

RESPONSE OF SEED IRRADIATION WITH GAMMA RAY, N-FERTILIZATION AND BIO FERTILIZATION OF BARLEY (*Hordeum vulgare* L.) GROWN ON A SAND SOIL

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ABSTRACT

Seed irradiation during pre-sowing processes is one of the most effective methods to increase plant growth, yield components and its chemical composition. A three factor split-split plot, factorial experiment was conducted on barley to study seed irradiation, biofertilization with N₂ fixing bacteria (NFB), P-dissolving bacteria (PDB) and N fertilization in the Agricultural Research Station of El-Zagazig University at El-Khattara region, El-Sharkia Governorate, Egypt during 2009/2010 season. Main plots were assigned to gamma irradiation: non-radiated, 20 and 40 Gy gamma radiations. Sub-plots were assigned to N: 0, 119, 238 and 298 kg N ha⁻¹. Sub-sub plots were assigned to biofertilization: none, (*Azospirillum lipoferum* + *Bacillus polymyxa* "NFB1"), (*Azospirillum brasilense* + *Azotobacter chroococcum* "NFB2" + *Bacillus megatherium* "PDB") and NFB1 + NFB2 + PDB. The NFB1 was given in a commercial product of "Cerealin" while (NFB2 + PDB) was in a product of Microbin. Barley yield and yield components as well as N, P and K content and uptake increased by gamma irradiation, N rates and biofertilization singly or combined. Number of spike per m², grain weight per spike, yields of: grains + straw, grains and straw increased also, highest response occurred by N238 + (Cerealin + Microbin) with 40Gy gamma ray. The highest straw yield was observed due to N179 + (Cerealin + Microbin) with 40Gy gamma ray. Treatment of N179 + Cerealin with 40Gy gamma ray gave highest N-uptake in straw, as well as P-uptake in grains and straw. Protein content and protein yield increased by treatments especially with increasing N rate up to N298 + Microbin + 20Gy and gave highest protein content. Nitrogen use efficiency (NHI) was increased with increasing N rates up to N238 followed by decrease at N298.

Keywords: Gamma irradiation, Barley, N fertilization, Biofertilizers, Sand soil

INTRODUCTION

Barley (*Hordeum vulgare* L.) is one of the most important cereal crops in Egypt. Total production of barley in Egypt reached 102000 megagrams (Mg) in 2011, produced from an area of 65000 ha, (FAO, 2012). Recently, a great attention has been directed to increase the productivity of barley to minimize the gap between the production and consumption. Gamma radiation can be useful for the alteration of physiological characters (Kiong *et al.*, 2008). The biological effect of gamma rays is based on the interaction with atoms or molecules in the cell, particularly water, to produce free radicals (Kovacs and Keresztes 2002). Seed irradiation during the pre-sowing is one of the effective methods to improve plant production, yield components and chemical composition. Gamma ray ionizes molecules and causes free radicals that attack DNA molecules which break one or two chains of DNA (Jyoti *et al.*, 2009). Artik and Peksen (2006) investigated the effect of gamma irradiation of 25, 50, 75 and 100 Gy, they found that low doses of stimulated cell division, growth and development of faba bean plants. Rahimi and Abdallah (2011) reported that doses of 25 and 50Gy were the most effective for increasing grain yield, harvest index and grain protein content of wheat.

Farag and El-Khawaga, (2013) found that gamma irradiation in a low dose (10, 20 and 30Gy), increased seed yield of sesame plants.

Extending the role of biofertilizers can reduce the need for chemical fertilizers, decrease adverse environmental effects and fix atmospheric N₂. Therefore, biofertilization is of great importance in alleviating environmental pollution (Namvar *et al.*, 2012 and Rana *et al.*, 2012). Inocula of *Azotobacter* sp. and *Azospirillum* sp. are used as biofertilizers for many crops. The estimated contribution of these free-living N fixing prokaryotes to the N input of soil ranges from 0–60 kg/ha per year (Vessey, 2003). Existence of microbial communities like *Azotobacter* sp. and *Azospirillum* sp. in the rhizosphere promotes the growth of the plant through the cycling and availability of nutrients, increasing the health of roots during the growth stage by competing with root pathogens and increasing the absorption of nutrients and water (Daneshmand *et al.*, 2012). Kizilkaya (2008), Sary *et al.* (2009) and Kandil *et al.* (2011) studied the effects of inoculation with *Azotobacter* sp. and *Azospirillum* sp. on wheat and observed that inoculated wheat plants gave higher plant height, spike per unit of area, grains per spike, grain weight, biological yield, grain yield and straw yield. Saini *et al.* (2004) and Piccinin *et al.* (2013) suggested that integrated nutrient management strategies involving inoculation of seeds with *Azotobacter* sp. and *Azospirillum* sp. in combination with chemical fertilizers result in improving both growth and yield of crops. Inocula of organisms which act as biofertilizers are prepared in different forms (in suspensions or on solid organic matter) and are marketed commercially under different trade names. In Egypt one of such products is Cerealin (produced by Ministry of Agriculture, Egypt) which consists of inocula of N₂ fixing strains of *Azospirillum lipoferum* and *Bacillus polymyxa*. Another product is Microbin which consists of N₂-fixing microorganisms along in the P-dissolving microorganisms (El-Kramany *et al.*, 2000).

Nitrogen is the most important essential nutrient in plant nutrition. It is a constituent of a large number of necessary organic compounds such as amino acids, proteins, coenzymes, nucleic acids, ribosomes, chlorophyll, cytochrome and some vitamins. Thus, N supply to the plant will influence the amount of protein, cell size, leaf area and photosynthetic activity (Diacono *et al.*, 2013). N fertilizer causes positive effect on the number of grains spike⁻¹, spike weight, 1000-grain weight and grain yield of wheat (Campuzano *et al.*, 2012 and Liu and Shi, 2013). Namvar and Khandan, (2013) found that high rates of N fertilization and biofertilizer (*Azotobacter* sp. and *Azospirillum* sp.) inoculation increased grains number spike⁻¹, 1000-grain weight, grain yield, biological yield and grain protein content of wheat plant.

The current investigation aimed at assessing the effect gamma irradiation, different nitrogen rates and biofertilizers on nitrogen utilization as well as some plant characteristics, yield and yield composition of barley (*Hordeum vulgare* L.) c.v Giza 123 grown on a sand soil.

MATERIALS AND METHODS

A field experiment on barley was conducted at El-Khattara region El-Sharkia Governorate, Egypt during winter season 2009 / 2010 to investigate

the effect of gamma-irradiation as well as the effect of nitrogen fertilization and biofertilization of barley plants (*Hordeum vulgare* L.) c.v Giza 123, grown in a sandy soil. The chemical analysis of soil of the experimental field (30cm depth) showed sand, silt and clay as 91.8, 6.0 and 7.6%, respectively (sand in texture), having EC in its saturation extract of 0.77 dS m^{-1} and contents of CaCO_3 and organic matter of 7.5 and 7.8 g kg^{-1} , respectively. Available macronutrients were $18.5 \text{ mg N kg}^{-1}$ (mineral N extracted by 2M KCl) $8.19 \text{ mg P kg}^{-1}$ (extracted by Na-bicarbonate 0.5 M) and $29.4 \text{ mg K kg}^{-1}$ (extracted by 1.0 M $\text{NH}_4 \text{OAc}$, pH 7.0) as described by Jackson (1958) Page *et al.* (1982) and Black *et al.* (1982).

Prior to sowing, seed inoculation was carried out using biofertilizers of nitrogen fixing bacteria (NFB) and phosphorus dissolving bacteria (PDB). The first group of NFB: NFB1 are *Azospirillum lipoferum* and *Bacillus polymyxa* in the form of the commercial biofertilizer "Cerealin". The second group NFB2 are *Azospirillum brasilense* + *Azotobacter chroococcum* combined with PDB (i.e., phosphorus dissolving bacteria of *Bacillus megatherium*) are in a form of the commercial biofertilizer Microbin. Both produced by the Egyptian Ministry of Agriculture as inocula carried on organic, peat like substances to treat seeds. Seed inoculation was performed by mixing barley grains with the appropriate Cerealin and Microbin using Arabic gum as adhesive material. The coated grains were then air dried in shade for 30 minutes and sown immediately on 22th of October 2009.

The experiment was a 3-factor factorial split-split plot in a randomized complete block design with three replications. The plot area was 5 m^2 ($2.5 \times 2 \text{ m}$). Main plots, were assigned to irradiation, none, 20 and 40 Gy gamma irradiation, irradiation facility used was, cobalt 60 gamma chamber 4000-A-India, Egyptian Atomic Energy Establishment, (EAEE), Inshas, Egypt. Sub-plots were assigned to N: 0, 119, 238 and 298 kg N ha^{-1} in form of ammonium sulphate, AS (205 g N kg^{-1}) in three equal splits: 20 days after sowing, "DAS" (immediately after thinning), 40 and 60 DAS. Sub-sub plots were assigned to biofertilizers: none, Cerealin, Microbin and Cerealin + Microbin. Soil was supplied with phosphorus in form of Calcium superphosphate (67.6 g P kg^{-1}) at a rate of 31 kg P ha^{-1} during seed bed preparation; and with potassium 119 kg K ha^{-1} as potassium sulphate (400 g K kg^{-1}) in two equal doses 30 and 45 days after planting. Harvest was done on, 25th of April 2010.

