Chapter

Enhancing Soil Properties and Maize Yield through Organic and Inorganic Nitrogen and Diazotrophic Bacteria

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Abstract

In arid and semiarid ecosystems, low organic matter is an important threat to soil fertility, crop productivity, and economic returns. Sustainable approaches are required to build organic matter in such soils to improve nutrient use efficiency and food security. Therefore, we conducted an experiment on spring maize to test with and without diazotrophic bacteria (BM) (*Azotobacter chroococcum* and *Azospirillum brasilense*) on crop productivity and soil properties when applied with organic (farm yard manure FYM) and inorganic (commercial fertilizer) nitrogen (N) sources (with percentile of 0, 25, 50, 75, and 100%) in 2014. The analysis of the study showed that the application of BM and organic and inorganic N ratio were significant and have a positive effect in crop yield and soil properties. BM with a 50:50 ratio of organic and inorganic N was improved biological yield (kg ha^{-1}), grain yield (kg ha^{-1}), stover nitrogen (%), and grain nitrogen (%). However, soil organic matter (%) and soil total nitrogen (%) were enhanced with the application of BM with 100% organic source. Soil bulk density (g cm^{-3}) was significantly reduced by BM with 100% organic. From overall results, it is concluded that the application of beneficial microbes and organic and inorganic N positively improved maize yield and quality and soil health in Peshawar valley.

Keywords: plant growth-promoting bacteria, nitrogen fertilization, soil quality, grain yield

1. Introduction

Maize (*Zea mays* L.) is the third most important cereal crop after wheat and rice, while in the farming system of Khyber Pakhtunkhwa, it ranks third after wheat and rice in its importance [1, 2]. It is an exhaustive and multipurpose cereal crop that provides food for human, feed for animals, and raw material for the industries [3]. It has greater nutritional value as it contains about 72% starch, 10.4% proteins, and 4.5% fats, minerals, and non-cholesterol oil [2, 4].

To mitigate the problem of low yield and contamination in an eco-friendly way is to use effective microorganisms (EM) [5] also known as beneficial microorganism (BM). Microorganisms economically support the farmer community by improving the soil activities [6] and assimilate accumulation in the final product of the production which in turn maintains the balance of organic and inorganic mechanisms of the soil and plant [7]. Many researches reflected advantageous effects of BM on soil physicochemical status [8, 9]. Beneficial microorganism increases the decomposition rate of organic fertilizer and increases nutrients availability [10]. Beneficial microorganism also promotes soil fertility, crop growth, and yield [11]; also improves soil health, soil quality, yield, and quality [12] of various physiological attributes; and regulates various metabolites and atmospheric nitrogen [13].

Nitrogen significantly improves crop productivity [14]. Fertilizers are usually applied to soil for increasing or maintaining crop yields to meet the increasing demand of food [15, 16]. The application of inorganic fertilizers results in higher soil organic matter (SOM) accumulation and biological activity due to increased plant biomass production and organic matter return to the soil in the form of decaying roots, litter, and crop residues [17, 18]. The addition of SOM enhances soil organic carbon (SOC) content, which is an important indicator of soil quality and crop productivity [19]. Chemical fertilizer applications could also affect soil physical properties directly or indirectly such as aggregate stability, water holding capacity, porosity, infiltration rate, hydraulic conductivity, and bulk density due to increases in SOM and SOC content [20, 21]. In turn, the formation of stable aggregates enhances physical protection of SOM against microbial decomposition [22]. Some fertilizer additions also affect the chemical composition of soil solution which can be responsible for dispersion/flocculation of clay particles and thus affect the soil aggregation stability [21, 23]. We can see the plant and microbial interaction in the retention and improvement of N cycle for better plant growth (**Figure 1**).

The present study aimed to investigate the effect of organic and inorganic nitrogen ratios along with the effect of beneficial diazotrophic bacteria on maize yield and quality and physio-chemical properties of soil.

