90 kg N/ha also produced 20.8 and 20.6% more grain and straw yields over control (N_0). Overall, metsulfuron methyl and N application at the rate of 90 kg/ha proved their superiority w.r.t. weed management, productivity and profitability in barley in hot semi–arid region of western India.

Key words*:* Barley, Nitrogen, Nutrient depletion, Productivity, Profitability, Weed management

The major constraints limiting barley (*Hordeum vulgare* L.) production are: cultivation on marginal and sub-marginal lands coupled with inadequate nutrition, moisture stress, raising the crop on saline and alkaline soils with poor quality of irrigation water, and heavy weed infestation with both grassy and broadleaved. The losses caused by weeds have been estimated to be much higher than those caused by insects, pests and diseases together (Fakkar and Amin 2012). Weeds germinate even before its germination and flourish luxuriously taking advantage of its slow initial growth. Weed competition throughout the crop season reduces yield by 10–38% depending upon time and intensity of weed infestation (Balyan and Malik 1994). So, there is need to ascertain the critical period of crop–weed competition and evolve appropriate weed management strategy for both grassy and broadleaf weeds for exploring the yield potential of this crop.

Conventional cultural practices of weed management are time-consuming and labour-intensive, however, the additional benefits of providing greater aeration, improving root growth enabling greater absorption of moisture and nutrients from deeper soil layers and moisture conservation cannot be ignored. The increasing demand of labour due to rapid industrialization and adoption of intensive and multiple cropping systems, sometimes the farmers fail to carry–out the timely agricultural operations, if any. Thus, to combat this situation, exploring the possibility of a suitable broad–spectrum and cost–effective herbicide deserves dire attention. In general, chemical weed management is more cost–effective and easy compared to manual weeding. From plant nutrition view point, nitrogen is a vitally important and is one of the universally deficient plant nutrients in most of Indian soils especially inherited light–textured semi–arid region of Rajasthan. It is an essential constituent of plant proteins and chlorophyll and is present in many other compounds of greater physiological importance in plant metabolism, viz. nucleotides, phospholipids, enzymes, hormones, vitamins etc. It governs to a considerable degree of utilization of carbohydrates, potassium, phosphorous and other elements. In intensive agriculture, adoption of exhaustive high-yielding varieties has led to nutrient mining particularly N, but the fertilizer use remained below than its removal (Choudhary and Suri 2014a). Hence, there is a

[1]Ph D Scholars (e mail: mmpuniya2011@gmail.com), [2]Principal Scientist, Department of Agronomy, SKN Agricultural University, Jobner, Rajasthan 303 338. [3]Scientist, Institute of Pesticide Formulation Technology, Gurgaon 122 016. [4]Present address: Ph D Scholar, Indian Institute of Maize Research, New Delhi 110 012.

need to revisit the N requirement of barley for breaking the barriers to harness higher productivity. Nitrogen–use efficiency can be improved by adopting management practices like effective weed management and minimizing N depletion by weeds, thus, adding to better crop N uptake and consequently higher N–use efficiency. Keeping in view above aspects, current experimentation was conducted to evolve efficient weed management and nitrogen fertilization strategy to minimize the weed infestation with minimal nutrient depletion, better weed control indices with higher productivity and profitability in barley.