Dry matter and grain yield

At harvest, ten plants were taken randomly from each plot and tagged for yield assessment. Number of spikes, grain weight spike⁻¹ and 1000-grain weight were measured. Plants were harvested, air dried, then straw yield, Mg ha^{-1} and grain yield, Mg ha^{-1} were measured. The following parameters were determined: (1) N, P and K content and uptake by plant (straw and grains). (2) Grain protein content was calculated by multiplying grain N content by 5.83 (Baker, 1979). (3) Grain protein yield in kg ha^{-1} {protein content g kg^{-1} x grain yield Mg ha^{-1} }. (4) Harvest index % by {grain yield / grains + straw yield} x 100. (5) Nitrogen harvest index (NHI) = Grain nitrogen uptake / Total nitrogen uptake (after, Nyborg *et al.*, 1995).

Methods of Analysis

Macronutrients content in plant were determined in aliquots of digested solutions resulting from the digestion of grains and straw samples by a mixture of concentrated sulphuric and perchloric acids after drying in an oven at 70° C as described by Ryan *et al.* (1996).

RESULTS AND DISCUSSION

Effect of treatments on growth parameters and yield of barley

Growth parameters

Table 1 reveals that the growth parameters of number of spikes m^{-2} , grain weight spike $^{-1}$ and 1000-grain weight significantly increased due to gamma irradiation, N fertilization and biofertilization solely or in combinations. Farag and El-Khawaga (2013) reported that gamma irradiation of sesame and N-application increased the 1000-seed weight. Namvar and Khandan (2013) reported that number of spikes *per m*², number of grain *per spike* and the 1000-grain weight of wheat increased significantly by N-fertilization and biofertilizer inoculation. These results are in agreement with those of Sary *et al.* (2009) and Kandil *et al.* (2011). There was no significant difference between the two gamma irradiation doses of 20 and 40 Gy for all parameters. As for N effect, there was the following descending order: N238 > N298 > N179 > N0 for grain weight spike $^{-1}$ and 1000-grain weight. As for the number of spikes *per m*², the order was N238 > N179 > N298 > N0. Regarding the response to biofertilization, the main effect followed a descending of: Cerealine + Microbin > Microbin > Cerealine > none for number of spikes *per m*² and 1000-grain weight; the order for grain weight *per spike* was: Cerealine + Microbin > Cerealine > Microbin > none.

The highest increase in number of spikes *per m*² (198%) and grain weight *per spike* (173%) were recorded in plants treated with N238 + (Cerealine+ Microbin) irradiated with gamma dose 40Gy. The treatment of N238 + (Cerealine+ Microbin) irradiated with 20Gy gamma irradiation caused highest increase in 1000-grain weight (104%).

Straw and grain yields

The data of straw and grain yield of barley plants are presented in Table 2. The obtained results exhibited significant increases due to application of N, biofertilization, irradiation and their combinations compared to the non-treated plants. Low doses of gamma rays increase enzymatic activation, which result in stimulating cell division, and affects germination, and vegetative growth (Ashri, 2007). The favorable effect of nitrogen fertilizer may be due to N stimulation of plant growth, which would increase the amount of light energy intercepted by leaves and increase photosynthetic pigments and photosynthesis, and in turn increase synthesized metabolites and consequently leaves and seeds (Wortman *et al.*, 2011). Growth promoting substances (phytohormones) which would be produced by these organisms play a key role in plant growth and promote seed germination and root elongation. Root development and proliferation of plants in response to biofertilizer activities enhance water and nutrients uptake (Kandil *et al.*, 2011) and Joshi *et al.*, 2012). These results agree with those obtained by, Siam *et al.* (2013) and Piccinin *et al.* (2013).

Table1: Yield components of barley as affected by gamma irradiation, biofertilizers and N rates

| N- Rate (N) kg N ha ⁻¹ | | Biofertilizer (B) | Gamma irradiation dose, Gy (G) | | | | | | | | | | | |
|---|------------|----------------------|------------------------------------|-------|-------|-------|--------------------------------------|--------|--------|--------|-----------------------|--------|--------|--------|
| | | | 0 | 20 | 40 | Mea | 0 | 20 | 40 | Mean | 0 | 20 | 40 | |
| | | | Number of spikes (m ²) | | | | Grain weight spike ⁻¹ (g) | | | | 1000-grain weight (g) | | | |
| N0 | Without | | 157 | 234 | 276 | 222 | 0.83 | 0.97 | 1.04 | 0.94 | 32.8 | 33.7 | 34.6 | 33.7 |
| | Cerealin | | 281 | 299 | 303 | 294 | 0.90 | 1.00 | 0.97 | 0.96 | 33.9 | 36.5 | 37.0 | 35.8 |
| | Microbin | | 310 | 320 | 324 | 318 | 1.00 | 1.04 | 1.08 | 1.04 | 35.1 | 37.2 | 36.6 | 36.3 |
| | Cer.+ Mic. | | 326 | 338 | 369 | 344 | 1.02 | 1.12 | 1.16 | 1.10 | 35.9 | 37.7 | 37.2 | 36.9 |
| | Mean | | 269 | 298 | 318 | 295 d | 0.94 | 1.03 | 1.06 | 1.01 d | 34.4 | 36.3 | 36.3 | 35.7 d |
| N179 | Without | | 251 | 286 | 289 | 275 | 1.07 | 1.10 | 1.19 | 1.12 | 34.7 | 36.5 | 36.2 | 35.8 |
| | Cerealin | | 315 | 339 | 329 | 328 | 1.23 | 1.36 | 1.40 | 1.33 | 37.8 | 39.0 | 39.4 | 38.7 |
| | Microbin | | 326 | 406 | 378 | 370 | 1.47 | 1.57 | 1.65 | 1.56 | 38.7 | 39.6 | 41.7 | 40.0 |
| | Cer.+ Mic. | | 331 | 425 | 389 | 382 | 1.50 | 1.66 | 1.587 | 1.58 | 38.2 | 40.5 | 41.9 | 40.2 |
| | Mean | | 306 | 364 | 346 | 339 b | 1.32 | 1.42 | 1.46 | 1.40 c | 37.4 | 38.9 | 39.8 | 38.7 c |
| N238 | Without | | 263 | 288 | 296 | 282 | 1.26 | 1.48 | 1.39 | 1.37 | 39.5 | 51.2 | 44.6 | 45.1 |
| | Cerealin | | 331 | 368 | 349 | 349 | 1.30 | 1.59 | 1.70 | 1.53 | 41.7 | 49.0 | 54.8 | 48.5 |
| | Microbin | | 347 | 429 | 411 | 396 | 1.39 | 2.02 | 1.98 | 1.80 | 46.5 | 55.7 | 60.5 | 54.2 |
| | Cer.+ Mic. | | 336 | 438 | 468 | 414 | 1.57 | 1.97 | 2.27 | 1.94 | 48.9 | 66.9 | 61.9 | 59.2 |
| | Mean | | 319 | 381 | 381 | 360 a | 1.38 | 1.76 | 1.83 | 1.66 a | 44.2 | 55.69 | 55.4 | 51.8 a |
| N298 | Without | | 259 | 268 | 276 | 268 | 1.13 | 1.35 | 1.29 | 1.25 | 36.5 | 44.4 | 46.5 | 42.4 |
| | Cerealin | | 279 | 318 | 336 | 311 | 1.36 | 1.65 | 1.75 | 1.59 | 39.5 | 47.4 | 43.6 | 43.5 |
| | Microbin | | 341 | 385 | 397 | 374 | 1.45 | 1.55 | 1.60 | 1.53 | 44.2 | 51.4 | 52.5 | 49.4 |
| | Cer.+ Mic. | | 325 | 379 | 388 | 364 | 1.40 | 1.48 | 1.54 | 1.47 | 41.3 | 53.9 | 52.0 | 49.1 |
| | Mean | | 301 | 338 | 349 | 329 c | 1.33 | 1.51 | 1.55 | 1.46 b | 40.4 | 49.3 | 48.6 | 46.1 b |
| Grand mean (G) | | | 299 b | 345 a | 349 a | | 1.24 b | 1.43 a | 1.47 a | | 39.0 b | 45.0 a | 45.0 a | |
| F – test | G: | | ** | N: | ** | G: | ** | N: | ** | G: | ** | N: | ** | |
| | B: | | ** | GxN: | ** | B: | ** | GxN: | ** | B: | ** | GxN: | ** | |
| | GxB: | | ** | BxN: | ** | GxB: | NS | BxN: | ** | GxB: | ** | BxN: | ** | |
| | GxNB: | | ** | | | GxNB: | NS | | | GxNB: | ** | | | |
| Cer.: Cerealin; Mic.: Microbin; NS: Not significant | | | | | | | | | | | | | | |
| Means of biofertilizer | | | | | | | | | | | | | | |
| Whitout | | | 262 d | | | | 1.17 c | | | | 39.2 d | | | |
| Cerealin | | | 321 c | | | | 1.35 b | | | | 41.6 c | | | |
| Microbin | | | 365 b | | | | 1.48 a | | | | 45.0 b | | | |
| Cerealin+Microbin | | | 376 a | | | | 1.52 a | | | | 46.3 a | | | |
| Grand mean | | | 331 | | | | 1.38 | | | | 43.0 | | | |

Interaction effects of nitrogen fertilization rates and biofertilizer inoculation were significant for yields of straw, grains and grains + straw at all doses of gamma irradiation especially 40Gy which was superior to 20Gy gamma ray. A descending order characterized the effects of N fertilization on straw and grain yield as follows: N298 > N179 > N238 > N0 for straw yield and N238 > N298 > N179 > N0 for grain yield. As for the main effect of biofertilizer inoculation on grain yield; the order was: Cerealain + Microbin > Cerealain > Microbin > without. For straw yield, the main effect shows no significant difference.

