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Research Paper

Integrated nutrient management in barley (*Hordeum vulgare*) under central plateau and hills agroecological region

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ABSTRACT

A field experiment was conducted during the winter (*rabi*) seasons of 2017–18 and 2018–19 at the Rajasthan College of Agriculture, Maharana Pratap University of Agriculture and Technology, Udaipur, Rajasthan, to find out best integrated nutrient management strategy in barley (*Hordeum vulgare* L.). The correlation and regression were studied between yield attributes and yield as influenced by these treatments. The experiment was laid out in a randomized block design (factorial), comprising combinations of 6 fertility levels [75% recommended dose of fertilizers (RDF), (45 kg N and 22.5 kg P_2O_5) 100% RDF (60 kg N and 30 kg P_2O_5); 125% RDF (75 kg N and 37.5 P_2O_5); 75% RDF + farmyard manure (FYM) 5 t/ha; 100% RDF + FYM 5 t/ha; and 125% RDF + FYM 5 t/ha, and 4 liquid bio-inoculants, viz. *Azotobacter*, phosphate solubilizing bacteria (PSB), *Azotobactor* + PSB and *Azotobactor* + *Azospirillum* + phosphates solubilizer + PGPR (plant-growth promoting rhizobacteria) at the rate 5 ml/kg seed. The results indicated that, application of 125% RDF in conjunction with FYM 5 t/ha had significant effect on yield attributes, viz. effective tillers (45.36), ear length (9.37 cm), ear weight (3.22g), grains/ear (54.49), grain weight/ear (2.70 g), straw weight/ear (0.52 g), filled spikelet/ear (54.47), least number of unfilled spikelet/ear (3.24) and test weight (49.92 g), and grain (5.20 t/ha), straw (7.79 t/ha) and biological yield (12.99 t/ha) which was at par with 100% RDF + FYM 5 t/ha. However, both these fertility levels significantly increased the grain weight/ear over application of 75% RDF + FYM 5 t/ha, 125% RDF, 100% RDF and 75% RDF during both the years. The barley crop under the influence of conjoint inoculation with liquid bio-fertilizers, consisting combination of *Azotobacter* + *Azospirillum* + phosphates solubilizer + plant growth-promoting rhizobacteria (PGPR) recorded significantly higher yield attributes, grain (5.12 t/ha), straw (7.57 t/ha) and biological yields (12.69 t/ha) and was found at par with inoculation of *Azotobacter* + PSB inoculation. The results showed positive interrelationship between grain yield and yield components, viz. effective tillers, ear length, test weight, grain/ear and grain weight/ear, clearly indicate that grain yield is dependent on several component which are interrelated with each other.

Key words: *Azotobacter, Azospirillum,* Barley, Phosphates solubilizer, Plant growth-promoting rhizobacteria, Recommended dose of fertilizer

Barley (*Hordeum vulgare* L.) is an important winter (*rabi*) cereal crop of India. Being the most dependable crop in alkali soils and areas where frost or drought occurs, it is cultivated in almost all parts of the world. Among the cereals, it ranks fourth with respect to area and production after wheat, rice and maize. The average productivity of barley in the Rajasthan is far behind the attainable yield of 4.0–5.0 t/ha; the reasons being water and nutritional stresses. Barley requires considerable amounts of major nutrients, particularly nitrogen (N) and phosphorus (P) for harnessing potential yield. Adequate mineral fertilization is considered to be one of the most important pre-requisites in this respect. Despite the application of recommended quantities of major nutrients, the increase in yield is not encouraging. In nutrient management, organic manures are potential sources of micro-nutrients, which improve soil structure by providing binding action to soil aggregates, water-holding and buffering capacity of soils. The FYM

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supplies all major nutrients (N, P, K, Ca, Mg, S,) necessary for plant growth, as well as micronutrients (Fe, Mn, Cu and Zn). Hence, it acts as a mixed fertilizer. The FYM improves soil physical, chemical and biological properties and soil water-holding capacity.

Biofertilizers play a very significant role in improving soil fertility by fixing atmospheric N, both, in association with plant roots and without it, solubilize insoluble soil phosphates and produce plant growth substances in the soil. *Azotobacter* is a biotic, free-living soil microbes which plays an important role for the N cycle in nature and binding atmospheric N which is inaccessible to plants. Inoculation with *Azotobacter* reduces the requirement of chemical fertilizer up to 50% (Soleimanzadeh and Gooshchi, 2013). Phosphate-solubilizing bacteria (PSB) play an important role in converting insoluble P (chemically fixed and applied) into available form, resulting in higher crop yields (Gull *et al.,* 2004). Among the whole microbial population in soil, PSB constitutes 1 to 50% in P solubilization potential (Chen *et al*., 2006). Plant growth-promoting rhizobacteria (PGPR) are a heterogeneous group of bacteria that can be found in the rhizosphere, at root surfaces and in association with roots, which can improve the extent or quality of plant growth directly or indirectly (Joseph *et al*., 2007). Therefore, keeping in view of above facts the present study was carried out to find out viable treatment for enhancing productivity.