MATERIALS AND METHODS

The field experiment was conducted during r*abi* seasons of 2012–13 and 2013–14 at Research Farm of SKN Agricultural University, Jobner (Rajasthan), India [27^0 05' N latitude; 75^0 28' E longitude; 427 m altitude]. The soil of the experimental field was loamy–sand with low organic carbon (0.20%), low in available nitrogen (129.6 kg/ha), medium in available phosphorus (14.1 kg/ha) and potassium (148.8 kg/ha), and slightly alkaline pH (8.3). The experiment was laid–out in split–plot design and replicated thrice. The main–plot treatments comprised seven weed control measures, viz. weedy check (WC); hand–weeding (HW) once at 25 days after sowing (DAS); HW twice at 25 and 50 DAS; 2,4–D ester @ 0.5 kg/ha at 30–35 DAS; metsulfuron methyl @ 4 g/ha at 30–35 DAS; sulfosulfuron @ 25 g/ha at 30–35 DAS; carfentrazone ethyl 15 g/ha at 30–35 DAS and sub–plot treatments comprised four N levels, viz. 0, 30, 60 and 90 kg N/ha. Barley RD–2052 was used as test crop. Post–emergence application of herbicides 2, 4–D ester (Cut–out, 38 EC), metsulfuron–methyl (Metstar, 20 WP), sulfosulfuron (Unik, 75 WP), and carfentrazone ethyl (Affinity, 40 EC) was done as per treatments using knapsack hydraulic sprayer. Sulfonylurea herbicides were applied with their surfactants. In hand–weeding earmarked plots, HW was done at 25 and 50 DAS using *kassi/khurpi*. N was applied through urea as per treatments in two equal splits, i.e. half as basal at the time of sowing and remaining half as top–dress after first irrigation. A uniform dose of 30 kg P_2O_5/ha was drilled through single super phosphate 8–10 cm deep at the time of last ploughing. Bullock drawn desi plough was used for *pora* sowing in rows spaced at 22.5 cm with average depth of 5 cm and seed rate at the rate of 100 kg/ha. All the plant–protection measures were adopted to ensure healthy crop. Total number of weeds were counted species–wise form each plot and analyzed after subjecting the original data to square root transformation ($\sqrt{[X+0.5]}$). Weed samples for drymatter production were taken to assess the effect of various treatments on weed growth. For weed population count, an area of 0.25 m^2 was selected randomly by a metallic quadrate of size 0.25 × 0.25 m at two places at 40 and 80 DAS and at harvest and expressed as No./m^2. For drymatter accumulation, the collected weed samples were first sun–dried and then in oven at 70°C till constant weight. The nutrient analysis (NPK) in weeds was done as per standard methods. 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 effect of different weed control treatments on weed growth. Net returns were calculated based on the grain and straw yield, and the prevailing market prices of barley during the respective crop seasons. Benefit: cost ratio (BCR) was calculated by dividing the net returns from cost of cultivation. All the observations were analyzed statistically for their test of significance of the individual years, and pooled analysis was done over the years.

RESULTS AND DISCUSSION

Weed flora in barley

Results of regular survey during experimentation showed that the crop was infested with a number of broad leaf and grassy weeds (Table 1). Among these, *Chenopodium album* and *Chenopodium murale* were the major dicot weeds that appeared with the emergence of crop. Whereas, *Rumex dentatus, Heliotropium ellipticum, Melilotus alba* and *Spergulla arvensis* were found at later stage of crop growth. *Cyperus rotundus, Phalaris minor* and *Asphodelus tenuifolius* were dominating monocot weed species during both the crop seasons.

Weed dynamics and weed drymatter accumulation

Effect of weed management practices: All the weed management practices (WMP) led to significant reduction in density, weed intensity, weed infestation and their drymatter accumulation (DMA) at all the growth stages of crop in comparison to weedy check. The minimum weed count, weed infestation and DMA at 40, 80 DAS and at harvest was observed with two hand weeding (HW) followed by metsulfuron methyl @ 4 g/ha which controlled the weeds to the extent of 93.7, 91.9 and 90.5% at 40, 80 DAS and at harvest stages, respectively over control. However, it remained at par with one HW at 25 DAS and application of 2,4–D ester at 0.5 kg/ha. The increase in density and DMA of weeds under weedy–check might be attributed to uninterrupted growth of weeds throughout the cropping season (Singh and Singh 2005). One hand weeding done at 25 DAS could retain the crop weed free for shorter period only, and thereafter the population and DMA of weeds increased progressively under this treatment with the advancement of crop growth due to later flushes of weeds, and thus relatively higher density and dry weight was recorded at subsequent growth stages. Contrary to this, another hand weeding done at 50 DAS under twice HW controlled the second flush of weeds as well that emerged at later growth stages and provided the complete weed free environment throughout the season. The luxuriant crop growth was observed in a weed free environment due to hoeing and aeration in rhizosphere during early stages and smothered weed growth altogether with a mean weed dry matter of 169 kg/ha at harvest as against 1 784.4 kg/ha recorded under control plots. These results are in close conformity with the findings of Pisal *et al.* (2009) in wheat.