The maximum (grains + straw) and grain yields (19.0 and 9.28 Mg ha⁻¹, respectively) were achieved due to application of N238 + (Cerealain + Microbin) when irradiated with 40Gy gamma ray and the corresponding increments over the non-treatment plants were 164 and 176%, respectively. With respect to straw yield, the greatest value (10.2 Mg ha⁻¹) was observed due to addition of N179 + (Cerealain + Microbin) with 40Gy gamma ray irradiation giving increases of 166% over the non-treated.

Table2: Grains and straw yield (Mg ha⁻¹) as well as harvest index (%) of barley as affected by gamma irradiation, biofertilizers and N rates

| N-Rate (N) kg N ha ⁻¹ | Biofertilizer (B) | Gamma irradiation dose, Gy (G) | | | | | | | | | | | |
|---|----------------------|--|------|------|--------|------------------------------------|------|------|--------|-------------------------------------|------|------|---------|
| | | 0 | 20 | 40 | Mean | 0 | 20 | 40 | Mean | 0 | 20 | 40 | Mean |
| | | (Grains + straw) yield (Mg ha ⁻¹) | | | | Straw yield (Mg ha ⁻¹) | | | | Grains yield (Mg ha ⁻¹) | | | |
| N0 | Without | 1.28 | 5.76 | 5.28 | 4.11 | 0.96 | 3.04 | 2.88 | 2.29 | 0.32 | 2.72 | 2.40 | 1.81 |
| | Cerealain | 1.76 | 7.04 | 8.00 | 5.60 | 1.04 | 3.84 | 4.48 | 3.12 | 0.72 | 3.20 | 3.52 | 2.48 |
| | Microbin | 1.84 | 8.00 | 7.84 | 5.89 | 1.12 | 4.48 | 4.64 | 3.41 | 0.72 | 3.52 | 3.20 | 2.48 |
| | Cer.+ Mic. | 1.44 | 6.08 | 7.20 | 4.91 | 1.04 | 3.36 | 3.84 | 2.75 | 0.40 | 2.72 | 3.36 | 2.16 |
| | Mean | 1.58 | 6.72 | 7.08 | 5.13 c | 1.04 | 3.68 | 3.96 | 2.89 d | 0.54 | 3.04 | 3.12 | 2.23 c |
| N179 | Without | 6.56 | 7.52 | 16.8 | 10.3 | 3.68 | 4.48 | 8.80 | 5.65 | 2.88 | 3.04 | 8.00 | 4.64 |
| | Cerealain | 7.20 | 10.1 | 18.6 | 12.0 | 3.68 | 5.92 | 9.92 | 6.51 | 3.52 | 4.16 | 8.64 | 5.44 |
| | Microbin | 9.92 | 9.44 | 18.9 | 12.8 | 5.92 | 4.80 | 10.1 | 6.93 | 4.00 | 4.64 | 8.80 | 5.81 |
| | Cer.+ Mic. | 7.52 | 11.7 | 18.5 | 12.5 | 3.84 | 4.64 | 10.2 | 6.24 | 3.68 | 7.04 | 8.32 | 6.35 |
| | Mean | 7.80 | 9.69 | 18.2 | 11.9 b | 4.28 | 4.96 | 9.76 | 6.33 b | 3.52 | 4.72 | 8.44 | 5.56 b |
| N238 | Without | 8.96 | 6.40 | 11.2 | 8.85 | 5.12 | 2.88 | 6.72 | 4.91 | 3.84 | 3.52 | 4.48 | 3.95 |
| | Cerealain | 10.2 | 9.92 | 16.8 | 12.3 | 5.44 | 3.20 | 8.80 | 5.81 | 4.80 | 6.72 | 8.00 | 6.51 |
| | Microbin | 9.28 | 11.4 | 15.4 | 12.0 | 5.12 | 5.28 | 7.68 | 6.03 | 4.16 | 6.08 | 7.68 | 5.97 |
| | Cer.+ Mic. | 9.12 | 13.4 | 19.0 | 13.9 | 5.60 | 5.92 | 9.76 | 7.09 | 3.52 | 7.52 | 9.28 | 6.77 |
| | Mean | 9.39 | 10.3 | 15.6 | 11.8 b | 5.32 | 4.32 | 8.24 | 5.96 c | 4.08 | 5.96 | 7.36 | 5.80 a |
| N298 | Without | 7.68 | 10.7 | 12.8 | 10.4 | 4.64 | 5.60 | 6.72 | 5.65 | 3.04 | 5.12 | 6.08 | 4.75 |
| | Cerealain | 9.44 | 14.4 | 16.2 | 13.3 | 6.08 | 8.16 | 7.84 | 7.36 | 3.36 | 6.24 | 8.32 | 5.97 |
| | Microbin | 9.76 | 12.3 | 15.8 | 12.6 | 6.40 | 7.36 | 7.68 | 7.15 | 3.36 | 4.96 | 8.16 | 5.49 |
| | Cer.+Mic. | 12.0 | 14.9 | 14.7 | 13.9 | 6.08 | 8.00 | 8.32 | 7.47 | 5.92 | 6.88 | 6.40 | 6.40 |
| | Mean | 9.72 | 13.1 | 14.9 | 12.6 a | 5.80 | 7.28 | 7.64 | 6.91 a | 3.92 | 5.80 | 7.24 | 5.65 ab |
| Grand means (G) | | 7.12 | 9.94 | 13.9 | a | 4.11 | 5.06 | 7.40 | a | 3.02 | 4.88 | 6.54 | a |
| F - test | G: | ** | N: | ** | G: | ** | N: | ** | G: | ** | N: | ** | |
| | B: | ** | GxN: | ** | B: | ** | GxN: | ** | B: | ** | GxN: | ** | |
| | GxB: | ** | BxN: | ** | GxB: | ** | BxN: | ** | GxB: | ** | BxN: | ** | |
| | GxNxB: | ** | | | GxNxB: | ** | | | GxNxB: | ** | | | |
| Means of biofertilizer | | | | | | | | | | | | | |
| Whitout | | 8.41 c | | | | 4.63 b | | | | 3.79 d | | | |
| Cerealain | | 10.8 b | | | | 5.88 a | | | | 5.10 b | | | |
| Microbin | | 10.8 c | | | | 5.71 a | | | | 4.94 c | | | |
| Cerealain+Microbin | | 11.3 a | | | | 5.87 a | | | | 5.42 a | | | |
| Grand mean | | 10.3 | | | | 5.52 | | | | 4.81 | | | |

Harvest index

Values of harvest index as affected by gamma irradiation, N fertilization and biofertilizer inoculation whether applied solely or in combinations are shown in Table 3. Grain harvest index, varied between 25.0 % to 67.7%. The plants treated with N238 + Cerealain under gamma irradiation dose of 20Gy gave the highest value while those of the non-treated gave the lowest value.

Gamma irradiation increased the harvest index. Difference between the 20 and 40Gy were an average not significant. As for the N rates, the main effect followed the order: N238 > N179 > N298 > N0. Main effect of

biofertilizers shows a slight increase over the non-biofertilized with no significant differences between Cerealin and Cerealin + Microbin or between Microbin and the non-biofertilized.

