Indian Journal of Agronomy **60** (4): 564–569 (December 2015)

Research Paper

Productivity, profitability and nitrogen-use efficiency of barley *(Hordeum vulgare)* as influenced by weed management and nitrogen fertilization under hot semi-arid ecologies of Rajasthan

M.M. PUNIYA[1], S.S. YADAV[2] AND A.C. SHIVRAN[3]

Sri Karan Narendra Agriculture University, Jobner, Rajasthan 303 329

Received : June 2015; Revised accepted : December 2015

ABSTRACT

A field experiment was conducted during winter (*rabi*) 2012–13 and 2013–14 at research farm, Jobner, Rajasthan, to evaluate the effect of weed-management practices and nitrogen fertilization on productivity, profitability and N-use efficiency of barley (*Hordeum vulgare* L.). The results indicate that plots under twice hand-weeding (HW) 25 and 50 days after sowing (DAS) had the highest growth and yield attributes followed by metsulfuron methyl 4.0 g/ha applied at 30–35 days after sowing (DAS). Among weed-management practices, the highest grain and straw yields (5.21 t/ha; 7.13 t/ha) were obtained with 2 HWs and metsulfuron methyl (4.76 t/ha; 6.40 t/ha) treatments (pooled data 2 years). The highest net returns were also obtained with 2 HWs, and the increment to the tune of 7.0, 12.2 and 15.5% over metsulfuron methyl, 1 HW and 2,4-D ester (0.5 kg/ha) respectively. Nitrogen 90 kg/ha significantly improved the yield attributes and yields over the control and 30 kg N/ha; however, it remained statistically at par with 60 kg N/ha. Metsulfuron methyl along with 90 kg N/ha was found to be best for benefit: cost ratio (4.37), followed by 2,4-D ester (E) (4.09) over the HWs treatments. Two HWs proved the best for agronomic efficiency (AE) and apparent recovery (RE) of applied N (16.2 kg grain/kg N; 69.1%). Physiological-use efficiency (PE) of applied N was the highest in plots under carfentrazone-ethyl 15 g/ha at 30–35 DAS and 30 kg N/ha.

Key words : Barley, Carfentrazone ethyl, Hand-weeding, Metsulfuron methyl, N fertilization, N- use efficiencies, Productivity, Profitability

Barley is generally grown on marginal and sub-marginal lands with low-inputs where the conditions for wheat and other cereals are not favourable. In Rajasthan, it is mostly grown on light-textured soils which have low nitrogen and organic matter content with poor moisture-retentive capacity. Thus, the easiest way of boosting the productivity and N-use-efficiency is through application of balanced fertilization following proper weed-management practices. Cultivation in poor fertility soils coupled with inadequate nutrition, moisture stress, saline and alkaline conditions with poor quality of irrigation water and heavy infestation with weeds are the major constraints in barley production. Barely crop is invaded with large number of fast-growing weeds species and 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 the crop germination and flourish more and taking the advantage of its slow initial growth. Weed competition in the cropping season reduces yield up to 10–38% depending on time and intensity of infestation (Balyan and Malik, 1994). Therefore, it is greatly needed to evolve appropriate weed-management strategy either through mechanical or herbicidal control for both grassy and broad-leaf weeds to harness the maximum yield even under unfavourable climatic conditions.

The chemical control of weeds in general has been realised to be more cost effective and easy compared to manual weeding (Garcia-Martin *et al.*, 2007). Yaduraju and Das (2002) suggested that chemical herbicides play an important role for weed control in close-spaced crops like wheat, barley where manual or mechanical weeding is difficult. For controlling of broad-leaf weeds, 2,4-D is recommended after the first irrigation, but no herbicide is available for control of grassy weeds in this crop. Sulfonylurea

Based on a part of Ph.D. thesis of the first author, submitted to Sri Karan Narendra Agriculture University, Jobner, Rajasthan 303 329, in 2015 (unpublished)