Table 1 Major weed flora of the experimental fields

Botanical name	Common name	English name	Family name	Growth habit
Chenopodium album L.	Bathua	Lambsquarter	Chenopodiaceae	AD* RS**
Chenopodium murale L.	Khartua	Goosefoot	Chenopodiaceae	AD RS
Asphodelus tenuifolius Cavan	Piazi	Wild onion	Liliaceae	AM RS
Rumex dentatus L.	Jangli palak	Sour dock	Polypogonaceae	AM RS
Melilotus alba L.	Safed senji	Sweet clover	Leguminoceae	AD RS
Spergula arvensis L.	Satgathia/ban-dhania	Corn spurry	Caryophyllaceae	AD RS
Cynodon dactylon L.	Doob grass	Bermuda grass	Poaceae	PM RS and RV**
Anagallis arvensis L.	Krishna neel	Pimpernel	Primulaceae	AD RS
Convolvulus arvensis L.	Hirankhuri	Field bind weed	Convolvulaceae	AD RS and RV
Heliotropium ellipticum	Kamera	Heliotrope	Boraginaceae	AD RS
Launea asplenifolia L.	Jangli gobhi	Wild gobhi	Asteraceae	AM RS
Cyperus rotundus L.	Motha	Purple nut-sedge	Cyperaceae	PM RS and RV
Phalaris minor Retz.	Gulli danda	Little canary grass	Poaceae	AM RS
Verbesina encelioides Gray	Jungli surajmukhi	Golden crown	Asteraceae	AD RS

*AD = , **RS =, ***RV.

Application of herbicides also resulted in significant reduction in weed–count and weed DMA at all the stages as compared to weedy check and other treatments. The magnitude of weed control varied significantly among herbicides. Post–emergence application of metsulfuron methyl recorded the mean weed density of 4.98, 4.3 and 4.5/ 0.25 m^2 and weed dry matter of 23.3, 216.1 and 565.8 kg/ ha at 40, 80 DAS and at harvest, respectively, which were significantly lower than weedy–check. This treatment controlled the weeds to the extent of 92.9, 83.5 and 68.8% at 40, 80 DAS and at harvest stage, respectively in comparison to weedy–check. These results are in agreement with the findings of Hada *et al.* (2008). The extent of weed control achieved with these herbicides, i.e. metsulfuron methyl and 2, 4–D seems to be due to their phytotoxic effects on weeds. Metsulfuron methyl is an effective herbicide to control broadleaf and monocot weeds as post–emergence. This herbicide molecule when present in the plant system, binds with the acetolactase synthase (ALS)/acetohydroxyacid synthase (AHAS) making the enzyme inactive and checks the synthesis of valine, leucine and isoleucine (Stidham 1991). Due to this, phloem transport in plant is hampered (Singh *et al.* 2013a). The mode of action of the sulfonyl ureas is to inhibit the enzyme acetolactate synthase (ALS), a key enzyme in the biosynthesis of branched chained amino acids (Chaleff and Mauvais 1984) or resulting in a decreased biosynthesis of the amino acids like leucine, isoleucine and valine (Gupta 2012). The primary mechanism of action of this group is inhibition of amino acid synthesis and the secondary is inhibition of photosynthetic, respiration and protein synthesis. Metsulfuron provides excellent control of broadleaf weeds. The results obtained in present study are in close agreement with the findings of Hada *et al.* (2008) and Bhatia *et al.* (2012).

Effect of N fertilization: N fertilization level up to 30 kg/ha represented significantly higher weed density at 80 DAS and harvest stage of crop as well as higher weed intensity namely *Chenopodium album* and *Chenopodium murale* at harvest stage than control, though maximum values were obtained at 90 kg/ha. Progressive N increase significantly increased the weed DMA up to 30 kg/ha at 40 DAS, 60 kg/ha at 80 DAS and 90 kg/ha at harvest stage and no significant differences were observed in weed infestation. The increase in density and dry weight of weeds might be attributed to better N availability leading to better nutritional environment for sustained growth and development. In contrast, N is highly mobile in soil and when N fertilizers are applied in soil, especially in the form of top dressing, a part of it also becomes available to weeds. Therefore, where weeds are present alongwith crop, additional N is taken up by weeds with advancing N levels which is directly responsible for higher weed biomass production. Significant variation in weed density may be due to very high degree of competition among weed plants for nutrients especially N to meet their growth requirement. The greater availability of N due to its increasing N addition sustained the growth of large number of rapidly growing weeds that would have otherwise been died under poor fertility levels. This could be assigned as the most crucial reason for lower weed density in control than higher N levels. These results corroborate with the findings of Jat *et al.* (2014).

