

Effect of Bio-Nitrogen as a Partial Alternative to Mineral-Nitrogen Fertiliser on Growth, Nitrate and Nitrite Contents, and Yield Quality in *Brassica oleracea* L.

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Abstract—Effects of bio-nitrogen fertilizer (bio-N), as a partial alternative to mineral-nitrogen fertilizer (mineral-N), on growth, yield and yield quality of broccoli plants were investigated. Bio-N was applied at 1, 2 or 3 doses in combination with 65% of the recommended dose of mineral-N (bio-N₁, bio-N₂ or bio-N₃ + $\frac{1}{2}$ mineral-N). However, 100% of the recommended dose of mineral-N was applied as a control. Significant positive influences of the bio-N₃ + $\frac{1}{2}$ mineral-N treatment were observed on growth traits, leaf contents of nitrogen, phosphorus, potassium, nitrate and nitrite, and yield quality when compared to the other two combined treatments. In contrast, there were no significant differences in these parameters between the bio-N₃ + $\frac{1}{2}$ mineral-N and the control treatments, except for leaf contents of nitrate and nitrite. They showed lower contents in the bio-N₃ + $\frac{1}{2}$ mineral-N treatment than the control. Therefore, we recommend using bio-N as a partial alternative to mineral-N for healthy nutrition.

Keywords—Bio-fertilization, broccoli, growth, nitrate, nitrite, yield quality.

I. INTRODUCTION

MINERAL nutrition is one of the most important factors for plant growth and yield. Mineral fertilizers, particularly mineral-nitrogen, are important means of plant nutrition; however, they are also a potential source of environmental pollution [1]. An attention has therefore focused on alternative fertilizers, including bio-fertilizers in Middle East. Nowadays, there is renewed interest in bio-fertilizers for nutrient supply and improve soil fertility and productivity in this region. The integrated use of bio-fertilizers and mineral fertilizers is considered as the best option not only to reduce the intensive consumption of chemical fertilizers, but also to sustain the soil with minimum undesirable impacts and to maximize fertilizer use efficiency in soil [2]-[4].

Bio-fertilizers are considered as eco-friendly way to sustainable agriculture. They positively affect plant growth

and yield, reduce the negative effects of chemical fertilizers and minimize some chemicals such as NO₃⁻ and NO₂⁻ ions in the soil and consequently in plants. Therefore, the way to a healthy agriculture with a minimum pollution requires a conjunctive use of bio-nitrogen and mineral-nitrogen fertilizers.

Bio-fertilizers, microbial inoculants that can promote plant growth and productivity, are internationally accepted as an alternative source of N-fertilizer. In the bio-fertilizer technology, new systems are being developed to increase the biological N₂-fixation with cereals and other non-legumes by establishing N₂-fixing bacteria within the roots [5]. The mechanisms by which bio-fertilizers can exert a positive effect on plant growth can be through the synthesis of phytohormones, N₂-fixation, reduction in membrane potential of roots, synthesis of some enzymes (such as ACC deaminase) that modulate the level of plant hormones. Free living nitrogen-fixing bacteria such as *Azotobacter* and *Azospirillum* have the ability not only to fix nitrogen but also to release certain phytohormones i.e. GA₃, IAA, and cytokinins which could stimulate plant growth and increase the availability of nutrients for plant roots by the increase in their dissolution. In addition, the increase in the capacity of photosynthesis is process in [6]-[8]. Several reports indicated that the inoculation of some plants with bio-fertilizers singly or in combination with mineral fertilizers improved plant growth, yield and chemical composition [9]-[11]. Inoculation of potato tuber seeds with bio-fertilizer [*Azotobacter chroococcum* (AT) + *Azospirillum brasilense* (AZ)] significantly increased growth and yield and its components [11], [12]. The application of bio-fertilizers increased the ability to convert N₂ to NH₄ and thus make it available to plants, and enhanced the concentration of nitrogen, phosphorus and potassium in onion [10], [13].