MATERIALS AND METHODS

A field experiment was conducted during the winter (*rabi*) seasons of 2017–18 and 2018–19 at Rajasthan College of Agriculture, Maharana Pratap University of Agriculture and Technology, Udaipur, Rajasthan. The soil of experimental site was clay loam, slightly alkaline, medium in available N (287.60–288.30 kg/ha), medium in available P (18.80–20.50 kg/ha) and high in available K status (338.70–346.40 kg/ha). The barley crop was sown on 19 and 21 November during 2017–18 and 2018–19, respectively, and harvested on 18 March 2018 and 23 March 2019. The total rainfall was 6.4 mm during 2017–18, whereas, it was 1.0 mm during 2018–19. The maximum and minimum temperature during crop-growing season ranged from 23.5 to 37.8°C and 5.2 to 19.8°C during the *rabi* 2017–18, respectively. The corresponding temperature fluctuations during the second year (2018–19) were between 21.6 and 39.4°C and 4.1 and 20.1°C respectively. The experiment was laid out in a randomized block design (factorial). The treatments comprising combinations of 6 fertility levels [75% Recommended dose of fertilizer, i.e. 45 kg N and 22.5 kg P_2O_5, 100% RDF (60 kg N and 30 kg P_2O_5), 125% RDF (75 kg N and 37.5 P_2O_5), 75% RDF + FYM 5 t/ha, 100% RDF + FYM 5 t/ha and 125% RDF + FYM5 t/ha, and 4 liquid bio-inoculants, viz. *Azotobacter*, PSB, *Azotobactor* + phosphate solubilizing bacteria (PSB) and *Azotobactor* + *Azospirillum* + phosphates solubilizer + PGPR (plant-growth promoting rhizobacteria) @ 5 ml/kg seed. These 24 treatment combinations were replicated thrice. Barley variety 'RD 2786' was used as a test crop. The seeds were sown in furrow opened at the depth of about 4–5 cm using seed rate of 100 kg/ha, with inter-row spacing of 22.5 cm.

RESULTS AND DISCUSSION

Yield attributs and yield

Fertility levels : The results indicated that, various yield attributes, viz. effective tillers, grains/ear, grain/weight ear, straw weight/ear, filled spikelets/ear, least number of unfilled spikelets/ear, test weight and yield (grain, straw and biological) were maximized when barley crop was fertilized with 125% RDF + FYM 5 t/ha over application of 75% RDF + FYM 5 t/ha, 125% RDF, 100% RDF and 75% RDF, but was on a par with the application of 100% RDF + FYM 5 t/ha during both years (Tables 1 and 2). The application of 125% RDF + FYM 5 t/ha significantly improved the effective tillers, ear length, ear weight, grains/ear, grain weight/ear, straw weight/ear, filled spikelets/ear, least number of unfilled spikelets/ear and test weight by 64.61, 2.44, 36.93, 42.49, 31.48, 74.08, 28.53, 28.53 and 25.74%, respectively over application of 75% RDF, whereas the grain, straw and biological yields by 42.46, 27.49 and 32.95% over 75% RDF, and the application of 100% RDF + FYM 5 t/ha significantly increased the effective tillers, ear length, ear weight, grains/ear, grain weight/ear, straw weight/ear, filled spikelets/ear, least number of unfilled spikelets/ear and test weight by 82.53, 2.44, 33.19, 37.24, 27.88, 69.10, 24.82, 24.82 and 24.28% respectively, over application of 75% RDF, whereas the grain, straw and biological yields by 38.90, 26.18 and 30.80% over 75% RDF.