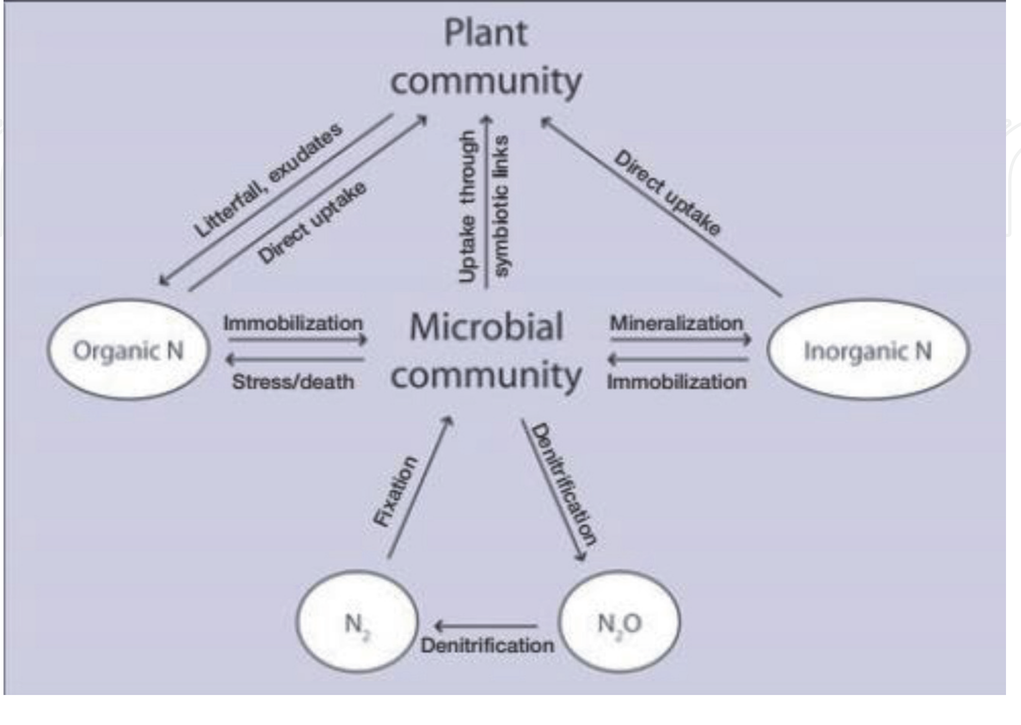

Figure 1.
Plants and microbial interaction in the retention and improvement of N cycle for better plant growth [24].

2. Materials and methods

2.1 Experimental site

The impact of beneficial microbes on enhancing efficiency of organic and inorganic N fertilizers sources was studied on spring maize cropping system in the year of 2014 at Agronomy Research Farm, The University of Agriculture Peshawar, Pakistan. The research area is geographically located at 17°, 35′ N and 35°, 41′ W and altitude of 450 m above sea level. The soil of the experimental farm was silt loam, well drained, and fine textured. The experimental site has a semiarid subtropical continental climate with a mean annual rainfall of about 550 mm. The soil is deficient in total N (<0.5%) and AB-DTPA extractable P (<4.0 mg kg^{-1} soil) but has adequate AB-DTPA extractable K (>100 mg kg^{-1} soil) with a pH of 7.60 and organic matter content <1% (**Table 1**). Rainfall and temperature data were collected from the weather station of Agronomy Research Farm and summarized in **Figure 2**. In addition to rainfall, crop water requirement was fulfilled by supplying water through surface irrigation according to crop requirement.

2.2 Materials and treatments

The experimental field was irrigated before sowing for weed germination and then plowed with cultivator to prepare a fine seed bed for sowing. The experiment consisted of two factors, i.e., beneficial diazotrophic bacteria (*Azotobacter chroococcum* and *Azospirillum brasilense*) (with BM and without BM) and organic (FYM) and inorganic (urea commercial fertilizer) N ratios (0:100, 25:75, 50:50, 75:25 and 100:0). The recommended doses of phosphorus (90 kg ha^{-1}) and potassium (60 kg ha^{-1}) were applied at the time of seed bed preparation from the sources of DAP and SOP. The fertilizer of nitrogen was applied in two equal splits, and organic N was applied 4 weeks before sowing.

2.3 Experimental design

The experiment was conducted at three factorial randomized complete block designs (RCBD) with three replications. The size of plots was 4.2 × 4 m. Row-to-row

Property	Unit	Data
Clay	%	2.8
Silt	%	50
Sand	%	47.2
Textural class	—	Silty loam
pH (1:5)	—	7.60
EC (1:5)	dS m^{-1}	0.18
Organic matter	%	0.39
Total nitrogen	%	0.06
Phosphorus	ppm	2.86
Potassium	Ppm	120.48
Mineral nitrogen	mg kg^{-1}	35

Table 1.
Pre-sowing physicochemical properties of soil (0–0.30 m depth).