Recently, an attention has focused on the increase in the production of some untraditional vegetable crops, including broccoli, because of their great importance. Broccoli has enormous nutritional and medicinal values due to its high content of vitamins (A, B₁, B₂, B₅, B₆ and E), minerals (Ca, Mg, Zn and Fe) and a number of antioxidants [14], [15], which prevent the formation of cancer-causing agents [16]. It is, therefore, widely cultivated in many European and

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American countries, but in Egypt it still grown in limited areas. The total cultivated area is not exactly known [17].

The objective of this study was to assess the effect of 65% of the recommended dose of mineral-nitrogen fertilizer in combination with bio-nitrogen fertilizer (*Azotobacter*

chroococcum + *Azospirillum brasilense*) in 1, 2 or 3 doses on the growth, nitrate and nitrite contents as contaminated agents, and yield quality in broccoli (*Brassica oleracea* L. var. *italica*) grown under Middle East conditions.

TABLE I

PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE EXPERIMENTAL SOIL BEFORE APPLICATION OF TREATMENTS (BT) AND AT WEEK-9 AFTER APPLICATION OF BIO-FERTILIZATION (AT) IN 2010/2011 AND 2011/2012 SEASONS

| Composition [% (w/w)] | | | pH | EC (dS m ⁻¹) | OC [#] (g kg ⁻¹) | N (mg kg ⁻¹) | P (mg kg ⁻¹) | K (mg kg ⁻¹) | Ca (mg kg ⁻¹) | Fe (mg kg ⁻¹) | Mn (mg kg ⁻¹) | Zn (mg kg ⁻¹) |
|--|------|------|-----|-----------------------------|--|-----------------------------|-----------------------------|-----------------------------|------------------------------|------------------------------|------------------------------|------------------------------|
| Clay | Loam | Sand | | | | | | | | | | |
| BT, 2010/2011 | | | | | | | | | | | | |
| 49.2 | 21.6 | 29.2 | 7.9 | 3.0 | 11.8 | 81.3 | 10.2 | 476.9 | 8.1 | 8.5 | 3.6 | 1.0 |
| AT [soil treated with 50% recommended N dose + 3 doses of bio-fertilization (AT + AZ)*], 2010/2011 | | | | | | | | | | | | |
| 49.6 | 21.3 | 29.1 | 7.1 | 2.7 | 14.2 | 108.6 | 11.4 | 513.0 | 10.2 | 9.4 | 4.3 | 1.3 |
| BT, 2011/2012 | | | | | | | | | | | | |
| 49.4 | 22.0 | 28.6 | 7.7 | 2.8 | 12.3 | 86.2 | 10.7 | 496.2 | 9.3 | 7.9 | 3.9 | 1.3 |
| AT [soil treated with 50% recommended N dose + 3 doses of bio-fertilization (AT + AZ)*], 2011/2012 | | | | | | | | | | | | |
| 49.6 | 22.3 | 28.1 | 7.0 | 2.4 | 15.3 | 111.6 | 11.7 | 529.6 | 9.9 | 9.8 | 4.5 | 1.7 |

[#]OC, organic content

*AT+AZ, a mixture of *Azotobacter chroococcum* and *Azospirillum brasilense*, respectively in a ratio of 1:1 (w/w)

II. MATERIALS AND METHODS

A. Treatments and Plant Material

Two field experiments were conducted, in the 2010/2011 and 2011/2012 seasons. The main characteristics of the soil (a private farm, Sonnuris district, Fayoum, Egypt) used in this research were determined [18], and are shown in Table I. During soil preparations for transplanting, all experimental areas received the complete dose of mineral-phosphorus [450 kg ha⁻¹ calcium superphosphate (15.5% P₂O₅)] and mineral-potassium [300kg ha⁻¹ potassium sulphate (48% K₂O)] fertilizers as recommended [19] under Egyptian conditions. They were then divided into 18m² (6m × 3m) plots. Prior to transplanting broccoli seedlings, 65% of the recommended dose of mineral-nitrogen fertilizer (mineral-N) in combination with 1, 2 or 3 doses of bio-nitrogen fertilizer (bio-N; *Azotobacter chroococcum* + *Azospirillum brasilense*) were applied to the plots as 3 combined treatments. In addition, the control plots were received 100% of the recommended dose of mineral-N [700kg ha⁻¹ ammonium nitrate (33.5% N)] as recommended under Egyptian conditions [19]. All treatments were conducted in a randomized complete blocks with four replicates. Transplanting was conducted on 19 October 2010 and on 16 October 2011 using 5-week-old broccoli (*Brassica oleracea* L. var. *italica*) seedlings obtained from the Ministry of Agriculture Nurseries, Cairo, Egypt. Each plot contained 75 plants, spaced at 40 cm in-row and 0.6 m between rows. All other standard cultural practices were followed as recommended for commercial broccoli production.