Grain protein content and grain protein yield

It can be seen from results presented in Table 3 that the protein content of barley grains significantly increased owing to application of gamma irradiation, N fertilization and biofertilizers inoculation. Siam, *et al.* (2013) pointed out that protein content in wheat grain increased with high rates of mineral N fertilizer up to 238 kg N ha⁻¹. Rahimi and Abdallah (2011) stated that gamma irradiation increased protein content of wheat grain and that 25 and 50Gy gamma irradiation produced the highest grain protein content. Namvar and Khandan (2013) reported that inoculation with *Azotobacter sp.* and *Azospirillum sp.* increased wheat grains protein content by 10%. The current results are in agreement with those reported by Abedi *et al.* (2010) and Rana *et al.* (2012). The main effect of irradiation shows increases and that the 20Gy dose was superior to the 40Gy dose. As for N fertilization, the main effect shows increases and that there were significant differences among the N rates; application of N238 was not different from the N298 treatment in majority of protein content. A descending order characterized the effects of biofertilization on protein content and is as follows: (Cerealin + Microbin) > Cerealin ≥ Microbin > non-biofertilized.

The highest increase in protein content (71%) was recorded in the plants treated with N298 + (Cerealin + Microbin) + 20Gy. The second highest (66%) was in plants of N238 + Cerealin + 20Gy.

Regarding the grain protein yield, results followed a trend rather similar to that of protein content.

The increase in protein yield could be attributed to the integrated effect of nitrogen plus bio effect of microorganisms such as N₂ fixing bacteria and P-dissolving bacteria increasing available nutrients for plant growth and accordingly maximizing the biological yield and grain quality of barley (Ewees and abdel Hafeez, 2010). Also, exudation of plant growth regulators such as auxins, gibberellin and cytokinin by *Azotobacter sp.* and *Azospirillum sp.* bacteria (Vessy, 2003) contribute to such positive effect. The maximum protein yield of (1117 kg ha⁻¹) was achieved due to N238 + Cerealin + Microbin with 40Gy gamma irradiation.

Results given in Table 4 reflected significant increases in the N concentration and uptake as affected by application of the treatments for straw and grain. The highest N content in straw and grain (11.85 and 24.9 g kg⁻¹, respectively) were produced by plants supplied by N298 + (Cerealin + Microbin) in combination with 20Gr gamma irradiation.

Table 3: Harvest index (%), grain protein content (g kg⁻¹) and grain protein yield (kg ha⁻¹) of barley as affected by gamma irradiation, biofertilizers and N rates

| N-Rate (N) kg N ha ⁻¹ | Biofertilizer (B) | Gamma irradiation dose, Gy (G) | | | | | | | | | | | |
|--|----------------------|--------------------------------|--------|--------|--------|---|-------|-------|-------|--|-------|-------|-------|
| | | 0 | 20 | 40 | Mean | 0 | 20 | 40 | Mean | 0 | 20 | 40 | Mean |
| | | Harvest index (%) | | | | Grain protein content (g kg ⁻¹) | | | | Grain protein yield (kg ha ⁻¹) | | | |
| N0 | Without | 25.0 | 47.2 | 45.5 | 39.2 | 85 | 98 | 92 | 91 | 27 | 265 | 219 | 170 |
| | Cerealine | 40.9 | 45.5 | 44.0 | 43.5 | 97 | 106 | 99 | 101 | 70 | 337 | 346 | 251 |
| | Microbin | 39.1 | 44.0 | 40.8 | 41.3 | 102 | 110 | 105 | 106 | 74 | 386 | 334 | 265 |
| | Cer.+ Mic. | 27.8 | 44.7 | 46.7 | 39.7 | 104 | 114 | 107 | 108 | 42 | 310 | 358 | 237 |
| | Mean | 33.2 | 45.4 | 44.2 | 40.9 d | 97 | 107 | 100 | 101 c | 53 | 325 | 314 | 231 c |
| N179 | Without | 43.9 | 40.4 | 47.6 | 44.0 | 92 | 102 | 95 | 96 | 265 | 310 | 760 | 445 |
| | Cerealine | 48.9 | 41.2 | 46.5 | 45.5 | 102 | 105 | 99 | 102 | 359 | 436 | 856 | 550 |
| | Microbin | 40.3 | 49.2 | 46.6 | 45.3 | 104 | 113 | 108 | 108 | 417 | 524 | 951 | 631 |
| | Cer.+ Mic. | 48.9 | 60.2 | 45.0 | 51.4 | 110 | 115 | 111 | 112 | 404 | 813 | 918 | 712 |
| | Mean | 45.5 | 47.7 | 46.4 | 46.5 b | 102 | 109 | 103 | 105 b | 361 | 521 | 871 | 584 b |
| N238 | Without | 42.9 | 55.0 | 40.0 | 46.0 | 104 | 107 | 105 | 105 | 399 | 374 | 471 | 415 |
| | Cerealine | 47.1 | 67.7 | 47.6 | 54.1 | 110 | 141 | 124 | 125 | 527 | 946 | 994 | 822 |
| | Microbin | 44.8 | 53.3 | 49.9 | 49.3 | 121 | 130 | 122 | 124 | 500 | 790 | 939 | 743 |
| | Cer.+ Mic. | 38.6 | 56.1 | 48.8 | 47.9 | 115 | 138 | 120 | 125 | 406 | 1038 | 1117 | 854 |
| | Mean | 43.3 | 58.0 | 46.6 | 49.3 a | 112 | 129 | 118 | 120 a | 458 | 787 | 880 | 708 a |
| N298 | Without | 39.6 | 47.9 | 47.5 | 45.0 | 100 | 105 | 103 | 103 | 306 | 537 | 626 | 490 |
| | Cerealine | 35.6 | 43.3 | 51.4 | 43.4 | 113 | 132 | 126 | 124 | 378 | 825 | 1049 | 751 |
| | Microbin | 34.4 | 40.3 | 51.6 | 42.1 | 114 | 136 | 115 | 122 | 381 | 675 | 942 | 666 |
| | Cer.+Mic. | 49.3 | 46.2 | 43.5 | 46.3 | 110 | 145 | 120 | 125 | 646 | 994 | 768 | 803 |
| | Mean | 39.7 | 44.4 | 48.5 | 44.2 c | 109 | 130 | 116 | 118 a | 428 | 758 | 846 | 677 a |
| Grand mean (G) | | 40.4 b | 48.9 a | 46.5 a | | 105 c | 119 a | 109 b | | 325 c | 598 b | 728 a | |
| F - test | | G: | ** | N: | ** | G: | ** | N: | ** | G: | ** | N: | ** |
| | | B: | ** | GxN: | ** | B | ** | GxN: | ** | B: | ** | GxN: | ** |
| | | GxB: | ** | BxN: | ** | GxB: | ** | BxN: | ** | GxB: | ** | BxN: | ** |
| | | GxNx B: | ** | | | GxNx B: | ** | | | GxNx B: | ** | | |
| Harvest index % = (grain yield / grains + straw yield) x 100 | | | | | | | | | | | | | |
| Means of biofertilizer | | | | | | | | | | | | | |
| Whitout | | | | 43.6 b | 99 c | | | | 380 c | | | | |
| Cerealine | | | | 46.6 a | 113 b | | | | 594 b | | | | |
| Microbin | | | | 44.5 b | 115 b | | | | 576 b | | | | |
| Cerealine+Microbin | | | | 46.3 a | 118 a | | | | 651 a | | | | |
| Grand mean | | | | 45.3 | 111 | | | | 550 | | | | |

Nitrogen content and uptake

This indicates that the addition of mineral N at high rate in presence of Cerealin and Microbin has more availability and solubility for plant and increases the ability of plant roots to uptake more elements in plant tissues by increasing the levels of nutrients in rooting zone (Hassan *et al.*, 2009).

The main effects of gamma irradiation, N-fertilization and biofertilization show the following: 40Gy > 20Gy; N238 ≥ N298 > N179 > N0 and (Cerealin + Microbin) > Cerealin ≥ Microbin > without.

Highest N uptake by straw (110 kg ha⁻¹) was obtained under applied treatment N179 + Cerealin with 40Gy gamma ray which caused an increase of 244%, while the highest N uptake by grain (191 kg ha⁻¹) was recorded in the plants treated with N238 + (Cerealin + Microbin) with 40 Gy gamma ray representing an increase of 208%.

Efficiency of applied N

Efficiency of the applied nitrogen for the different bio and irradiation treatments were calculated and the results are shown in Table 5.