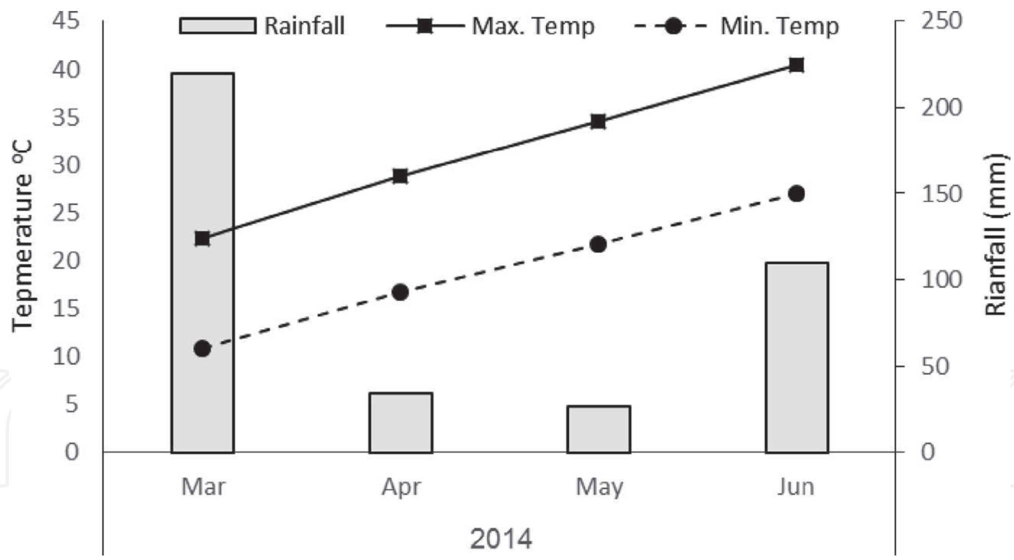

Figure 2.
Weather data of spring maize growing season from March to June, 2014.

distances for maize crop were 0.70 m, whereas plant-to-plant distances were 0.20 m. Each plot had six rows. There were 30 plots having treatment combination of two beneficial diazotrophic bacteria and five organic and inorganic source ratios.

2.4 Observations recorded

Biological yield data was recorded by harvesting four central rows in each plot, sundried and weighed by electronic balance whereas harvested central rows were threshed individually through electric thresher and weighed through electronic balance to obtain grain yield and then converted into kg ha^{-1} by the following formula:

$$\text{Grain yield}\ (\text{kg ha}^{-1}) = \frac{\text{grain yield in four central rows}}{\text{row} - \text{row distance (m)} \times \text{row length (m)} \times \text{no.of rows}} \times 10,000 \tag{1}$$

Organic matter in soil was determined by the modified method of Nelson and [25]. The nitrogen content in soil, stover, and grains were determined by following Kjeldahl method according to the proposed methodology of Bremner and Mulvaney [26].

2.5 Statistical analysis

The data recorded was analyzed statistically using analysis of variance techniques appropriate for randomized complete block design. Statistical analysis was done with Statistic-X software. Means were compared using LSD test at 0.05 level of probability, when the F-values was significant [27]. The possible interactions were graphically made using a software of Microsoft Excel 365.

3. Results and discussion

3.1 Biological and grain yield as influenced by organic and inorganic N with BM

Beneficial microbes significantly influenced biological yield (**Table 2**). Highest biological yield (11,708 kg ha^{-1}) has been observed with the application of

Beneficial microbes	Biological yield (kg ha^{-1})	Grain yield (kg ha^{-1})	Soil organic matter (%)	Bulk density (g cm^{-3})
Without BM	10,733 b	3662 b	0.87 b	1.19 a
With BM	11,708 a	3803 a	1.19 a	1.17 b
LSD	602.29	79.52	0.08	0.02
Organic and inorganic ratios				
0:100	10,961 b	3592 b	0.87 c	1.23 a
25:75	11,401 ab	3793 ab	0.94 bc	1.22 ab
50:50	12,092 a	3907 a	1.02 b	1.19 b
75:25	10,621 b	3684 b	1.10 ab	1.15 c
100:0	11,027 ab	3686 b	1.22 a	1.09 d
LSD	952.3	125.7	0.13	0.03
Interaction				
BM × R	**Figure 3**	ns	**Figure 4**	ns

Mean values of the different categories in each column with different letters discloses significant differences ($p \leq 0.05$) using LSD test.