[1]**Corresponding author Email:** mmpuniya2011@gmail.com
[1]Ph.D. Scholar; [2,3]Professor, Department of Agronomy, Sri Karan Narendra Agriculture University, Jobner, Rajasthan 303 329

herbicides are being considered as the substitute for existing herbicides because of their ability to control grassy as well as broad-leaf weeds, high potency and low dose requirement (Vicari *et al.*, 1994). The newly emerged herbicides of sulfonylurea group, i.e. metsulfuron-methyl and sulfosulfuron are of great importance, as they provide excellent control of weeds in wheat by inhibiting acetolactate synthase mechanism. Similarly, carfentrazone-ethyl is also a contact herbicide used to control broad-leaf and sedges in cereals and it is recommended for edible and non-edible crops including barley.

Nitrogen is a vitally important and is one of the universally deficient plant nutrients in most of the Indian soils particularly in the loamy sands of semi-arid agro-ecologies of Rajasthan. There is an urgent need to give a fresh look to nutrient requirement, especially of N for breaking the barrier in higher productivity of this crop. In intensive agriculture, adoption of exhaustive high-yielding varieties led to accumulation of nutrients, especially N but fertilizer use remained below than its removal. Nitrogen-use-efficiency can be improved by adopting the management practices like effective weed control that will minimize the N losses which leads to greater uptake of available N and consequently higher N-use-efficiency. However, till date no scientific studies and their documentation have been made in barley in respect of weed control and N fertilization. Thus, optimum quantity of nutrients and proper weed management is of paramount importance to enhance the productivity and use-efficiencies of N in barley.

MATERIALS AND METHODS

The field experiment was conducted during the winter (*rabi*) 2012–13 and 2013–14 at Jobner, Rajasthan (27˚05'N; 75˚28' E, of 427 above mean sea-level). The soil was loamy-sand having low organic carbon (0.20%) and available N (129.6 kg/ha), medium in available P (14.1 kg/ha) and K (148.8 kg/ha) and slightly alkaline (pH 8.25). The experiment was laid out in a split-plot design with 3 replications. The mainplot comprised 7 weed-control treatments, viz. (weedy check; HW once at 25 DAS; HW twice at 25 and 50 DAS; 2,4-D ester 0.5 kg/ha at 30–35 DAS; metsulfuron-methyl 4.0 g/ha at 30–35 DAS; sulfosulfuron 25 g/ha at 30–35 DAS; carfentrazone-ethyl 15 g/ha at 30–35 DAS); and 3 N levels (0, 30, 60 and 90 kg/ha) were taken as subplots. Barley cultivar 'RD 2052' was grown following all standard package and practices. Five irrigations were applied to the crop including irrigation at critical growth stages. Rainfall received during the crop period was 21.2 mm and 19.0 mm in 2012–13 and 2013–14 respectively. 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 at 30–35 DAS as per treatments. A knapsack hydraulic sprayer was used for spraying the herbicides using a spray volume of 700 litres/ha. Sulfonylurea herbicides were applied with their surfactants. In the plots ear marked for hand-weeding, the operation was done at 25 and 50 DAS with the help of *khurpi* as per treatment. Nitrogen was applied through urea as per treatments in 2 equal – splits, i.e. half as basal at the time of sowing and remaining as top-dressing at the time of first irrigation. All the plant-protection measures were adopted to ensure healthy crop. At maturity, after leaving the 2 border rows on each side as well as 50 cm along the width of each side, a net plot area of 3 m × 1.35 m was harvested separately for recording the yield attributes and yields. The harvested material of each plot was tied up in bundles, tagged and kept on threshing floor for sun drying. Barley grains were cleaned by winnower and yield was recorded at 15% moisture content. Straw yield was obtained by subtracting grain yield from the total biomass yield. Yields were expressed in t/ha. The harvest index was calculate by dividing the economic yield by biological yield and expressed in percentage. 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 was calculated by dividing the returns from cost of cultivation. Nitrogen concentration in barley grain and straw samples were determined by modified Kjeldahl method. The uptake/ accumulation of nitrogen in barley grain and straw was calculated by multiplying the dry matter yield with their concentrations. Agronomic efficiency (AE), recovery efficiency (RE) and physiological efficiency (PE) of applied N were computed using the standard formula.