Table 5: Nitrogen harvest index, NHI (kg kg⁻¹) as affected by gamma irradiation, biofertilizers and N rates

| N-Rate (N) kg N ha ⁻¹ | Biofertilizer (B) | Gamma irradiation dose, Gy (G) | | | |
|-------------------------------------|-------------------|--------------------------------|--------|--------|--------|
| | | 0 | 20 | 40 | Mean |
| N0 | Without | 0.41 | 0.66 | 0.69 | 0.59 |
| | Cerealin | 0.60 | 0.64 | 0.65 | 0.63 |
| | Microbin | 0.58 | 0.62 | 0.62 | 0.60 |
| | Cer.+ Mic. | 0.43 | 0.65 | 0.66 | 0.58 |
| | Mean | 0.51 | 0.64 | 0.65 | 0.60 c |
| N179 | Without | 0.60 | 0.61 | 0.61 | 0.60 |
| | Cerealin | 0.62 | 0.60 | 0.57 | 0.60 |
| | Microbin | 0.56 | 0.68 | 0.63 | 0.62 |
| | Cer.+ Mic. | 0.67 | 0.78 | 0.64 | 0.69 |
| | Mean | 0.61 | 0.67 | 0.61 | 0.63 b |
| N238 | Without | 0.60 | 0.70 | 0.59 | 0.63 |
| | Cerealin | 0.64 | 0.82 | 0.67 | 0.71 |
| | Microbin | 0.65 | 0.72 | 0.70 | 0.69 |
| | Cer.+ Mic. | 0.55 | 0.75 | 0.67 | 0.66 |
| | Mean | 0.61 | 0.75 | 0.66 | 0.67 a |
| N298 | Without | 0.58 | 0.65 | 0.68 | 0.63 |
| | Cerealin | 0.54 | 0.62 | 0.73 | 0.63 |
| | Microbin | 0.54 | 0.64 | 0.72 | 0.63 |
| | Cer.+ Mic. | 0.63 | 0.64 | 0.63 | 0.63 |
| | Mean | 0.57 | 0.64 | 0.69 | 0.63 b |
| Grand mean (G) | | 0.57 b | 0.67 a | 0.65 a | |
| F – test | | G: | ** | N: | ** |
| | | B: | ** | GxN: | ** |
| | | GxB.: | * | BxN: | ** |
| | | GxNx B: | ** | | |
| Means of biofertilizer | | | | | |
| Whitout | | | 0.61 b | | |
| Cerealin | | | 0.64 a | | |
| Microbin | | | 0.64 a | | |
| Cerealin+Microbin | | | 0.64 a | | |
| Grand mean | | | 0.63 | | |

Nitrogen harvest index, (NHI)

NHI which is the N uptake in grains in relation to the N-uptake in grains + straw followed a trend of increase up to N238 followed by a decrease at N298. The main effects of gamma irradiation, N rates and biofertilizer treatments showed a descending increase in the order: 20Gy \geq 40Gy; N238 \geq N298 = N179 > N0; Cerealin \geq Cerealin + Microbin \geq Microbin \geq without. Alves *et al.*, (2003) found no significant effect of N applications or bioinoculation on NHI values for soybeans. The lowest value of NHI (0.41 kg kg⁻¹) was recorded for the untreated plants. Low NHI indicates low N translocation from shoots to grains and this might be because of the high N requirements of barley plants inoculated with Cerealin that received 238 kg N ha⁻¹ and irradiated with 20Gr gamma ray recorded the highest NHI value (0.82 kg kg⁻¹) indicating 36.7% increase compared with the same treatment which received N179 and this indicates high translocation of N from shoots to grains.

Response curve

Fig. 1 presents the response of barley grain yield to nitrogen fertilization under three levels of gamma irradiation (A) and Biofertilization (B). As seen in the Fig.1 (A), the grain yield increased with increasing N rate up to 238 kg N ha⁻¹ with 0Gy irradiation and 20Gy gamma ray irradiated and then decreased gradually. Under 40Gy irradiation, it increased with increasing N rate up to 179 kg N ha⁻¹ then decreased the rate of increase with 40Gy gamma ray in combination with nitrogen rates was higher than the other irradiation of 20Gy gamma ray.

The biofertilization increased grain yield when N was increased up to N238 and then decreased. The rate of increase in grain yield for the Cerealin + Microbin with N rates application was higher than the other bio treatments.

Phosphorus uptake

Phosphorus content and uptake by barley straw and grain increased significantly as a result of N application, biofertilization and irradiation (Table 6) singly or in combinations. The positive effect of biofertilization is due to increased availability of P (Metwally, 2000). These findings are in agreement with those reported by El-Sebaey (2006) and Ibrahim *et al.* (2008).

The main effects of gamma irradiation, N application and biofertilization showed a descending increase for P uptake by grains in the order: 40Gy > 20Gy; N238 \geq N179 \geq N298 > N0 and Cerealin + Microbin > Microbin \geq Cerealin > without.

The highest P contents of 2.35 and 6.87 g kg⁻¹ in straw and grains, respectively were observed due to N238 + Microbin with 20Gy gamma ray and N179 + Cerealin irradiated with 40Gy gamma ray, respectively. The highest P uptake values for straw and grains (15.71 and 59.16 kg ha⁻¹, respectively) were obtained in plants treated with N238 + (Cerealin + Microbin) with 40Gy gamma ray and N179 + Cerealin with 40Gy gamma ray, respectively.

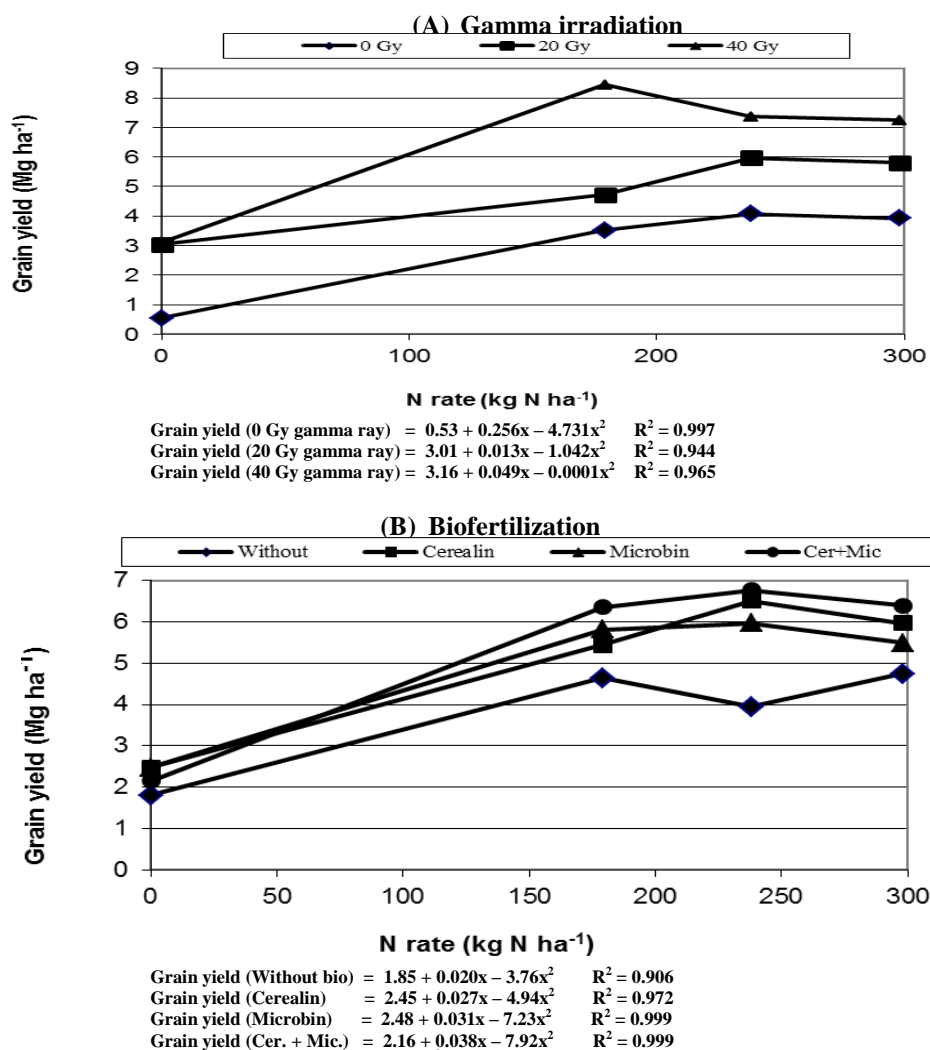


Fig.1: Response of grain yield (kg ha⁻¹) of barley to nitrogen rates as affected by gamma irradiation doses (a) and biofertilization (b)

Potassium uptake

As shown in Table 7, K content and uptake in straw and grains followed a rather similar as trend of that for N and increased significantly owing to application of gamma irradiation, nitrogen application and biofertilization. As for the effect of irradiation with gamma ray, the main effect shows 40 Gy > 20Gy gamma ray. The main effect of biofertilization shows: Microbin + Cerealin > Microbin > Cerealin > without biofertilization. The Main effect of N shows the order: N238 ≥ N179 ≥ N298 > N0 for K content in straw; N179 > N298 ≥ N238 > N0 for K content in grains; N298 > N179 > N238 > N0 for K uptake by straw. The pattern concerning response of K-uptake in grains is N179 ≥ N298 ≥ N238 > N0.

The maximum values of K uptake by straw and grain (62.87 and 35.06 kg ha⁻¹, respectively) were obtained due N238 + (Cerealin + Microbin) with 40Gy gamma ray for straw and N179 + Microbin irradiated with 40Gy gamma ray, for grains. Increases were 173% and 213%, respectively over the non-treated.