Table 2.
Biological yield and grain yield of spring maize and soil organic matter and soil bulk density as influenced by beneficial microbes and organic and inorganic ratios.

beneficial diazotrophic bacteria as compared to without beneficial microbes. This may be due to diazotrophic bacteria increase the speed of decomposition and mineralization that improve nutrients' availability to the crop and total dry matter production [28]. Similarly, the application of organic and inorganic fertilizers also significantly affects the biological yield, and greater biological yield (12,092 kg ha^{-1}) was achieved with the application of 50:50 N ratio of organic and inorganic fertilizers. Lower biological yield (10,961 kg ha^{-1}) was attained with the application of 100% N from inorganic source. It might be due to the reason that nitrogen from organic sources are slow release, while inorganic nitrogen is readily available to plant which may not be available at later stages. The combined application of N from inorganic source (urea) and organic source in a ratio of 75:25 improved grain yield, straw yield, and biological yield, whereas 50:50 N ratio increased uptake of nitrogen [29]. Biological and grain yield was significantly improved with the application of 50% nitrogen from inorganic sources in combination with the application of 25% N from FYM and 25% N from poultry manure [30]. The applications of organic and inorganic N fertilizers significantly enhanced biological yield and grain yield [31, 32]. The application of organic and inorganic nitrogen 50% from urea and 50% from FYM or 50% poultry manure significantly enhanced biological yield, grain yield, and harvest index (%) [28].

The graph trend showed that biological yield increased with organic and inorganic nitrogen ratio from 0:100 to 50:50, whereas a decreased trend in biological yield was observed from 50:50 to 100:0 with both beneficial microbes (**Figure 3**). This might be due to the fact that beneficial microbes rapidly decomposed organic matter, provided nutrients, and increased availability of nitrogen from both organic and inorganic sources [28].

Beneficial diazotrophic bacteria significantly increased the grain yield (**Table 2**). Highest grain yield (3803 kg ha^{-1}) has been noted with the application of beneficial microbes as compared to without beneficial microbes. This may be due to the reason that beneficial microbes increase decomposition and mineralization and improve nutrients availability for more total dry matter production [28].

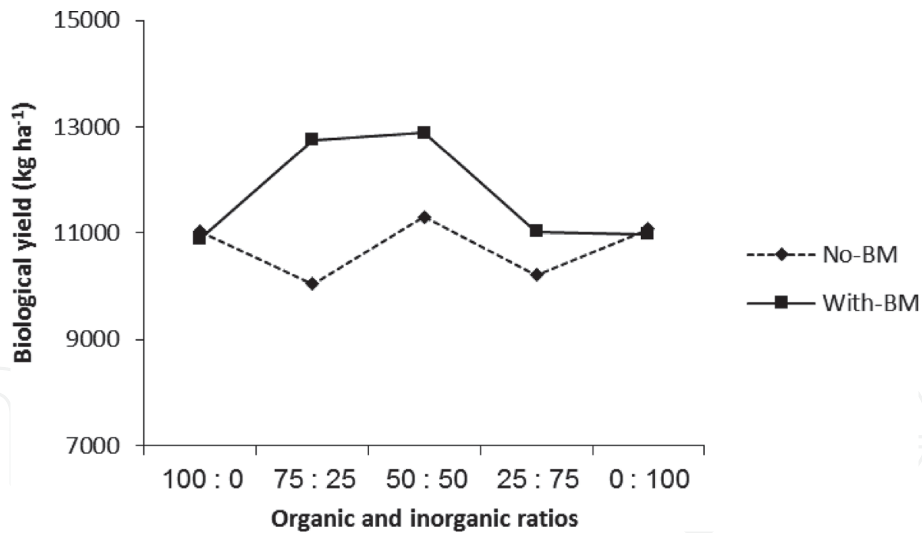

Figure 3.
Biological yield as affected by beneficial microbes and organic and inorganic ratios.

Organic and inorganic fertilizer significantly influenced grain yield, and higher grain yield (3907 kg ha^{-1}) was achieved with the application of 50:50 N organic and inorganic ratio, whereas lower grain yield (3592 kg ha^{-1}) was observed with the application of 100% N from inorganic. It might be due to the reason that N from organic sources is slow release, whereas inorganic nitrogen is readily available to plant that may function in vegetative growth. The application of organic and inorganic N with a ratio of 75:25 prominently improved yield and yield indices, whereas a 50:50 ratio increases nitrogen uptake [29]. Biological and grain yield was significantly higher with the application of 50% nitrogen from inorganic sources with the application of 25% N from FYM and 25% N from poultry manure [30]. The application from organic and inorganic N fertilizer significantly influenced biological yield and grain yield [31, 32]. The application of organic and inorganic nitrogen 50% from urea and 50% from FYM or 50% poultry manure significantly enhanced biological yield, grain yield, and harvest index % [28].