Nutrient concentrations and depletion by weeds

Effect of weed management practices: The N, P and K concentration in weed drymatter and their depletion was significantly influenced due to WMP treatments (Table 2). All the treatments registered higher N and P concentration in weed drymatter than weedy–check. The weedy–check wherein unrestricted growth of weeds was allowed throughout the growing season, recorded maximum mean depletion of 29.6, 4.77 and 26.4 kg N, P and K/ha, respectively, that was significantly higher than rest of the WMP treatments. Contrary to this, minimum depletion of 3.34, 0.5 and 2.71 kg N, P and K kg/ha was registered under

Table 2 Combined effect of weed management practices and nitrogen levels on weed dry matter production (kg/ha) at different growth stages (pooled mean of two years)

Treatment	Nitrogen levels (kg/ha)											
	40 DAS				80 DAS				At harvest			
	N_0	N_1	N_2	N_3	N_0	N_1	N_2	N_3	N_0	N_1	N_2	N_3
Weed management practices												
W_0 = Weedy check	317.9	333.0	337.1	340.4	1003.2	1376.8	1432.2	1440.5	1369.3	1789.5	1940.9	2037.8
W_1 = One HW at 25 DAS	20.4	21.4	21.7	21.9	168.8	232.0	241.4	242.8	440.5	576.2	625.1	656.3
W_2 = Two HW at 25 and 50 DAS	19.9	20.9	21.1	21.3	80.4	110.4	114.8	115.5	129.6	169.5	183.9	193.1
W_3 = 2,4–D ester @ 0.5 kg/ha (30–35 DAS)	22.5	23.6	23.9	24.1	177.4	243.9	253.8	255.3	466.1	609.5	661.2	694.2
W_4 = Metsulfuron methyl @ 4.0 g/ha (30–35 DAS)	22.3	23.4	23.7	23.9	164.8	226.6	235.8	237.2	433.8	567.5	615.6	646.3
W_5 = Sulfosulfuron @ 25 g/ha (30–35 DAS)	32.4	33.9	34.4	34.7	265.9	365.3	380.0	382.3	723.0	945.4	1025.5	1076.7
W_6 = Carfentrazone ethyl @ 15 g/ha (30–35 DAS)	25.1	26.3	26.7	26.9	192.4	264.4	275.1	276.7	486.9	636.9	690.9	725.4
For N at same level of W												
SEm+				2.3				13.2				30.7
CD (P=0.05)				6.5				37.0				86.2
For W at same or different levels of N												
SEm+				2.5				12.7				28.1
CD (P=0.05)				7.1				35.6				79.1

two HW treatment. Metsulfuron–methyl at 4 g/ha (11 kg N/ha), one HW at 25 DAS (11.1 kg/ha) and 2,4–D ester at 0.5 kg/ha (11.7 kg/ha) were noted to be the next superior and equally effective treatments in reducing nutrient depletion by weeds. These treatments reduced N depletion by 62.9, 62.6 and 60.6%, and P depletion by 65, 65.2 and 64.4% than weedy–check, respectively. The reduction in NPK depletion by weeds under these superior treatments might be assigned to the corresponding reduction in DMA of weeds by effective weed control and smothering effect of crop exerted on weed growth. Greater biomass of weeds accumulated under weedy–check might be attributed as the principal reason of higher nutrients depletion. It can be assigned to the high degree of competition for nutrient absorption among fast growing weeds themselves under infested conditions. On other hand, due to sparse weed population in other treatments, nutrient concentration in their drymatter was found to be more or less similar but more than weedy–check (Bhatia *et al.* 2012).