CONCLUSION

The nitrogen rate of 238 kg N ha⁻¹ when applied in combination with biofertilizers for plants irradiated with 20 or 40Gy gamma ray was superior to the other rates for enhancing barley yield and nutrient uptake. Biofertilization using N₂-fixing bacteria with or without P-dissolving bacteria could reduce requirements of chemical N-fertilizer with no toxic substances accumulating in the food chain. Reducing chemical fertilizer play a great role to protect environment from chemical pollution.

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**إستجابة الشعير النامي في الأرض الرملية (*Hordeum vulgare* L.) لتشيع
البذور بأشعة جاما ، التسميد النيتروجيني و الحيوي
أيمن محمود حلمي
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يعد معاملة النقاوي قبل الزراعة بأشعة جاما واحدة من أهم الطرق الفعالة لتحسين إنتاجية المحاصيل و مكوناتها وكذلك تركيبها الكيماوي لذلك تم إجراء تجربة حقلية باستخدام تصميم القطع المنشقة مرتين التامة كاملة العشوائية والمحتوية علي ثلاث مكررات وذلك بمحطة البحوث الخاصة بكلية الزراعة جامعة الزقازيق بمنطقة الخطارة – محافظة الشرقية خلال الموسم الشتوي 2010/2009 م. تم توزيع حبوب الشعير المعاملة بجرعات التشيع بأشعة جاما بثلاث معدلات (0 ، 20 و 40 جراي) في القطع الرئيسية بينما اشتملت القطع المنشقة الأولى علي معاملات التسميد النيتروجيني بسلفات الأمونيوم من خلال أربع معدلات (0 ، 119 ، 238 و 298 كيلو جرام ن الهكتار⁻¹) و القطع المنشقة الثانية عوملت بأربع معاملات للتسميد الحيوي (بدون ، السريالين ، الميكروبيين و السريالين + الميكروبيين) وقد أوضحت النتائج المتحصل عليها ما يلي:- إزداد محصول الشعير ومكوناته وكذلك محتوى القش و الحبوب من النيتروجين و الفسفور و البوتاسيوم معنوياً نتيجة المعاملة بأشعة جاما ، التسميد النيتروجيني بمعدلاته و التسميد الحيوي. إزداد معنوياً عدد السنبال للمتر المربع ، وزن الحبوب للسنبلة ، المحصول البيولوجي ، محصول الحبوب ، النيتروجين الممتص للحبوب ، الفسفور الممتص للقش و البوتاسيوم الممتص للقش وأعطت جميعها أعلى قيم نتيجة للمعاملة ن 238 + (السريالين + الميكروبيين) مع معاملة التشيع الجامي بجرعة 40 جراي. أعلى محصول للقش تم الحصول عليه نتيجة المعاملة ن 179 + (السريالين + الميكروبيين) مع معاملة التشيع الجامي بجرعة 40 جراي. أعطت المعاملة ن 179 + السريالين مع معاملة التشيع الجامي بجرعة 40 جراي أقصى محتوى للنيتروجين الممتص بالقش ، محتوى الفسفور للقش و الحبوب و كذلك محتوى الفسفور الممتص للحبوب. أنخفضت كفاءة النيتروجين المستخدم بزيادة معدلات النيتروجين المضافة وأعطى المعدل المنخفض ن 179 في وجود الميكروبيين مع معاملة التشيع الجامي بجرعة 40 جراي. إزداد محتوى البروتين ومحصوله معنوياً نتيجة للمعاملات المختلفة المستخدمة بالدراسة خاصة مع زيادة معدلات النيتروجين حتي 298 كجم ن الهكتار⁻¹ و التي أعطت أقصى محتوى للبروتين بالإشتراك مع الميكروبيين و التشيع الجامي 40 جراي. من النتائج المتحصل عليها يوصي باستخدام التسميد النيتروجيني بمعدل 238 كجم ن للهكتار في وجود التسميد الحيوي مع تشيع البذور قبل الزراعة بجرعات 20 أو 40 جراي حيث كانت الأفضل بالمقارنة بباقي المعاملات وأدت لتحسين إنتاجية وأمتصاص العناصر الغذائية بواسطة الشعير.

قام بتحكيم البحث

**كلية الزراعة – جامعة المنصورة
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Table 4: N content (g kg⁻¹) and N-uptake (kg ha⁻¹) by barley as affected by gamma irradiation, biofertilizers and N rates

| | | Gamma irradiation dose, Gy (G) | | | | | | | | | | | | | | | |
|-------------------------------------|----------------------|---------------------------------|--------|--------|----------|---------------------------------|--------|--------|----------|---------------------------------|--------|--------|----------|---------------------------------|-------|-------|----------|
| N-Rate (N) kg N ha ⁻¹ | Biofertilizer (B) | 0 | 20 | 40 | Mean | 0 | 20 | 40 | Mean | 0 | 20 | 40 | Mean | 0 | 20 | 40 | Mean |
| | | N-content (g kg ⁻¹) | | | | N-uptake (kg ha ⁻¹) | | | | N-content (g kg ⁻¹) | | | | N-uptake (kg ha ⁻¹) | | | |
| | | Straw | | | | | | | | Grain | | | | | | | |
| N0 | Without | 7.10 | 7.70 | 5.90 | 6.90 | 6.82 | 23.4 | 17.0 | 15.7 | 14.5 | 16.8 | 15.7 | 15.7 | 4.64 | 45.7 | 37.7 | 29.3 |
| | Cerealain | 7.70 | 8.30 | 7.10 | 7.70 | 8.01 | 31.9 | 31.8 | 23.9 | 16.7 | 18.2 | 16.9 | 17.3 | 12.0 | 58.2 | 59.5 | 43.3 |
| | Microbin | 8.30 | 8.90 | 7.70 | 8.30 | 9.30 | 39.9 | 35.7 | 28.3 | 17.5 | 18.8 | 18.0 | 18.1 | 12.6 | 66.2 | 57.6 | 45.5 |
| | Cer.+ Mic. | 8.90 | 8.55 | 8.30 | 8.58 | 9.26 | 28.7 | 31.9 | 23.3 | 17.8 | 19.5 | 18.3 | 18.5 | 7.12 | 53.0 | 61.5 | 40.5 |
| | Mean | 8.00 | 8.36 | 7.25 | 7.87 c | 8.34 | 31.0 | 29.1 | 22.8 c | 16.6 | 18.3 | 17.2 | 17.4 c | 9.10 | 55.8 | 54.1 | 39.6 c |
| N179 | Without | 8.30 | 7.70 | 9.45 | 8.48 | 30.5 | 34.5 | 83.2 | 49.4 | 15.8 | 17.5 | 16.3 | 16.5 | 45.5 | 53.2 | 130 | 76.4 |
| | Cerealain | 10.1 | 8.30 | 11.1 | 9.82 | 37.2 | 49.1 | 110.1 | 65.5 | 17.5 | 18.0 | 17.0 | 17.5 | 61.6 | 74.9 | 147 | 94.5 |
| | Microbin | 9.45 | 8.90 | 9.55 | 9.30 | 55.9 | 42.7 | 96.5 | 65.0 | 17.9 | 19.4 | 18.5 | 18.6 | 71.6 | 90.0 | 163 | 108 |
| | Cer.+ Mic. | 9.00 | 8.60 | 8.90 | 8.83 | 34.6 | 39.9 | 90.8 | 55.1 | 18.8 | 19.8 | 19.0 | 19.2 | 69.2 | 139 | 158 | 122 |
| | Mean | 9.20 | 8.38 | 9.75 | 9.11 b | 39.6 | 41.6 | 95.1 | 58.7 b | 17.5 | 18.7 | 17.7 | 17.9 b | 62.0 | 89.4 | 150 | 100 b |
| N238 | Without | 8.90 | 9.45 | 8.30 | 8.88 | 45.6 | 27.2 | 55.8 | 42.9 | 17.8 | 18.3 | 18.0 | 18.0 | 68.4 | 64.4 | 80.6 | 71.1 |
| | Cerealain | 9.45 | 11.3 | 9.45 | 10.1 | 51.4 | 36.2 | 83.2 | 56.9 | 18.8 | 24.1 | 21.3 | 21.4 | 90.2 | 162 | 170 | 141 |
| | Microbin | 9.00 | 10.1 | 8.90 | 9.32 | 46.1 | 53.3 | 68.4 | 55.9 | 20.7 | 22.3 | 21.0 | 21.3 | 86.1 | 136 | 161 | 128 |
| | Cer.+ Mic. | 10.1 | 9.95 | 9.45 | 9.82 | 56.6 | 58.9 | 92.2 | 69.2 | 19.8 | 23.7 | 20.6 | 21.4 | 69.7 | 178 | 191 | 146 |
| | Mean | 9.35 | 10.2 | 9.03 | 9.52 a | 49.9 | 43.9 | 74.9 | 56.2 b | 19.3 | 22.1 | 20.2 | 20.5 a | 78.6 | 135 | 151 | 122 a |
| N298 | Without | 8.30 | 8.90 | 7.70 | 8.30 | 38.5 | 49.8 | 51.7 | 46.7 | 17.2 | 18.0 | 17.6 | 17.6 | 52.3 | 92.2 | 107 | 83.8 |
| | Cerealain | 8.90 | 10.7 | 8.30 | 9.28 | 54.1 | 87.3 | 65.1 | 68.8 | 19.3 | 22.7 | 21.6 | 21.2 | 64.8 | 142 | 180 | 129 |
| | Microbin | 8.55 | 9.00 | 8.30 | 8.62 | 54.7 | 66.2 | 63.7 | 61.6 | 19.5 | 23.3 | 19.8 | 20.9 | 65.5 | 116 | 162 | 114 |
| | Cer.+ Mic. | 10.7 | 11.9 | 9.45 | 10.65 | 65.1 | 95.2 | 78.6 | 79.6 | 18.8 | 24.9 | 20.6 | 21.4 | 111 | 171 | 132 | 138 |
| | Mean | 9.10 | 10.1 | 8.44 | 9.21 b | 53.1 | 74.6 | 64.8 | 64.2 a | 18.7 | 22.2 | 19.9 | 20.3 a | 73.5 | 130 | 145 | 116 a |
| Grand means | | 8.91 b | 9.24 a | 8.63 c | | 37.7 c | 47.8 b | 66.0 a | | 18.0 c | 20.3 a | 18.8 b | | 56.0 c | 103 b | 125 a | |
| F - test | G: | | ** | N: | | G: | | N: | | G: | | N: | | G: | | N: | |
| | B: | | ** | GxN: | | B: | | GxN: | | B: | | GxN: | * | B: | | GxN: | ** |
| | GxB.: NS | | BxN: | | GxB.: NS | | BxN: | | GxB.: NS | | BxN: | | GxB.: NS | | BxN: | | GxB.: NS |
| | GxNxB: ** | | | | | GxNxB: ** | | | | GxNxB: ** | | | | GxNxB: ** | | | |
| Means of biofertilizer | | | | | | | | | | | | | | | | | |
| Whitout | | 8.15 d | | | | 38.7 c | | | | 1.70 c | | | | 65.2 c | | | |
| Cerealain | | 9.20 b | | | | 53.8 ab | | | | 1.93 a | | | | 102 b | | | |
| Microbin | | 8.85 c | | | | 52.7 b | | | | 1.97 b | | | | 98.9 b | | | |
| Cerealain+Microbin | | 9.45 a | | | | 56.8 a | | | | 2.01 a | | | | 114 a | | | |
| Grand mean | | 8.91 | | | | 50.5 | | | | 1.90 | | | | 95.0 | | | |