All the observations were analyzed statistically for their test of significance of the individual years, and pooled analysis was done over the years using the F -test (Gomez and Gomez, 1984). The significance of difference between treatment means were compared with critical differences at 5% level of probability.

RESULTS AND DISCUSSION

Weed management

Growth parameters: Different weed-control treatments significantly influenced plant height, effective tillers, dry-matter accumulation (DMA), spike length and grains/ spike of barley. Weed-control treatments, i.e. hand-weedings and herbicides application significantly enhanced growth and yield characteristics at most of the stages compared to the weedy check (Table 1). Two HWs at 25 and 50 DAS recorded the maximum plant height at all the stages with 28.4% taller plant than weedy check at harvesting stage. The same treatment also showed significantly highest DMA at harvesting. Application of metsulfuron methyl 4 g/ha, 1 HW at 25 DAS and 2,4-D ester 0.5 kg/ha registered higher DMA by 41.8, 39.0 and 34.4% at 40 DAS; 46.5, 45.8 and 43.9% at 80 DAS; and 47.4, 46.4 and 44.5% at harvesting stage, respectively, than the control. The corresponding increase was also observed in effective tillers and grains/spike. The improvement in growth characters through weed control could mainly be ascribed to the reduced density and dry weight of weeds and thus, resulted in the least competition for space, moisture, nutrients, light etc. The weed-free environment reduced the crop–weed competition to the extent of their efficacy which led to enhance plant height, tillering and DMA. On contrary to this, uncontrolled weed growth throughout the cropping season in weedy check plots arrested the crop growth due to severe crop-weed competition. Significantly the highest 1,000-seed weight was also observed with 2 HWs and metsulfuron methyl and 1 HW treatments. Meena and Singh (2011) reported significant improvement in growth attributes by 2 HWs and metsulfuron methyl in wheat. One HW and 2,4-D significantly enhanced growth attributes of wheat (Pandey *et al.*, 2006; Chaudhary *et al.,* 2013). Since hand-weeding provided weed-free environment to crop, excellent growth was observed under twice HW treatments in comparison to herbicides alone. Nadeem *et al.* (2007) reported effective weed control in wheat with 2 HWs in comparison to chemical treatments alone. Although carfentrazone ethyl 15 g/ha also resulted in significantly higher values of growth parameters of crop than weedy check, it proved lesser effective than metsulfuron methyl and 2,4-D. Carfentrazone and sulfosulfuron applications showed some phytotoxic effects on crop plants during early growth stages. At later stages, the crop recovered growth up to satisfactorily level but could not as observed in HW and other herbicidal treatments despite of excellent weed control in these plots, which was also documented by Singh and Punia (2007). Poor growth of crop obtained with sulfosulfuron 15 g/ha was owing to insufficient control of weeds.

Productivity: All the weed-control treatments differed in influencing grain and straw yields of barley. Two HW done at 25 and 50 DAS resulted in the highest grain and straw yields of barley and found to be significantly superior to all the treatments except metsulfuron methyl. Two HW treatments provided the season-long weed-free conditions and hence resulted in appreciably higher yields than the other treatments. Post-emergence application of metsulfuron methyl, 1 HW at 25 DAS and 2, 4-D ester were the next superior treatments with respect to barley yields, as they improved the grain and straw yields to the tune of 49.1, 45.5, 40.5% and 42.3, 42.0, 35.3% over the weedy check. Application of sulfosulfuron and carfentrazone ethyl also gave 26.6 and 19.0% and 22.4 and 18.7% higher grain and straw yield over the weedy check (Fig. 1). The higher yields under weed control could

Table 1. Effect of weed management and nitrogen fertilization on growth and yield parameters of barley at different stages (pooled data of 2 years)