3.2 Soil nitrogen analysis as influenced by organic and inorganic N with BM

Beneficial microbes significantly affected soil organic matter (**Table 2**). Highest soil organic matter (1.19%) has been perceived with the application of beneficial microbes as compared to without diazotrophic bacteria. This may be due to the beneficial microbe increases the speed of decomposition and increase mineralization and produced more exudes [28]. Organic and inorganic ratios significantly affected soil organic matter. More soil organic matter (1.22%) was achieved with the application of a 100:0 ratio of organic and inorganic fertilizer, whereas less soil organic matter (0.87%) was perceived by the application of 100% from inorganic fertilizer. It might be due to beneficial microbe rate of decomposition of organic fertilizer which improves soil organic matter and soil organic carbon. The combined application of organic and inorganic fertilizers improved soil organic matter and total nitrogen [33]. Organic manure linearly increased soil organic matter [34]. The integration of organic with inorganic fertilizer significantly improved crop production and N, P, K, soil pH, soil EC, and organic matter [35, 36]. Organic sources improved soil nutrient, soil organic matter, and soil organic carbon [37]. The graph trend showed that soil organic matter increased linearly with the increased of organic and inorganic ratio from 0:100 to 100:0 in both beneficial and without beneficial microbes (**Figure 4**). This might be due to organic matter was applied

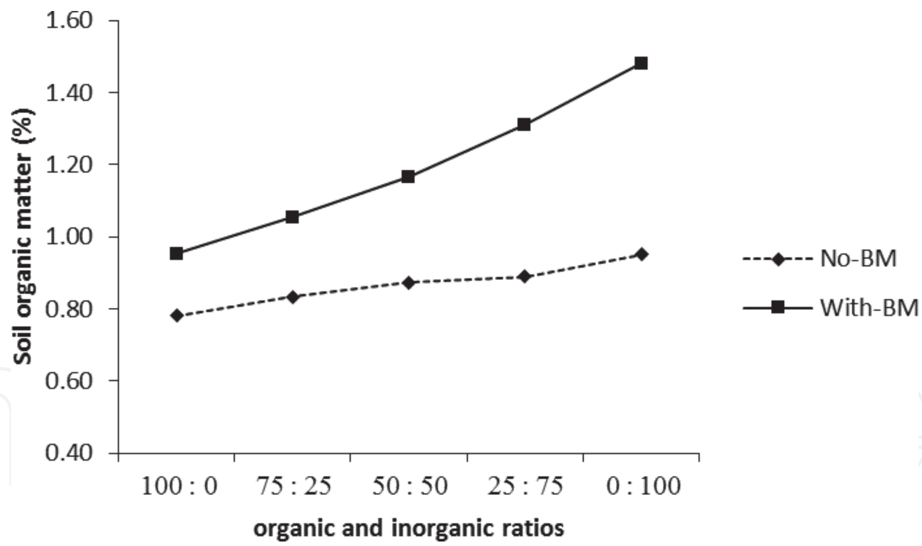

Figure 4.
Soil organic matter as affected by beneficial microbes and organic and inorganic ratios.

100% from organic sources, and beneficial microbes rapidly decomposed organic matter, thus increasing mineralization and soil organic matter [28].

Beneficial microbes significantly affected soil bulk density as highest soil bulk density (1.19 g cm^{-3}) has been perceived without the application of beneficial microbes as compared to with beneficial microbes (**Table 2**). This may be due to beneficial microbes increase the speed of decomposition and increase mineralization and provide nutrients, thus decreasing bulk density; these results are in line with Muhammad et al. [28]. Organic and inorganic ratios significantly affected soil bulk density. Soil bulk density (1.23 g cm^{-3}) was recorded with the application of a 0:100 ratio of organic and inorganic, whereas less soil bulk density (1.09 g cm^{-3}) was determined by the application of 100% of organic. It might be due to the integration of organic and inorganic fertilizer which improved soil bulk density. Bulk density decreased with the application of FYM and poultry manure to soil [38]. Bulk density linearly decreased with soil organic matter [34]. The integration of organic with inorganic fertilizer significantly decreased bulk density of soil [35, 36].