Effect of nitrogen fertilization: Gradual increase in N levels from 0 to 30 kg/ha significantly increased the N and P concentration in weeds, whereas, significant increase in NPK depletion by weeds at harvest stage was registered upto 90 kg N/ha (Table 2). Application of 90 kg/ha N was increased 69.4, 66.4 and 49.8% of N, P and K depletion over control. As nitrogen plays a vital role in growth and development of every plant, the increased soil N availability due to its external application which was otherwise deficient in its status led to more and more N absorption by fast growing weeds to meet their growth requirement in comparison to the plots that were poorly N fertilized. It seems to be the principal reason of greater N concentration in weeds at harvest stage. Increase in P concentration appears to be directly associated with synergistic effect of N. NPK depletion by weeds in response to applied–N followed the trend of its effect on DMA by weeds. The huge weed biomass accumulated under 90 kg N/ha with a concomitant increase in its nutrient concentration appeared to be directly responsible for higher NPK depletion by the weeds.

Weed control efficiency (WCE) and weed competition index (WCI)

Effect of weed management practices: Weed control efficiency (WCE) at harvest and weed competition index (WCI) ranged between 46.9 to 90.5, and 8.58 to 38.6% (Table 3). The highest WCE of 93.7, 91.9 and 90.5% were observed at 40, 80 DAS and at harvest stage with two HW at 25 and 50 DAS. One HW at 25 DAS controlled the weeds to the extent of 93.5, 83.1 and 67.6% at 40, 80 DAS and harvest stages. Application of metsulfuron–methyl also controlled the weeds to the extent of 92.9, 83.5 and 68.1% at 40, 80 DAS and at harvest stages than control plots and found to be most superior herbicidal treatment. The variation in WCE is directly associated with the amount of weed DMA under different treatments. Removing two initial flushes of weeds by two HW at 25 and 50 DAS reduced the weed growth effectively for most of the crop period. While one HW at 25 DAS or using herbicides alone, controlled the weeds less effectively and resulted in quite higher weed DMA than above described treatments, though, it remained significantly lower than weedy–check. Metsulfuron methyl emerged out for broad leaf weeds, sulfosulfuron for annual

Table 3 Influence of weed management practices and nitrogen levels on nutrient concentration and depletion in weed dry matter at crop harvesting stage, weed competition index (WCI) and weed control efficiency (WCE) (pooled mean of two years)

Treatment	Nutrient concentration (%)			Nutrient depletion (kg/ha)			Weed competition index	Weed control efficiency (%)		
	N	P	K	N	P	K		40 DAS	80 DAS	At harvest
Weed management practices										
W_0=Weedy check	1.65	0.27	1.48	29.6	4.8	26.4	38.6			
W_1=One HW at 25 DAS	1.92	0.29	1.59	11.1	1.7	9.1	10.7	93.6	83.1	67.6
W_2=Two HW at 25 & 50 DAS	1.96	0.30	1.60	3.3	0.5	2.7		93.7	92.0	90.5
W_3=2,4–D ester @ 0.5 kg/ha (30–35 DAS)	1.91	0.28	1.55	11.7	1.7	9.4	13.8	92.9	82.2	65.7
W_4=Metsulfuron methyl @ 4.0 g/ha (30–35 DAS)	1.93	0.29	1.60	11.0	1.7	9.0	8.6	93.0	83.5	68.1
W_5=Sulfosulfuron @ 25 g/ha (30–35 DAS)	1.77	0.27	1.52	16.8	2.5	14.4	22.3	89.8	73.4	47.0
W_6=Carfentrazone ethyl @ 15 g/ha (30–35 DAS)	1.89	0.27	1.55	12.1	1.7	9.8	27.0	92.1	80.7	64.2
SEm±	0.03	0.01	0.03	0.25	0.04	0.26		1.66	1.66	1.66
CD (P=0.05)	0.08	0.02	0.08	0.74	0.10	0.77		4.83	4.83	4.83
Nitrogen levels (kg/ha)										
0	1.72	0.263	1.55	9.62	1.49	8.83		92.5	82.5	67.2
30	1.83	0.280	1.56	13.39	2.07	11.58		92.5	82.5	67.2
60	1.93	0.284	1.56	15.33	2.28	12.58		92.5	82.5	67.2
90	1.96	0.294	1.56	16.30	2.48	13.23		92.5	82.5	67.2
SEm±	0.02	0.004	0.02	0.20	0.03	0.20		1.49	1.49	1.49
CD (P=0.05)	0.07	0.011	NS	0.56	0.08	0.56		NS	NS	NS