It has been well emphasized that, conjoint application of chemical fertilizer and organic manure significantly improved overall growth of crop in term of dry-matter accumulation per unit area by virtue of its impact on morphological and photosynthetic component of growth along with accumulation of nutrients. This indicates greater availability of nutrients and metabolites for growth and development of each reproductive structure which ultimately led to realization of their genetic potential up to the highest level. A faster growth rate in terms of dry-matter production as evident from higher crop-growth rate (CGR) and relative growth rate (RGR) under the influence of adequate fertilization (chemical + organic manure) might have played a significant role in reducing competition for photosynthates and nutrients with mother shoots as well as

Table 1. Effect of integrated nutrient management on yield attributes of barley (pooled data of 2 years)

Treatment	Effective tillers/0.5m	Ear length (cm)	Weight/ ear (g)	Grains/ ear	Grain weight/ ear (g)	Straw weight/ ear/grain	Filled spikelets/ ear	Unfilled spikelets/ ear	Test weight (g)
Fertility levels									
75% RDF	24.61	6.93	2.353	38.24	2.052	0.301	42.38	5.47	39.70
100% RDF	32.97	7.62	2.602	44.97	2.226	0.375	45.85	5.07	42.82
125% RDF	34.33	7.96	2.712	46.53	2.325	0.387	47.28	4.90	44.23
75% RDF + FYM 5 t/ha	35.62	8.19	2.829	47.96	2.427	0.402	49.25	4.67	45.62
100% RDF + FYM 5 t/ha	44.92	9.01	3.134	52.48	2.624	0.509	52.90	3.43	49.34
125% RDF + FYM 5 t/ha	45.36	9.37	3.222	54.49	2.698	0.524	54.47	3.24	49.92
SEm±	0.53	0.13	0.046	0.72	0.042	0.006	0.81	0.10	0.68
CD (P=0.05)	1.49	0.37	0.129	2.04	0.117	0.018	2.29	0.27	1.91
Liquid bio-inoculants									
Azotobacter	31.79	7.65	2.525	42.91	2.273	0.252	47.11	5.60	43.81
PSB	31.70	7.37	2.487	41.59	2.191	0.296	45.83	5.80	42.82
Azotobacter + PSB	40.27	8.71	3.074	52.16	2.522	0.553	50.21	3.33	46.75
Azotobazter + azospirillum + phosphates solubilizer + PGPR	41.44	9.00	3.148	53.11	2.583	0.565	51.62	3.12	47.71
SEm±	0.43	0.11	0.037	0.59	0.034	0.005	0.66	0.08	0.56
CD (P=0.05)	1.21	0.31	0.105	1.66	0.095	0.015	1.87	0.22	1.56

*RDF, Recommended dose of fertilizer; PSB, phosphate solubilizing bacteria; PGPR, plant-growth promoting rhizobacteria

Table 2. Effects of integrated nutrient management on yield of barley (pooled data of 2 years)

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	Biological yield (t/ha)
Fertility levels			
75% RDF	3.65	6.11	9.77
100% RDF	4.13	6.65	10.78
125% RDF	4.34	6.90	11.24
75% RDF + FYM 5 t/ha	4.46	7.18	11.65
100% RDF + FYM 5 t/ha	5.07	7.71	12.78
125% RDF + FYM 5 t/ha	5.20	7.79	12.99
SEm±	0.08	0.12	0.21
CD (P=0.05)	0.22	0.34	0.60
Liquid bio-inoculants			
Azotobacter	3.97	6.80	10.77
PSB	3.80	6.57	10.37
Azotobacter + PSB	4.99	7.31	12.30
Azotobazter + azospirillum + phosphates solubilizer + PGPR	5.12	7.57	12.69
SEm±	0.06	0.10	0.17
CD (P=0.05)	0.18	0.28	0.49

*RDF, Recommended dose of fertilizer; PSB, phosphate solubilizing bacteria; PGPR, plant-growth promoting rhizobacteria

between tillers resulting in their greater survival till harvesting. On the other hand, adequate supply of photosynthates owing higher photosynthetic efficiency at ear emergence might have enhanced the number of flowers and their fertilization, resulting in higher number of filled spikelet and grains/ear. Further, greater assimilating surface at reproductive development and improvement in nutritional condition of grain under the influence of adequate fertilization seems to have provided congenial environment for grain growth because of adequate supply of metabolites and nutrients. This is well reflected from increased weight of individual grain expressed in term of test weight. The significant positive correlation between test weight and nutrient concentration of grain, viz. N ($r = 0.999^{**}$), P ($r = 0.982^{**}$) and K ($r = 0.859^{**}$) also indicates key role of increasing adequate fertilization in improving grain growth through increasing nutrient status and their mobilization towards sink components. Since grain yield/ear is dependent on number of grains/ear and weight of individual grain, thus the highest grain yield/ear under adequate fertilization could be ascribed to the improvement in both these parameters. Farmyard manure (FYM) is source of organic matter is also known to favourably improve soil structure, increase water-holding capacity and provide energy for nitrogen fixation by free-living heterotrophic micro-organisms. Thus, significant improvement in various components can be ascribed not only to adequate supply of assimilates/nutrients but also to their pivotal role in increasing physico-chemical and biological properties of soil, thereby, enhancing root growth and synthesis of cytokinnins. The results of present investigation indicating positive response of various yield components to fertility levels corroborate findings of Sepat *et al*., (2010), Chesti *et al.,* (2013) and Shantveerayya *et al.,* (2017).