Table 6. P-content (g kg⁻¹) and P-uptake (kg ha⁻¹) by barley as affected by gamma irradiation, biofertilizers and N rates

| | | Gamma irradiation dose, Gy (G) | | | | | | | | | | | | | | | |
|-------------------------------------|----------------------|---------------------------------|--------|--------|--------|---------------------------------|--------|--------|--------|---------------------------------|--------|--------|--------|---------------------------------|--------|--------|--------|
| N-Rate (N) kg N ha ⁻¹ | Biofertilizer (B) | 0 | 20 | 40 | Mean | 0 | 20 | 40 | Mean | 0 | 20 | 40 | Mean | 0 | 20 | 40 | Mean |
| | | P-content (g kg ⁻¹) | | | | P-uptake (kg ha ⁻¹) | | | | P-content (g kg ⁻¹) | | | | P-uptake (kg ha ⁻¹) | | | |
| | | Straw | | | | | | | | Grain | | | | | | | |
| N0 | Without | 0.06 | 0.46 | 0.22 | 0.25 | 0.07 | 1.41 | 0.62 | 0.70 | 4.15 | 4.43 | 4.36 | 4.32 | 1.33 | 12.1 | 10.6 | 7.99 |
| | Cereal | 0.11 | 0.86 | 0.56 | 0.51 | 0.12 | 3.31 | 2.49 | 1.97 | 4.32 | 4.68 | 5.39 | 4.79 | 3.11 | 15.0 | 18.9 | 12.3 |
| | Microbin | 0.26 | 0.98 | 0.64 | 0.63 | 0.29 | 4.37 | 2.95 | 2.54 | 4.43 | 5.90 | 6.66 | 5.66 | 3.19 | 20.8 | 21.4 | 15.1 |
| | Cer.+ Mic. | 0.16 | 0.88 | 0.61 | 0.55 | 0.16 | 2.94 | 2.36 | 1.82 | 4.49 | 6.00 | 6.75 | 5.74 | 1.80 | 16.3 | 22.8 | 13.6 |
| | Mean | 0.15 | 0.79 | 0.51 | 0.48 d | 0.16 | 3.01 | 2.10 | 1.76 d | 4.35 | 5.25 | 5.79 | 5.13 b | 2.36 | 16.0 | 18.4 | 12.3 a |
| N179 | Without | 0.07 | 0.875 | 0.79 | 0.58 | 0.27 | 3.92 | 6.91 | 3.70 | 4.25 | 4.43 | 5.30 | 4.66 | 12.2 | 13.5 | 42.5 | 22.7 |
| | Cereal | 0.14 | 1.329 | 1.16 | 0.88 | 0.50 | 7.89 | 11.6 | 6.65 | 5.30 | 5.90 | 6.86 | 6.02 | 18.7 | 24.6 | 59.2 | 34.1 |
| | Microbin | 0.22 | 1.991 | 1.39 | 1.20 | 1.33 | 9.56 | 14.1 | 8.31 | 5.59 | 6.12 | 6.52 | 6.08 | 22.4 | 28.4 | 57.4 | 36.0 |
| | Cer.+ Mic. | 0.19 | 1.865 | 1.32 | 1.12 | 0.71 | 8.69 | 13.5 | 7.64 | 5.65 | 6.24 | 5.58 | 5.82 | 20.8 | 43.9 | 46.6 | 37.1 |
| | Mean | 0.16 | 1.52 | 1.17 | 0.95 c | 0.70 | 7.52 | 11.5 | 6.58 c | 5.20 | 5.67 | 6.06 | 5.64 a | 18.5 | 27.6 | 51.4 | 32.5 a |
| N238 | Without | 0.08 | 1.23 | 1.09 | 0.80 | 0.42 | 3.55 | 7.33 | 3.77 | 4.36 | 5.13 | 5.02 | 4.84 | 16.7 | 18.1 | 22.5 | 19.1 |
| | Cereal | 0.11 | 1.99 | 1.58 | 1.23 | 0.60 | 6.37 | 13.9 | 6.94 | 5.41 | 5.34 | 5.26 | 5.33 | 26.0 | 35.9 | 41.9 | 34.6 |
| | Microbin | 0.30 | 2.35 | 1.69 | 1.45 | 1.53 | 12.5 | 13.1 | 9.04 | 6.34 | 6.46 | 5.59 | 6.13 | 26.4 | 39.3 | 43.1 | 36.2 |
| | Cer.+ Mic. | 0.20 | 2.12 | 1.61 | 1.31 | 1.10 | 12.4 | 15.7 | 9.75 | 6.20 | 6.28 | 5.74 | 6.07 | 21.8 | 47.2 | 53.3 | 40.8 |
| | Mean | 0.17 | 1.92 | 1.49 | 1.20 a | 0.91 | 8.72 | 12.5 | 7.38 b | 5.58 | 5.80 | 5.40 | 5.59 a | 22.7 | 35.1 | 40.2 | 32.7 a |
| N298 | Without | 0.07 | 1.17 | 1.04 | 0.76 | 0.32 | 6.50 | 6.88 | 4.57 | 4.49 | 4.66 | 4.66 | 4.60 | 13.7 | 23.9 | 28.5 | 22.0 |
| | Cereal | 0.11 | 1.66 | 1.47 | 1.08 | 0.66 | 13.5 | 11.6 | 8.61 | 5.30 | 6.52 | 5.22 | 5.68 | 17.8 | 40.7 | 43.7 | 34.1 |
| | Microbin | 0.26 | 1.85 | 1.54 | 1.22 | 1.68 | 13.6 | 11.8 | 9.03 | 5.95 | 6.87 | 5.40 | 6.07 | 20.0 | 34.1 | 44.2 | 32.8 |
| | Cer.+ Mic. | 0.30 | 1.77 | 1.46 | 1.18 | 1.82 | 14.2 | 12.2 | 9.40 | 5.59 | 6.49 | 5.58 | 5.89 | 33.1 | 44.6 | 35.9 | 37.9 |
| | Mean | 0.19 | 1.61 | 1.38 | 1.06 b | 1.12 | 12.0 | 10.6 | 7.90 a | 5.33 | 6.13 | 5.22 | 5.56 a | 21.1 | 35.8 | 38.1 | 31.7 a |
| Grand means | | 0.17 c | 1.46 a | 1.14 b | | 0.72 c | 7.78 b | 9.19 a | | 5.11 b | 5.72 a | 5.62 a | | 16.2 c | 28.3 b | 37.0 a | |
| F - test | G: | ** | | N: | ** | | G: | ** | N: | ** | G: | ** | N: | ** | G: | ** | N: |
| | B: | ** | | GxN: | ** | | B: | ** | GxN: | ** | B: | ** | GxN: | * | B: | ** | GxN: |
| | GxB: | ** | | BxN: | ** | | GxB: | ** | BxN: | ** | GxB: | NS | BxN: | NS | GxB: | ** | BxN: |
| | GxNB: | ** | | | | | GxNB: | ** | | | GxNB: | ** | | | GxNB: | ** | |
| Means of biofertilizer | | | | | | | | | | | | | | | | | |
| Whitout | | | 0.60 d | | | | | 3.19 c | | | | 4.61 c | | | | 18.0 c | |
| Cereal | | | 0.92 c | | | | | 6.03 b | | | | 5.46 b | | | | 28.8 b | |
| Microbin | | | 1.12 a | | | | | 7.23 a | | | | 5.99 a | | | | 30.1 b | |
| Cereal+Microbin | | | 1.04 b | | | | | 7.14 a | | | | 5.88 a | | | | 31.9 a | |
| Grand mean | | | 0.92 | | | | | 4.53 | | | | 5.49 | | | | 27.2 | |