grassy weeds and carfentrazone–ethyl as broad spectrum during this experiment. It seems to be the most spectacular reason for wide variation in WCE (Bhatia *et al.* 2012). The WCI also declined due to weed control treatments in comparison to weedy–check. Metsulfuron–methyl recorded lowest mean WCI of 8.57%, as against the maximum of 38.6% observed under weedy–check. One HW at 25 DAS and 2, 4–D ester at 0.5 kg/ha were found the next superior treatments that represented WCI of 10.7 and 13.8%. Use of sulfosulfuron at 25 g/ha (22.3%) and carfentrazone ethyl alone (27%) were found comparatively lesser effective in reducing the grain yield losses due to weeds. The higher weed DMA and nutrient depletion by weeds and corresponding reduction in grain yield is directly associated with variation in WCI among different WMP treatment (Pisal *et al.* 2009).

Barley productivity

Effect of weed management practices: The WMP significantly influenced the barley grain and straw yields. The variation in these treatments w.r.t. above parameter appears to be directly associated with the similar variation in weed control and growth parameters of barley. Two HW at 25 and 50 DAS resulted in highest grain (5.21 tonnes/ha) and straw (7.13 tonnes/ha) yields. Because of differential competitive ability of various weed species found in experimental field, it has been further established that for similar weed densities, a composite stand of weed species is always more competitive than solid stand of a single weed species. Two HW provided long–time weed control, and hence resulted in appreciably higher yields over to un–weeded plots. Post–emergence application of metsulfuron–methyl, one HW at 25 DAS and 2, 4–D ester, were the next superior and equally effective WMP for enhancing barley yields. They also improved the grain yield by margin of 49.1, 45.5 and 40.5% over weedy-check. Corresponding increase in straw yield was 42.3, 42 and 35.3%. Higher grain and straw yields obtained under superior treatments could be better explained on the basis of their effectiveness in weed control compared to control. These treatments kept the crop almost weed free during 40–70 DAS that markedly reduced the competition for nutrients and other resources by weeds as a consequence of which reduction in DMA and nutrient depletion by weeds occurred. Similar findings were also reported by Surin *et al.* (2013) in wheat and Kumar *et al.* (2010) in barley. The considerably higher grain yield obtained under twice HW and metsulfuron methyl treatments was obviously due to cumulative effect of lowest weed–crop competition and higher growth and yield determining characters. On the other hand, relatively poor yield attributes and yield recorded under inferior treatments like sulfosulfuron might be attributed to poor crop growth owing to insufficient weed control that could not reduce weed–crop competition to the tune as achieved under above mentioned superior treatments. Furthermore, most severe competition throughout the crop season due to unrestricted

Table 4 Combined effect of weed management practices and nitrogen levels on nutrient depletion (kg/ha) by weeds at harvest stage (pooled mean of two years)

Treatment	Nitrogen levels (kg/ha)											
	Nutrient depletion (kg/ha)											
	N				P				K			
	N_0	N_1	N_2	N_3	N_0	N_1	N_2	N_3	N_0	N_1	N_2	N_3
Weed management practices												
W_0=Weedy check	20.9	29.1	33.3	35.3	3.4	4.8	5.2	5.7	20.2	26.5	28.8	30.2
W_1=One HW at 25 DAS	7.8	10.9	12.5	13.3	1.2	1.7	1.8	2.0	7.0	9.2	9.9	10.5
W_2=Two HW at 25 and 50 DAS	2.4	3.3	3.7	4.0	0.4	0.5	0.6	0.6	2.1	2.7	3.0	3.1
W_3=2,4–D ester @ 0.5 kg/ha (30–35 DAS)	8.2	11.5	13.1	13.9	1.2	1.7	1.9	2.0	7.2	9.5	10.3	10.8
W_4=Metsulfuron methyl @ 4.0 g/ha (30–35 DAS)	7.7	10.8	12.3	13.1	1.2	1.7	1.8	2.0	6.9	9.1	9.8	10.3
W_5=Sulfosulfuron @ 25 g/ha (30–35 DAS)	11.8	16.5	18.8	20.0	1.8	2.5	2.8	3.0	11.0	14.4	15.6	16.4
W_6=Carfentrazone ethyl @ 15 g/ha (30–35 DAS)	8.5	11.9	13.6	14.4	1.3	1.7	1.9	2.1	7.5	9.8	10.7	11.2
For N at same level of W												
SEm±				0.52				0.07				0.52
CD (P=0.05)				1.48				0.21				1.47
For W at same or different levels of N												
SEm±				0.48				0.07				0.49
CD (P=0.05)				1.35				0.19				1.37