Treatment	Plant height (cm) at harvesting	DMA (g/m row length) at harvesting	Effective tillers/plant at harvesting	Spike length (cm)	Grains/ spike	1,000-seed weight (g)
Weed management						
Weedy check	92.9	227.5	5.38	6.61	34.5	38.0
One HW at 25 DAS	111.1	333.0	6.79	9.03	42.5	40.9
Two HW at 25 and 50 DAS	119.3	366.2	7.59	9.59	45.9	42.6
2,4-D ester 0.5 kg/ha (30–35 DAS)	110.8	328.7	6.73	8.73	42.2	39.8
Metsulfuron methyl 4.0 g/ha (30–35 DAS)	111.6	335.4	6.95	9.19	42.6	41.8
Sulfosulfuron 25 g/ha (30–35 DAS)	103.0	296.8	6.02	7.79	38.8	38.6
Carfentrazone ethyl 15 g/ha (30–35 DAS)	101.4	288.3	5.95	7.56	38.6	38.3
SEm±	1.89	6.15	0.13	0.17	0.80	0.66
CD (P=0.05)	5.52	17.9	0.39	0.51	2.33	1.93
Nitrogen (kg/ha)						
0	98.4	268.4	5.55	7.22	36.0	37.6
30	106.2	306.8	6.36	8.18	39.9	39.6
60	111.2	330.8	6.97	8.93	43.1	41.3
90	112.8	337.3	7.07	9.11	44.1	41.5
SEm±	1.34	4.52	0.10	0.12	0.57	0.49
CD (P=0.05)	3.76	12.6	0.29	0.35	1.59	1.36

be explained with their effectiveness to reduce density of weeds over weedy check. These treatments kept the crop almost weed free up to 60 days that markedly reduced the competition for nutrients and other resources by weeds which ultimately reduce weed dry-matter production and nutrient depletion. Reduction in weed-crop competition under weed control treatments saved a considerable amount of nutrients for crop growth which led to enhanced crop growth by utilizing greater moisture and nutrients from deeper soil layers. Under weed-infested condition, although the vegetative growth reached at satisfactorily level, the sink was not sufficient enough to accumulate the meaningful photosynthates translocating towards grain formation. Nadeem *et al.* (2007) and Surin *et al.* (2013) also reported similar findings. The higher grain yield under twice HW and metsulfuron methyl plots was due to cumulative effect of lowest crop weed competition and more yield determining characteristics. While in sulfosulfuron-applied plots, it might be attributed to poor crop-growth due to insufficient weed control that could have not reduced the crop-weed competition to the tune as under 2 superior treatments (hand-weeding and metsulfuron methyl). Furthermore, the most severe competition throughout the cropping season due to unrestricted weed growth in weedy check plots led to enhanced nutrient removal and moisture by weeds; thereby, adversely affecting the crop growth. Our results support the findings of Singh and Singh (2005), Pisal and Sagarka (2013) in wheat.

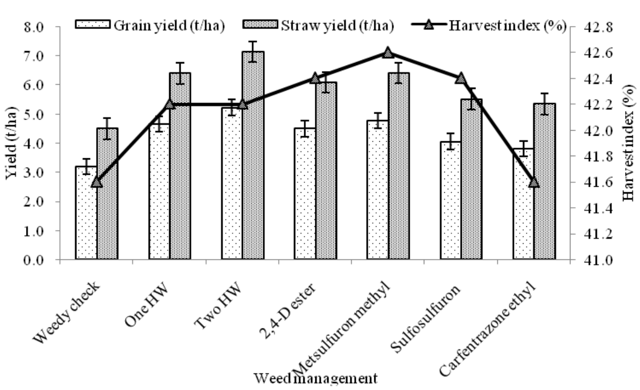

Fig. 1. Yield and harvest index of barley as influenced by weed-control treatments. The vertical bars indicate CD at $P = 0.05$