The highest grain yield realized with the addition of 125% RDF, 100% RDF + FYM 5 t/ha could be owing due to its profound influence on vegetative and reproductive growth of crop. In the present investigation (Table 3), estimated positive interrelationship between grain yield and yield components, viz. effective tillers (r = 0.963**), ear length (r = 0.988**), test weight (r = 0.951**), grain/ear (r = 0.993**) and grain weight/ear (r = 0.977**) clearly indicates that, grain yield is dependent on several components which are interrelated with each other. This is also substantiated through regression studies which revealed that, a unit increase in aforesaid parameters increased the grain yield by 103, 52, 10, 71 and 184 kg/ha. Hence marked increase in grain yield with 125% RDF + FYM 5 t/ha fertilization seems to be owing to realization of crop genetic yield potential. Our results are in close agreement with the findings of Kotangale *et al.,* (2009), Meena *et al.,* (2012), Jat *et al.,* (2013) and Singh *et al.,* (2013).

The significant increase in straw yield owing 125% RDF + FYM 5 t/ha could be ascribed to their direct influence on dry matter production at successive stages by virtue of increased photosynthetic efficiency. While indirect influence seems to be because of increase in plant height and number of tillers. The higher nutrient uptake with adequate fertilization perhaps be another reason for observed improvement in the straw yield. The profound influence of NPK + FYM on biological yield seems to be on account of its significance on vegetative (straw) and reproductive growth (grain). The regression analysis also indicated that, a unit increase in grain and straw yield enhanced the biological yield by 200 and 203 kg/ha. The results of present investigation confirm the findings of Rai *et al.,* (2013) and Prasad *et al*., (2019).

Liquid bio-inoculants

The inoculation of barley seed with liquid bio fertilizer consisting combinations of *Azotobacter* + *Azospirillum* + phosphates solubilizer + PGPR, resulted in the highest yield attributes (number of effective tillers, ear length, ear weight, grains/ear, grain weight/ear, straw weight/ear, filled spikelets/ear, least number of unfilled spikelets/ear and test weight), grain, straw and biological yields which was found at par with inoculation of *Azotobacter* + PSB and both these treatments significantly increased the yield attributes over inoculation of *Azotobacter* and PSB alone during both years and in pooled analysis. On pooled basis, co-inoculation of *Azotobacter* + *Azospirillum* + phosphates solubilizer + PGPR (5.12 t/ha) and *Azotobacter* + PSB (4.99 t/ha) significantly improved the grain yield by 28.96, 25.70 and 34.73, 31.32% respectively, over single inoculation of *Azotobacter* and PSB. Further results indicated that, both the combinations of liquid bio-inoculants *Azotobacter* + *Azospirillum* + phosphates solubilizer + PGPR and *Azotobacter* + PSB were equally efficient in improving productivity.

It was observed that in comparison to seed inoculation with *Azotobactor* and PSB alone, conjoint inoculation with liquid bio-fertilizer *Azotobactor* + *Azospirillum* + phosphates solubilizer + PGPR significantly enhanced yield attributes, viz. effective tillers/0.5 m row, filled spikelets/ear, grains/ear, ear length, ear weight and test weight. These improvements ultimately manifested in production of higher grain, straw and biological yields by 28.96, 11.32, 17.82 and 25.69.7.50, 12.20% over single inoculation of *Azotobactor* and PSB respectively. While inoculation of liquid biofertilizer *Azotobactor* + PSB enhanced aforesaid productivity parameters by 34.73, 15.22 and 22.37, 31.32, 11.26 and 18.61% respectively. Further results indicated that, both the combinations of liquid bio-inoculants *Azotobactor* + *Azospirillum* + phosphates solubilizer + PGPR and *Azotobactor* + PSB were equally efficient in improving productivity.