weed growth under weedy-check plots increased the nutrient and moisture removal by weeds, thereby, adversely affecting crop growth. It also reduced the translocation of photosynthates towards seed formation having adverse effect on yield attributes which in turn reduced the yield to minimum level. These results are strongly supported by the finding of Singh and Singh (2005); Pisal and Sagarka (2013) and Singh *et al.* (2013).

Effect of nitrogen fertilization: The grain and straw yield of barley increased with increasing N levels up to 60 kg/ha. As, grain yield is primarily a function of cumulative effect of yield attributing characters, the higher values of these attributes can be assigned as the most probable reason for significantly higher grain yield (Choudhary and Suri 2014a, b). It is well evidenced from positive correlation between crop dry matter and nutrient uptake by the crop. These improvements suggest greater availability of metabolites and nutrients synchronized for growth and development of each reproductive structure. The N and P fertilization plays a vital role in improving major aspects of yield determination, i.e. formation of vegetative structure for nutrient absorption, photosynthesis and strong sink strength through development of reproductive structure and production of assimilates to fill economically improved sink and source strength (Choudhary and Suri 2014a, b). Sharma and Verma (2010) have documented significant positive influence of nitrogen application on yield attributes and yield of barley crop. Straw yield was also recoded higher with increasing N application. It might be due to improved biomass/plant at successive growth stages and increase in various morphological parameters like plant height, number of tillers etc.

Barley profitability

Effect of weed management practices: All the WMP fetched significantly higher net returns over weedy-check which might be due to higher grain yield registered under these treatments. Two HW fetched maximum net returns (₹ 73 678/ha), thus, increasing the net returns by ₹ 32 454/ha over weedy check. Metsulfuron methyl proved as next superior treatment w.r.t. net returns (₹ 68 846/ha. However, it remained at par with one HW at 25 DAS (₹ 65 665/ha). Sulfosulfuron and carfentrazone-ethyl applied plots had net returns of ₹ 55 114 and 51952/ha with about 33.7 and 26% higher over weedy-check, respectively. It might be due to cost-effective herbicides against labor-intensive hand-weeding operation which led to higher cultivation cost and lowering the yield benefits occurred in these plots. Similar findings were also reported by Pandey *et al.* (2006) and Verma *et al.* (2008).

Effect of N fertilization: Increase in N level from 0 to 90 kg/ha also fetched additional returns (₹ 15 426/ha) over control, primarily due to higher grain yield with comparatively lesser additional cost of N. Significant improvement in yield attributes and yield due to N application has also been reported by Katiyar and Uttam (2007) in barley and Choudhary and Suri (2014a) in wheat. From economic point of view, application of metsulfuron methyl in conjunction with 90 or 60 kg N/ha was proved as best treatment combination to achieve higher profitability in barley.

This study conclusively indicated that two hand–weedings at 25 and 50 DAS, and metsulfuron methyl @ 4 g/ha resulted in significant reduction in weed infestation and weed biomass production at different growth stages of barley. Similarly, highest weed control efficiency was recorded with 2 HWs' at 25 and 50 DAS followed by metsulfuron methyl with lowest NPK depletion by weeds than other treatments. Two HWs' also remained superiormost w.r.t. barley grain and straw yield. Metsulfuron methyl also exhibited higher grain yield with minimum weed competition index. Among N levels, 90 kg N/ha to barley resulted in highest weed count, weed intensity, weed infestation and their dry weight at all the stages as well as NPK concentrations in weeds and NPK depletion at harvest stage producing 20.8 and 20.6% more grain and straw yield over control (N_0). Overall, application of metsulfuron methyl and 90 kg N/ha proved their superiority w.r.t. weed management, wheat productivity and profitability in hot semi–arid region of western India.

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