Profitability and N use-efficiency: All the weed control treatments fetched significantly higher net returns and benefit: cost ratio over weedy check which might be due to higher grain yield registered under these treatments (Table 2). Two HWs fetched the maximum net returns and benefit: cost ratio, thus increasing the net returns over the weedy check. Application of metsulfuron methyl proved as next superior treatment for net returns and benefit: cost ratio. However, it remained at par with 1 HW at 25 DAS. Sulfosulfuron and carfentrazone ethyl treatments had net returns 33.7 and 26% higher over the weedy check respectively. The highest benefit: cost ratio was exhibited by metsulfuron methyl than hand-weeding treatments. It might be due to labour intensive hand-weeding operation which led to higher cultivation cost and lowering the ben-

Table 2. Profitability and nitrogen-use-efficiencies as influenced by weed management and nitrogen fertilization (pooled data of 2 years)

Treatment	Net returns (×10^3 ₹/ha)	Benefit: cost ratio	Agronomic efficiency (kg grain/kg N)	Recovery efficiency (%)	Physiological efficiency (kg grain/kg N uptake)
Weed management					
Weedy check	41.2	3.09	9.96	35.6	26.7
One HW at 25 DAS	65.7	3.96	14.5	60.9	28.0
Two HW at 25 and 50 DAS	73.7	3.99	16.2	69.1	26.6
2,4-D ester 0.5 kg/ha (30–35 DAS)	63.8	4.09	14.0	58.2	27.1
Metsulfuron methyl 4.0 g/ha (30–35 DAS)	68.8	4.37	14.8	62.5	29.0
Sulfosulfuron 25 g/ha (30–35 DAS)	55.1	3.62	12.6	48.8	27.0
Carfentrazone ethyl 15 g/ha (30–35 DAS)	51.9	3.54	11.8	45.7	44.8
SEm±	1.15	0.08	0.37	1.63	0.49
CD (P=0.05)	3.34	0.23	1.07	4.75	1.44
Nitrogen (kg/ha)					
0	50.4	3.43	-	-	-
30	59.4	3.81	18.0	66.4	32.3
60	64.4	3.99	13.1	55.1	29.2
90	65.8	4.01	9.08	41.7	28.1
SEm±	0.89	0.05	0.30	1.32	0.41
CD (P=0.05)	2.52	0.14	0.85	3.70	1.16

efits occurred in these plots. Similar findings were also reported by Pandey *et al.* (2006), Mishra (2006) and Verma *et al.* (2008). The highest AE and RE efficiencies were reported with 2 HW plots, followed by metsulfuron methyl. The AE of applied N varied from 9.96 to 18 kg/kg of N and RE values for N were about 35.6–69.1% being quite closer to the values reported by Pooniya and Shivay (2010) in cereals. The main reason of low N use-efficiency is N loss mechanism, especially leaching in loamy sand soils. The AE and RE declined with the increase in N application rate increased from 30 to 90 kg N/ha. On other hand, PE of N in barley was ranged of 26.6–44.8 kg grain/kg of N uptake in both weed control and N-fertilized plots. Thus, 30 kg N/ha registered significantly highest values of PEn compared to 60 or 90 kg N/ha application.

Nitrogen fertilization

Growth parameters: The results revealed that barley crop responded well to N fertilization in terms of growth and yield attributes (Table 1). Significant response in these parameters was obtained up to 60 kg N/ha at all the stages except plant height at 40 DAS, wherein it was noted up to 30 kg N/ha only. It can be ascribed to the better nutritional rhizospheric environment for growth and development of crop. Our findings confirm the results of Kumawat and Jat (2005) in barley and Jat *et al.* (2014) in wheat. A strong positive correlation was observed between grain yield and growth and yield-attributing characters of barley crop (Table 3).