It is an established fact that, availability of assimilates (source) and nutrients together with storage organs (sink) exerts an important regulative function on complex process of barley yield formulations. It is believed that, *Azotobactor* + *Azospirillum* + phosphates solubilizer + PGPR produce phytohormones, antibacterial and antifungal compounds which stimulate root-system and change in root morphology which in turn affect the assimilates of nutrients thus influence the development of reproductive structures. Amongst phytohormones, auxin, gibberellins and cytokinins are considered to play a vital role at early stage (vegetative) by affecting bud formation therefore development of effective tillers. While at later stage (reproductive) influence the first phase of seed growth through promotion of cell-division and buildup of its storage capacity and thereafter retardation of senescence and keeping surface green for greater period thus increase grain-growth period. Hence it has been interpreted that, any agronomic factor which enhances activities of root helps in increasing phytohormone synthesis and its regulation in plant system.

The marked increase in various yield components with the inoculation of *Azotobactor* + *Azospirillum* + phosphates solubilizer + PGPR can be ascribed not only to adequate supply of assimilates/ nutrients but also to their pivotal role in improving physical, chemical and biological properties of soil thereby enhancing root growth. The significant increase in grain yield with inoculation of liquid bio-inoculants could be ascribed to their positive influence on maintaining source-sink relationship which is clearly evident from improvement in dry-matter production along with its efficiency (CGR) and sink components. The positive interrelationship between grain yield and CGR between various crop duration as well as yield components also substantiated that, marked increase in grain yield with inoculation with bio-inoculants was on account of their profound influence on both source as well as sink component of crop.

The increase in straw yield with the inoculation of liquid bio-inoculants *Azotobactor* + *Azospirillum* + phosphates solubilizer + PGPR could be partly attributed to its direct influence on dry-matter production by each vegetative part and indirectly through increased morphological parameters of growth (plant height and tillers/0.5 m row). The correlation (Table 3) also substantiates significant positive interrelationship between straw yield and plant height (r = 0.983**), tillers/0.5 m row (0.983**) and dry-matter accumulation of stem + leaves at harvesting (0.993**). Since biological yield is a function of grain and straw yield, representing vegetative and reproductive growth of crop, the profound influence of liquid bio-inoculants *Azotobactor* + *Azospirillum* + phosphates solubilizer + PGPR and *Azotobactor* + PSB on both these events of crop growth led to realization of higher biological yield. This is also evident from regression analysis which indicated that, a unit increase in grain and straw yield increased the biological yield by 200 and 203 kg/ha. The results of this investigation corroborated the findings of Yadav *et al*., (2011), Choudhary *et al.,* (2018) and Malik (2018). The results show positive interrelationship between grain yield and yield components (effective tillers, ear length, test weight, grains/ ear and grain weight/ear) clearly indicate that grain yield is dependent on several component which are interrelated with each other under integrated nutrient management.

Based on results emanated from the present investigation it is concluded that integrated nutrient management in barley crop with the application of 125% RDF (75 kg N + 37.5 kg ha-1) + 5 t FYM/ha and seed inoculation with liquid biofertilizer Azotobactor + Azospirillum + phosphates solubilizer + PGPR (5 ml/kg seed) gave maximum grain yield (6100 kg/ha).

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Table 3. Correlation coefficient and regression equations showing relationship between yield attributes and yield of barley

Dependent variable (Y)	Independent variable (X)	Correlation coefficient (r)	Regression equation (Y = a + bx)
Grain yield (t/ha)	Effective tiller	0.963**	Y= -2.807+1.031x
Grain yield (t/ha)	Ear length (cm)	0.988**	Y= -1.503+0.518x
Grain yield (t/ha)	Weight/ear (g)	0.997**	Y= 1.371+0.085x
Grain yield (t/ha)	Grains/ear (no.)	0.993**	Y= -1.368+0.714x
Grain yield (t/ha)	Grain weight/ear (g)	0.977**	Y= -0.700+1.842x
Grain yield (t/ha)	Test weight (g)	0.951**	Y= -0.509+0.105x
Straw yield (t/ha)	Plant height (cm)	0.983**	Y= 1.352+0.059x
Straw yield (t/ha)	Dry matter at harvesting (g)	0.993**	Y= 1.643+0.053x
Biological yield (t/ha)	Grain yield (t/ha)	0.991**	Y= 3.047+1.997x
Biological yield (t/ha)	Straw yield (t/ha)	0.990**	Y= -2.783+2.028x
Test weight (g)	N content in grain (%)	0.990**	Y= 19.837+15.436x
Test weight (g)	P content in grain (%)	0.982**	Y= 8.335+97.692x
Test weight (g)	K content in grain (%)	0.859**	Y= 22.618+49.712x

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