B. Preparation of Inocula

Modified Ashby's medium was used to grow the *Azotobacter chroococcum* [20]. In addition, Dobereiner medium was used to grow the *Azospirillum brasilense* [21].

The strains (*A. chroococcum* FN 33 and *A. brasilense* FN 17) were isolated and identified in the microbiological laboratory, Faculty of Agriculture, Fayoum University, from the soil in which the experiments were performed. Isolates and inoculates were prepared immediately before inoculation. At the logarithmic growth phase, cultures were centrifuged at 1000rpm and the cell pellets were washed three times with sterile phosphate buffer (100mM, pH = 7.0). The washed cells were resuspended in the same buffer to the final concentration of about 4 × 10⁸ cfu ml⁻¹.

C. Inoculation of Bio-Nitrogen Fertilizer

Roots of broccoli seedlings were dipped in a mixture of *Azotobacter chroococcum* FN 33 and *Azospirillum brasilense* FN 17 in a ratio of 1:1 (v/v). In addition, the rhizosphere of each plant was injected once (at 4 weeks after transplanting) or twice (at 4 and repeated at 7 weeks after transplanting) in a rate of about 50ml plant hole⁻¹.

D. Determination of Growth Traits, Yield and Yield Quality Components

Nine-week-old broccoli plants were used to determine plant leaf number, plant leaf area, leaf dry weight (DW) plant⁻¹ and stem DW plant⁻¹. Six plants were randomly chosen from each experimental plot, cut off at the ground level and divided into leaves and stems. Leaf area plant⁻¹ (dm²) was recorded using a digital leaf meter (LI-3000 Portable Area meter Produced by LI-COR Lincoln, Nebraska, USA). Leaf and stem DWs plant⁻¹ (in g) were estimated after drying the appropriate tissues to constant weight at 70°C using a forced air-oven.

At harvest, total yields; central and lateral heads having closed floral buds, dark green color and good compactness were weighed using all experimental plants. In addition, yield quality components; weights of central head and lateral heads

plant⁻¹, and number of lateral heads plant⁻¹ were considered using six plants that were randomly chosen from each experimental plot.

E. Determination of Nitrogen, Phosphorus and Potassium

Total leaf nitrogen (% DW) was estimated using the Microkjeldahal apparatus as described in A.O.A.C. [22]. The molybdenum-reduced molybdophosphoric blue color method [23], in sulphuric acid (with reduction to exclude arsenate), was the method used for leaf phosphorus determination (% DW). In addition, sulphomolybdic acid (molybdenum blue), diluted sulphomolybdic acid, and 8% (w/v) sodium bisulphite-H₂SO₄ solution were used as reagents. Leaf potassium content (% DW) were assessed using a Perkin-Elmer Model 52-A Flame Photometer [24].

F. Leaf Nitrate (NO₃⁻) and Nitrite (NO₂⁻) Determinations

Leaf samples of broccoli plants were prepared by washing in tap water, then several times in distilled water, then cut into nearly uniform-sized pieces (2.0cm²) to facilitate drying at the same rate. The samples were dried in an oven at 105°C for 24 h until they were brittle and crisp. At this stage, no microorganisms could grow and care was taken to avoid any such contamination. The dried samples were ground into fine particles using a clean mortar and pestle, and sieved to obtain a < 2.0mm size-fraction. A portion (1.0g) of each sieved sample was placed in a 100ml polyethylene or glass bottle and 40ml of distilled water was added, then capped and shaken for 30min. The mixture was filtered, and the filtrate was made up to 100ml in a volumetric flask [25].