Productivity and profitability: The barley yield also increased significantly with every increment of N up to 60 kg/ha, being highest yield at 90 kg/ha (Fig. 2). 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. It is well evinced from the positive correlation between crop DMA and nutrient uptake by the crop. Sharma and Verma (2010) also reported signifi-

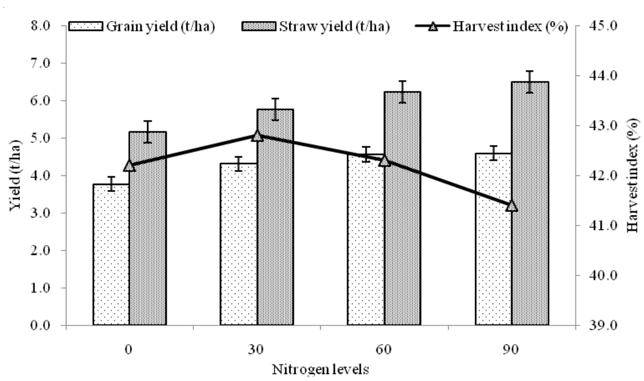

Fig. 2. Effect of nitrogen levels (kg/ha) on yield and harvest index of barley. The vertical bars indicate CD at P=0.05

Table 3. Correlation coefficients (r) and regression equations for the relationship between grain yield (Y) and growth and yield-attributing characters (x)

Treatment	2012–13		2013–14		Pooled	
	Correlation coefficient (r)	Regression equation $Y = a + b_y \times X$	Correlation coefficient (r)	Regression equation $Y = a + b_y \times X$	Correlation coefficient (r)	Regression equation $Y = a + b_y \times X$
DMA at harvesting (kg/ha)	0.984**	$Y = -2.990 + 0.147\ X_4$	0.983**	$Y = -2.990 + 0.147\ X_5$	0.985**	$Y = -0.432 + 0.140\ X_5$
Effective tillers/plant	0.968**	$Y = -3.499 + 7.289\ X_6$	0.952**	$Y = -3.499 + 7.289\ X_6$	0.962**	$Y = -4.758 + 7.383\ X_6$
Grains/spike	0.962**	$Y = -14.397 + 1.373\ X_7$	0.984**	$Y = -14.397 + 1.373\ X_7$	0.954**	$Y = -15.572 + 1.440\ X_7$
Spike length (cm)	0.982**	$Y = -2.076 + 5.249\ X_8$	0.974**	$Y = -2.076 + 5.249\ X_8$	0.978**	$Y = -5.393 + 5.955\ X_8$
1,000-seed weight (g)	0.931**	$Y = -61.526 + 2.587\ X_9$	0.904**	$Y = -61.526 + 2.587\ X_9$	0.920**	$Y = -79.790 + 3.100\ X_9$

** P=0.01

cant positive influence of nitrogen application on yield attributes and yield of barley crop. Straw yield was also recoded higher with increasing rates of N application. It might be due to improved biomass per plant at successive growth stages and increase in various morphological parameters like plant height, number of tillers etc. Increase in N level from 0 to 90 kg/ha in barley also fetched additional returns with a higher benefit: cost ratio over the control (Table 2), primarily owing to higher grain yield with comparatively lesser additional cost of N. Significant improvement in yield attributes and yield owing to N application was also reported by Katiyar and Uttam (2007) in barley.

Thus, 2 hand-weedings at 25 and 50 DAS and application of 90 kg N/ha increased the yield attributes, productivity and N-use-efficiency of barley as compared to rest of the treatments. From economic point of view, application of metsulfuron methyl @ 4 g/ha in conjunction with 90 or 60 kg N/ha proved best treatment combination in achieving higher profitability in barley under hot semi-arid climate of Rajasthan.

REFERENCES

Balyan, R.S. and Malik, R.K. 1994. Chemical weed control studies in barley (*Hordeum vulgare* L.*). Indian Journal of Weed Science* **26**: 1–5.

Chaudhary, G., Sharma, J.D. and Yadav, A.S. 2013. Productivity and economics of late-sown wheat under different sowing methods and weed management practices. *Indian Journal of Weed Science* **45**(4): 294–95.

Fakkar, A.A.O. and Amin, I.A. 2012. Integration between sowing methods, mechanical weed control and their effect on wheat productivity. *Australian Journal of Basic and Applied Science* **6**: 519–29.

Garcia-Martin, A., Lopez-Bellido, R. and Coleto, J. 2007. Fertilization and weed control effects on yield and weeds in durum wheat grown under rainfed conditions in a Mediterranean climate. *Weed Research* **47**: 140–48.