Table 7: K content (g kg⁻¹) and K-uptake (kg ha⁻¹) by barley as affected by gamma irradiation, biofertilizers and N rates

| | | Gamma irradiation dose (Gy) | | | | | | | | | | | | | | | |
|-------------------------------------|----------------------|---------------------------------|--------|--------|---------|---------------------------------|--------|--------|---------|---------------------------------|--------|--------|---------|---------------------------------|--------|--------|--------|
| N-Rate (N) kg N ha ⁻¹ | Biofertilizer (B) | 0 | 20 | 40 | Mean | 0 | 20 | 40 | Mean | 0 | 20 | 40 | Mean | 0 | 20 | 40 | Mean |
| | | K-content (g kg ⁻¹) | | | | K-uptake (kg ha ⁻¹) | | | | K-content (g kg ⁻¹) | | | | K-uptake (kg ha ⁻¹) | | | |
| | | Straw | | | | | | | | Grain | | | | | | | |
| N0 | Without | 2.73 | 3.35 | 4.14 | 3.41 | 2.62 | 10.2 | 11.9 | 8.25 | 1.17 | 1.37 | 2.60 | 1.71 | 0.37 | 3.72 | 6.30 | 3.46 |
| | Cerealain | 3.63 | 4.56 | 4.76 | 4.32 | 3.78 | 17.5 | 21.4 | 14.2 | 1.95 | 1.69 | 2.86 | 2.17 | 1.41 | 5.42 | 10.1 | 5.65 |
| | Microbin | 4.39 | 3.96 | 5.57 | 4.64 | 4.92 | 17.7 | 25.9 | 16.2 | 2.86 | 2.73 | 3.53 | 3.04 | 2.06 | 9.62 | 11.2 | 7.63 |
| | Cer.+ Mic. | 3.89 | 4.14 | 6.00 | 4.67 | 4.04 | 13.9 | 23.0 | 13.7 | 2.15 | 2.86 | 3.69 | 2.90 | 0.86 | 7.79 | 12.4 | 7.03 |
| | Mean | 3.66 | 4.00 | 5.12 | 4.26 b | 3.84 | 14.8 | 20.6 | 13.1 | 2.03 | 2.16 | 3.17 | 2.46 c | 1.18 | 6.64 | 10.0 | 5.94 b |
| N179 | Without | 3.80 | 4.22 | 4.65 | 4.22 | 14.0 | 18.9 | 40.9 | 24.6 | 2.21 | 2.47 | 2.99 | 2.56 | 6.37 | 7.52 | 24.2 | 12.7 |
| | Cerealain | 4.65 | 4.04 | 5.24 | 4.64 | 17.1 | 24.0 | 52.0 | 31.0 | 2.99 | 2.86 | 3.46 | 3.11 | 10.5 | 11.9 | 29.9 | 17.4 |
| | Microbin | 3.97 | 4.39 | 6.08 | 4.81 | 23.5 | 21.1 | 61.5 | 35.4 | 2.47 | 2.99 | 3.97 | 3.15 | 9.90 | 13.9 | 35.1 | 19.6 |
| | Cer.+ Mic. | 4.04 | 4.22 | 5.90 | 4.72 | 15.5 | 19.7 | 59.9 | 31.7 | 2.60 | 2.95 | 4.05 | 3.20 | 9.58 | 20.8 | 33.8 | 21.4 |
| | Mean | 4.11 | 4.22 | 5.47 | 4.60 a | 17.5 | 20.9 | 53.6 | 30.7ab | 2.57 | 2.82 | 3.62 | 3.00 a | 9.10 | 13.5 | 30.7 | 17.8 a |
| N238 | Without | 2.86 | 4.39 | 4.85 | 4.03 | 14.7 | 12.7 | 32.7 | 20.0 | 1.69 | 2.21 | 2.60 | 2.17 | 6.50 | 7.79 | 11.7 | 8.67 |
| | Cerealain | 3.63 | 5.07 | 5.57 | 4.76 | 19.6 | 16.2 | 49.1 | 28.3 | 1.95 | 3.46 | 3.29 | 2.90 | 9.37 | 23.3 | 26.4 | 19.7 |
| | Microbin | 4.22 | 3.46 | 6.51 | 4.73 | 21.6 | 18.4 | 50.6 | 30.2 | 2.08 | 2.86 | 3.38 | 2.78 | 8.67 | 17.4 | 26.1 | 17.4 |
| | Cer.+ Mic. | 4.13 | 4.65 | 6.46 | 5.08 | 23.1 | 27.3 | 62.9 | 37.8 | 2.86 | 2.99 | 3.46 | 3.11 | 10.08 | 22.5 | 32.2 | 21.6 |
| | Mean | 3.71 | 4.39 | 5.85 | 4.65 a | 19.8 | 18.7 | 48.8 | 29.1 b | 2.15 | 2.88 | 3.18 | 2.74 b | 8.66 | 17.8 | 24.1 | 16.8 a |
| N298 | Without | 2.34 | 4.05 | 4.22 | 3.54 | 10.9 | 22.6 | 28.5 | 20.7 | 1.56 | 2.34 | 3.63 | 2.51 | 4.75 | 12.0 | 22.2 | 13.0 |
| | Cerealain | 4.56 | 4.39 | 4.90 | 4.62 | 27.7 | 35.8 | 38.6 | 34.1 | 1.95 | 2.60 | 3.13 | 2.56 | 6.56 | 16.3 | 26.1 | 16.3 |
| | Microbin | 3.29 | 5.49 | 5.74 | 4.84 | 21.1 | 40.3 | 44.0 | 35.1 | 2.04 | 2.86 | 4.05 | 2.99 | 6.84 | 14.2 | 33.2 | 18.1 |
| | Cer.+ Mic. | 4.42 | 5.57 | 5.66 | 5.22 | 26.8 | 44.7 | 47.1 | 39.6 | 2.08 | 3.13 | 4.31 | 3.17 | 12.33 | 21.5 | 27.6 | 20.5 |
| | Mean | 3.65 | 4.88 | 5.13 | 4.55 a | 21.6 | 35.9 | 39.6 | 32.4 a | 1.91 | 2.73 | 3.78 | 2.81 b | 7.62 | 16.0 | 27.3 | 17.0 a |
| Grand mean | | 3.79 c | 4.37 b | 5.39 a | | 15.7 c | 22.5 b | 40.7 a | | 2.17 c | 2.65 b | 3.44 a | | 6.66 c | 13.5 b | 23.0 a | |
| F - test | G: | ** | N: | ** | G: | ** | N: | ** | G: | ** | N: | ** | G: | ** | N: | ** | |
| | B: | ** | GxN: | ** | B: | ** | GxN: | ** | B: | ** | GxN: | ** | B: | ** | GxN: | ** | |
| | GxB: | ** | BxN: | ** | GxB: | ** | BxN: | ** | GxB: | ** | B x N: | ** | GxB: | ** | BxN: | ** | |
| | GxNx B: | ** | | | GxNx B: | ** | | | GxNx B: | ** | | | GxNx B: | ** | | | |
| Means of biofertilizer | | | | | | | | | | | | | | | | | |
| Whitout | | | | | 3.80 d | | | | | | 2.24 d | | | | | | 9.48 d |
| Cerealain | | | | | 4.58 c | | | | | | 2.69 c | | | | | | 14.8 c |
| Microbin | | | | | 4.76 b | | | | | | 2.99 b | | | | | | 15.7 b |
| Cerealain+Microbin | | | | | 4.92 a | | | | | | 3.10 a | | | | | | 17.6 a |
| Grand mean | | | | | 4.52 | | | | | | 2.76 | | | | | | 14.4 |