Determinations of NO₃⁻ content in each leaf and fruit sample solution were performed using a spectrophotometer (Model 2000; Kwf Sci-Tech Development Co. Ltd., Beijing, P.R. China) at a wavelength of 543nm. The pre-programme for NO₃⁻ (64 NO₃⁻-N) was selected and the readings were converted to NO₃⁻ by multiplying using a conversion factor of 4.4 [26]. The NO₃⁻ content of samples was calculated using the formula:

$$\text{NO}_3^- \text{ content } (\mu\text{g g}^{-1}) = C \times V / M$$

where, *C* was the concentration of NO₃⁻ in the sample (μg g⁻¹), *V* was the total volume of the sample solution (100ml), and *M* was the weight of the sample (1.0g). The data obtained were converted to mg NO₃⁻ g⁻¹ leaf DW.

NO₂⁻ ion contents were determined in a similar manner except that different reagents were used. The pre-programme number for NO₂⁻ was 67 NO₂⁻-N, and the reaction time was 5 min compared to 10 min for NO₃⁻. NO₂⁻-N contents were converted to NO₂⁻ by multiplying by 3.3 [26]. The NO₂⁻ contents of samples were calculated using the formula:

$$\text{NO}_2^- \text{ content } (\mu\text{g g}^{-1}) = C \times V / M$$

where, *C* was the concentration of NO₂⁻ in the sample (μg g⁻¹), *V* was the total volume of the sample solution (100 ml), and *M*

was the weight of the sample (1.0 g) [25]. The data obtained were converted to mg NO₂⁻ g⁻¹ leaf DW.

G. Statistical analysis

All data were subjected to ANOVA using SAS software [27], and means comparisons between the different treatments were performed using the Least Significant Differences (LSD) procedure at the *P* = 0.05 level [28].

III. RESULTS AND DISCUSSION

A. Growth Traits as Affected by Bio- and/or Mineral-Nitrogen Fertilizer

Broccoli plants grown under the combined treatment of bio-N applied at 3 doses + 65% of the recommended dose of mineral-N (bio-N₃ + 2/3mineral-N) exhibited the highest number of leaves plant⁻¹, plant leaf area, leaf dry weight (DW) plant⁻¹ and stem DW plant⁻¹ when compared to the other two combined treatments (bio-N₁ or bio-N₂ + 2/3mineral-N; Table II). There were no significant differences in these parameters between the bio-N₃ + 2/3mineral-N treatment and the control (100% of the recommended dose of mineral-N). The same trend was observed over both growing seasons. These results are in agreement with those obtained in several studies [7]-[10]. In addition, Osman [11] found that inoculation of bacteria (bio-N) singly or in combination with chemical fertilizers positively affected growth characters of potato plants. This may be attributed to the increased activity and efficiency of bacteria in reduction of soil pH (Table I) by secreting organic acids i.e. acetic, propionic, fumaric and succinic [29], and consequently more solubility and availability of nutrients for plants. Furthermore, bio-fertilizers can exert a positive effect on plant growth through the enhanced levels of phytohormones (GA₃, IAA and cytokinins) that modulated by ACC deaminase enzyme, N₂-fixation, and the reduction in root membrane potential. The noticeable increases of growth traits of broccoli plants by the increase in the applied bio-fertilizer dose may be confirmed by the progressively increase in the nutritional elements in the tested soil (Table I) and in plants (Table III). Our results indicated that, bio-N is beneficial for sustainable agriculture and human healthy nutrition as a partial alternative to mineral-N fertilizer.