Gomez, K.A., and Gomez, A.A., 1984. *Statistical Procedures for Agricultural Research,* edn 2. An International Rice Research Institute Book. Wiley-Inter-Science Publication, John Wiley & Sons, New York.

Jat, S.L., Nepalia, V. Choudhary, J. and Singh, D. 2014. Effect of nitrogen and weed management on productivity and quality of durum wheat (*Triticum durum*). *Indian Journal of Agronomy* **59**(2): 281–85.

Katiyar, A.K. and Uttam, S.K. 2007. Effect of fertility levels and weed control measures on growth, yield attributes and yield of barley (*Hordeum vulgare* L.) under rainfed condition. *Bhartiya Krishi Anusandhan Patrika* **22**: 324–26.

Kumawat, P.D. and Jat, N.L. 2005. Effect of organic manure and nitrogen fertilization on productivity of barley (*Hordeum vulgare*). *Indian Journal of Agronomy* **50**(3): 200–02.

Meena, R.S. and Singh, M.K. 2011. Weed management in late sown zero-till wheat (*Triticum aestivum*) with varying seed rate. *Indian Journal of Agronomy* **56**(2): 127–32.

Mishra, J.S. 2006. Efficacy of herbicides in wheat (*Triticum aestivum*) with special reference to wild oat (*Avena sterillis ludoviciana*) in vertisols. *Indian Journal of Agronomy* **51**(4): 307–09.

Nadeem, M.A., Tanveer, A., Ali, A., Ayub, M.K. and Tahir, M. 2007. Effect of weed control practices and irrigation levels on weeds and yield of wheat (*Triticum aestivum*). *Indian Journal of Agronomy* **52**(1): 60–3.

Pandey, A.K., Gopinath, A.K. and Gupta, H.S. 2006. Evaluation of sulfosulfuron and metribuzin for weed control in irrigated wheat (*Triticum aestivum*). *Indian Journal of Agronomy* **51**(2): 135–38.

Pisal, R.R. and Sagarka, B.K. 2013. Integrated weed management in wheat with new molecules. *Indian Journal of Weed Science* **45**(1): 25–28.

Pooniya, V. and Shivay, Y.S. 2013. Enrichment of *Basmati* rice grain and straw with zinc and nitrogen through ferti-fortification and summer green manuring crops under Indo-Gangetic Plains of India. *Journal of Plant Nutrition* **36**(1): 91–117.

Sharma, R.K. and Verma, R.P.S. 2010. Effect of irrigation, nitrogen and varieties on the productivity and grain malting quality in barley. *Cereals Research Communication* **38**: 419–28.

Singh, R. and Singh, R.K. 2005. Effect of time and levels of nitrogen application on malt barley (*Hordeum vulgare*). *Indian Journal of Agronomy* **50**(2): 137–39.

Singh, S. and Punia, S.S. 2007. Sensitivity of barley (*Hordeum vulgare*) to herbicides of different modes of action. *Indian Journal of Weed Science* **39**(3 and 4): 205–10.

Surin, S.S., Singh, M.K., Upasani, R.R., Thakur, R. and Pal, S.K. 2013. Weed-management in rice (*Oryza sativa*)–wheat (*Triticum aestivum*) cropping system under conservation tillage. *Indian Journal of Agronomy* **58**(3): 288–91.

Verma, S.K., Singh, S.B., Sharma, R. Rai, O.P. and Singh G. 2008. Effect of cultivars and herbicides on grain yield and nutrient uptake by wheat (*Triticum aestivum*) and weeds under zero-tillage system. *Indian Journal of Agricultural Sciences* **78**(11): 984–87.

Vicari, A., Catizonme, P. and Zimdahl, R.L. 1994. Persistence and mobility of chlorsulfuron and metsulfuron under different soil and climatic conditions. *Weed Res*earch **34**(3): 147–55.

Yaduraju, N.T. and Das, T.K. 2002. Bio-efficacy of metsulfuron-methyl and 2, 4-D on Canada thistle. *Indian Journal of Weed Science* **34**: 110–11.