TABLE II
NUMBER OF LEAVES PLANT⁻¹, PLANT LEAF AREA, LEAF DRY WEIGHT (DW) PLANT⁻¹, AND STEM DW PLANT⁻¹ [MEANS (N = 6) ± STANDARD DEVIATIONS] OF 9-WEEK-OLD BROCCOLI PLANTS GROWN UNDER MINERAL-N OR BIO-FERTILIZATION IN 2010/2011 AND 2011/2012 SEASONS

| Treatments | Parameters | | | |
|---------------------------------|--------------------------------|--|---------------------------------|---------------------------------|
| | Leaves No. plant ⁻¹ | Leaf area plant ⁻¹ (dm ²) | Leaf DW plant ⁻¹ (g) | Stem DW plant ⁻¹ (g) |
| 2010/2011 season: | | | | |
| *Control | 37.5 ± 3.4a | 67.4 ± 4.2a | 58.7 ± 5.2a | 57.4 ± 4.2a |
| Bio-N ₁ + ½mineral-N | 24.5 ± 2.6c | 44.0 ± 3.1c | 38.3 ± 4.1c | 37.5 ± 2.6c |
| Bio-N ₂ + ½mineral-N | 31.7 ± 3.1b | 56.8 ± 4.3b | 49.5 ± 4.3b | 48.4 ± 4.4b |
| Bio-N ₃ + ½mineral-N | 38.2 ± 3.0a | 68.7 ± 5.2a | 59.8 ± 4.9a | 58.5 ± 4.7a |
| 2011/2012 season: | | | | |
| Control | 38.7 ± 2.9a | 68.5 ± 5.1a | 60.1 ± 4.9a | 59.9 ± 4.4a |
| Bio-N ₁ + ½mineral-N | 24.8 ± 2.4c | 44.5 ± 3.2c | 39.3 ± 3.2c | 39.1 ± 3.3c |
| Bio-N ₂ + ½mineral-N | 32.6 ± 3.2b | 57.8 ± 4.4b | 50.3 ± 4.9b | 50.0 ± 4.1b |
| Bio-N ₃ + ½mineral-N | 37.9 ± 4.0a | 69.6 ± 4.9a | 60.7 ± 4.7a | 60.6 ± 4.4a |

*Control = 100% of recommended mineral-N fertilizer

In a column, treatment means having a common letter(s) are not significantly different at the 5% level

B. Leaf Nitrogen, Phosphorus and Potassium Contents as Affected by Bio- and/or Mineral-Nitrogen Fertilizer

Based on leaf nitrogen (N), phosphorus (P) and potassium (K) contents (Table III), the bio-N₃ + ½mineral-N treatment produced broccoli plants had higher N, P and K contents than

all other two combined treatments (bio-N₁ or bio-N₂ + ⅓ mineral-N). Using 100% of the recommended dose of mineral-N (control treatment) resulted in no significant differences in these nutrient contents when compared to the treatment of bio-N₃ + ⅓ mineral-N. The same trends were seen in 2010/2011 and 2011/2012. These results emphasized that the bio-N₃ + ⅓ mineral-N treatment was a great enough to reach the highest levels of N, P and K. This may be attributed to the increased availability of these nutrients because of the beneficial effects of bacteria (*Azotobacter chroococcum* and *Azospirillum brasilense*) on the soil. They reduced soil pH (Table I) by secreting some organic acids (e.g. acetic, propionic, fumaric and succinic) and maintaining a suitable air-moisture regime. In addition, *Azospirillum*-inoculated plants exhibited higher foliar N, P and K contents in marigold [30], and in coffee [31]. They also showed increased growth of root system that enables them to absorb more nutrients from soil [32]. Similar observations were noted by Hemavathi [33] and Shubha [34] using chrysanthemum and marigold, respectively. The increased availability of nutrients in the soil and their enhanced absorption by plant roots (Table III) due to the combined bio-N + mineral-N application resulted in increased yields and more stable soil health.

C. Leaf Nitrate and Nitrite Contents as Affected by Bio- and/or Mineral-Nitrogen Fertilizer

Broccoli plants grown in the bio-N₃+⅓ mineral-N treatment showed the lowest leaf contents of NO₃⁻ and NO₂⁻ when compared to the other two combined treatments (Table III). However, all three combined treatments (bio-N₁, bio-N₂ or bio-N₃ + ⅓ mineral-N) resulted in lower leaf contents of NO₃⁻ and NO₂⁻ than those in the control treatment. The same trends were observed over both growing seasons. The combined application is bio-N and mineral.

TABLE III
NITROGEN (N), PHOSPHORUS (P), POTASSIUM (K), NITRATE (NO₃⁻) AND NITRITE (NO₂⁻) CONTENTS [MEANS (N = 6) ± STANDARD DEVIATIONS] IN 9-WEEK-OLD BROCCOLI PLANTS GROWN UNDER MINERAL-N OR BIO-FERTILIZATION IN 2010/2011 AND 2011/2012 SEASONS

| Treatments | Parameters | | | | |
|---------------------------------|--------------|--------------|--------------|--|--|
| | N (% DW) | P (% DW) | K (% DW) | NO ₃ ⁻ (mg g ⁻¹ DW) | NO ₂ ⁻ (mg g ⁻¹ DW) |
| 2010/2011 season: | | | | | |
| *Control | 3.55 ± 0.24a | 0.35 ± 0.02a | 2.23 ± 0.16a | 2.53 ± 0.12a | 0.188 ± 0.015a |
| Bio-N ₁ + ½mineral-N | 2.32 ± 0.26c | 0.23 ± 0.02c | 1.46 ± 0.15c | 2.22 ± 0.10b | 0.125 ± 0.012b |
| Bio-N ₂ + ½mineral-N | 3.00 ± 0.25b | 0.30 ± 0.04b | 1.88 ± 0.17b | 1.64 ± 0.11c | 0.095 ± 0.007c |
| Bio-N ₃ + ½mineral-N | 3.63 ± 0.29a | 0.36 ± 0.03a | 2.27 ± 0.18a | 0.94 ± 0.08d | 0.069 ± 0.004d |
| 2011/2012 season: | | | | | |
| Control | 3.51 ± 0.26a | 0.37 ± 0.03a | 2.27 ± 0.21a | 2.45 ± 0.14a | 0.181 ± 0.014a |
| Bio-N ₁ + ½mineral-N | 2.33 ± 0.22c | 0.24 ± 0.02c | 1.50 ± 0.15c | 2.10 ± 0.11b | 0.131 ± 0.011b |
| Bio-N ₂ + ½mineral-N | 2.95 ± 0.24b | 0.31 ± 0.03b | 1.91 ± 0.15b | 1.50 ± 0.09c | 0.098 ± 0.008c |
| Bio-N ₃ + ½mineral-N | 3.58 ± 0.28a | 0.39 ± 0.04a | 2.29 ± 0.21a | 0.86 ± 0.07d | 0.062 ± 0.004d |

*Control = 100% of recommended mineral-N fertilizer

In a column, treatment means having a common letter(s) are not significantly different at the 5% level

TABLE IV
TOTAL YIELD AND ITS QUALITY [MEANS (N = 6) ± STANDARD DEVIATIONS] OF BROCCOLI PLANTS GROWN UNDER MINERAL-N OR BIO-FERTILIZATION IN 2010/2011 AND 2011/2012 SEASONS

| Treatments | Parameters | | | | |
|---------------------------------|-------------------------------------|---------------|---------------------------------------|--|--|
| | Total yield (ton ha ⁻¹) | | Yield quality parameters | | |
| | Central heads | Lateral heads | Central head plant ⁻¹ (kg) | Lateral heads plant ⁻¹ (kg) | No. of lateral heads plant ⁻¹ |
| 2010/2011 season: | | | | | |
| *Control | 10.17 ± 0.81a | 11.19 ± 1.12a | 0.27 ± 0.03a | 0.30 ± 0.02a | 5.82 ± 0.55a |
| Bio-N ₁ + ½mineral-N | 6.62 ± 0.62c | 7.33 ± 0.76c | 0.18 ± 0.02c | 0.19 ± 0.02c | 3.80 ± 0.32c |
| Bio-N ₂ + ½mineral-N | 8.57 ± 0.83b | 9.43 ± 0.99b | 0.23 ± 0.03b | 0.26 ± 0.03b | 4.91 ± 0.37b |
| Bio-N ₃ + ½mineral-N | 10.36 ± 0.93a | 11.48 ± 0.96a | 0.28 ± 0.03a | 0.31 ± 0.03a | 5.94 ± 0.64a |
| 2011/2012 season: | | | | | |
| Control | 10.48 ± 0.62a | 11.57 ± 1.10a | 0.29 ± 0.02a | 0.31 ± 0.04a | 6.05 ± 0.54a |
| Bio-N ₁ + ½mineral-N | 6.83 ± 0.52c | 7.57 ± 0.74c | 0.18 ± 0.02c | 0.20 ± 0.01c | 3.95 ± 0.41c |
| Bio-N ₂ + ½mineral-N | 8.83 ± 0.57b | 9.71 ± 0.88b | 0.24 ± 0.02b | 0.25 ± 0.02b | 5.10 ± 0.48b |
| Bio-N ₃ + ½mineral-N | 10.69 ± 0.67a | 11.74 ± 0.97a | 0.29 ± 0.03a | 0.32 ± 0.03a | 6.11 ± 0.58a |

*Control = 100% of recommended mineral-N fertilizer

In a column, treatment means having a common letter(s) are not significantly different at the 5% level

N, particularly bio-N₃ + ½mineral-N treatment resulted in production of broccoli plants with lower contents of NO₃⁻ and NO₂⁻ for human healthy nutrition. Increased availability of N in the soil by the extensive use of mineral-N as applied in the control treatment led to an obvious increase in the contents of NO₃⁻ and NO₂⁻ in broccoli leaves. The accumulation of NO₃⁻ and NO₂⁻ ions in edible plant parts poses a problem. This was attributed to the continuous supply of NO₃⁻ and NO₂⁻ to the plants from mineral-N fertilizer [35]. In contrast, in the bio-N₃ + ½mineral-N-treated plots the release of NO₃⁻ and NO₂⁻ was comparatively slow. In addition, the increase in the organic matter content in the plots treated with bio-N₃ + ½mineral-N (Table I) may control the release and transformation of N-fertilizer to NO₃⁻ and NO₂⁻. The addition of bio-N to cultivated soil was effective in minimizing the NO₃⁻ and NO₂⁻ toxicity in broccoli plants. This may be attributed to the incorporation of organic material that enhanced the soil organic carbon content and had direct and indirect effects on soil properties and processes.

D. Yield and Its Quality as Affected by Bio- and/or Mineral-Nitrogen Fertilizer

No significant differences were noted in total yields of central and lateral heads ha⁻¹ and their quality components (weight of central and lateral heads plant⁻¹ and No. of lateral heads plant⁻¹) between the bio-N₃ + ½mineral-N and control treatments (Table IV). Lower yields and their quality parameters were obtained from the bio-N₁ + ½mineral-N treatment than all other treatments including the control. The same trends were observed in both growing seasons. These findings may be attributed to the slow and steady supply of N by bio-N, particularly at the highest dose, which met the N requirements of plants at different stages of development. Bio-N acts as a nutrient reservoir through N₂-fixation and N ions are released slowly over the entire growth period leading to higher yields and their quality. The favorable conditions of soil nutrients status (Table I) as a result of the bio-N₃ + ½mineral-N treatment were positively reflected in the nutritional status of broccoli plants (Table III) and consequently reflected in the increased growth, yields and their quality components. These results may be explained by

the role of *Azospirillum* in atmospheric nitrogen fixation, better root proliferation and uptake of nutrients and water [36]. Our results are in agreement with those obtained by Osman [11] who pointed out that total yield was highly correlated with the development of vegetative growth as well as dry matter accumulation.

IV. CONCLUSIONS

Results of this study show that using the bio-nitrogen fertilizer (*Azotobacter chroococcum* and *Azospirillum brasilense*) as a partial alternative to mineral-nitrogen fertilizer enabled broccoli plants to produce higher yields with minimized levels of NO₃⁻ and NO₂⁻. Bio-N fertilizers increased soil organic matter content and the availability of nutrients to plant roots, thus increased plant growth and yields with higher quality. Application of Bio-N fertilizer reduced the amount of synthetic chemical-N fertilizer needed for crop production, and can ameliorate or reduce the negative effects of chemical-N fertilizer on the environment. Therefore, production of broccoli plants having lower contents of NO₃⁻ and NO₂⁻ ions for human healthy nutrition is obtainable.

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