Beneficial diazotrophic bacteria significantly affected soil nitrogen content (**Table 3**). Highest soil nitrogen content (0.39%) has been received with the application of beneficial microbes as compared to without beneficial microbes. It may be due to beneficial microbe increases the speed of decomposition and increases mineralization and provides nutrients, thus more nitrogen in soil; these results are in line with Muhammad et al. [28]. Organic and inorganic ratios significantly affected soil nitrogen content. More soil nitrogen content (0.47%) was achieved with the application of 50:50 ratio of organic and inorganic, whereas less soil nitrogen content (0.24%) was recorded by the application of 100% from inorganic. It might be due to the decomposition of organic matter is slow and the slow release of nutrients; therefore, plots of organic sources have higher N, P, and K than plots having inorganic fertilizer. Organic sources improved soil nutrient and organic carbon [37]. Soil mineral nitrogen increased (22.4%) with the addition of organic fertilizers like FYM, poultry, and legume residues [39]. For better crop growth and sustainability, addition of organic matter is best source of nutrient availability [34]. The integration of organic with inorganic fertilizer significantly improved crop production and N, P, K, soil pH, soil EC, and organic matter [35, 36].

The graph trend showed that soil organic matter increased linearly with the increased of organic and inorganic ratio from 0:100 to 100:0 in both beneficial and without beneficial microbes (**Figure 5**). This might be due to organic matter was

Beneficial microbes	Soil nitrogen content (%)	Stover nitrogen content (%)	Grain nitrogen content (%)
Without BM	0.34 b	0.88 b	1.74 b
With BM	0.39 a	1.10 a	1.91 a
LSD	0.01	0.08	0.01
Organic and inorganic ratios			
0:100	0.24 e	0.89 b	1.56 c
25:75	0.30 d	0.98 ab	1.81 b
50:50	0.38 c	1.11 a	2.01 a
75:25	0.44 b	0.99 ab	1.97 ab
100: 0	0.47 a	0.98 ab	1.78 b
LSD	0.02	0.13	0.16
Interaction			
BM × R	**Figure 5**	ns	**Figure 6**

Mean values of the different categories in each column with different letters discloses significant differences ($p \leq 0.05$) using LSD test.

Table 3.
Soil nitrogen content, stover, and grain nitrogen content of spring maize as influenced by beneficial microbes and organic and inorganic ratios.

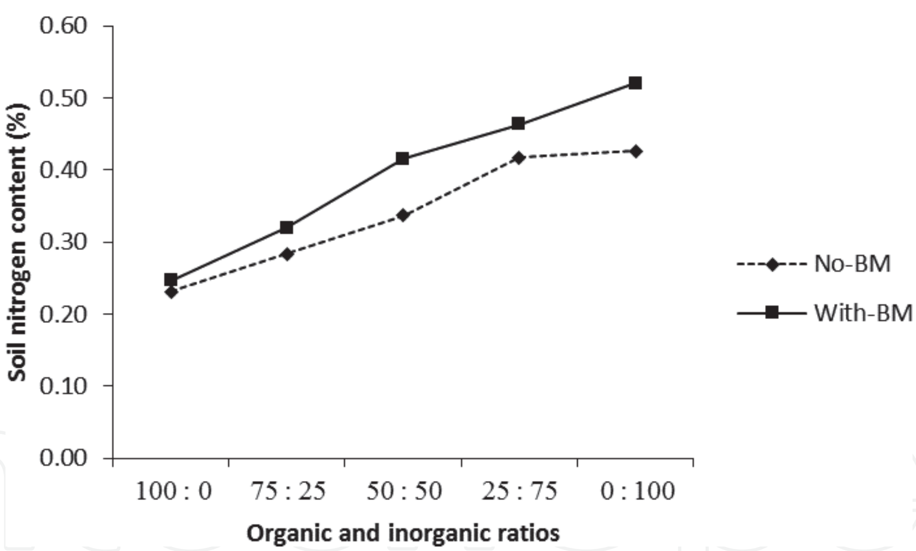

Figure 5.
Soil nitrogen content as affected by beneficial microbes and organic and inorganic ratios.

applied 100% from organic sources, and beneficial microbes rapidly decomposed organic matter, thus increasing mineralization and soil organic matter [28].

3.3 Plant nitrogen analysis as influenced by organic and inorganic N with BM

Beneficial diazotrophic bacteria significantly affected stover nitrogen content (**Table 3**). Highest stover nitrogen content (1.1%) has been perceived with the application of beneficial microbes as compared to without beneficial microbes. It can be due to beneficial microbes increase the speed of decomposition and increase mineralization and provide nutrients for crop to achieved more total nutrient

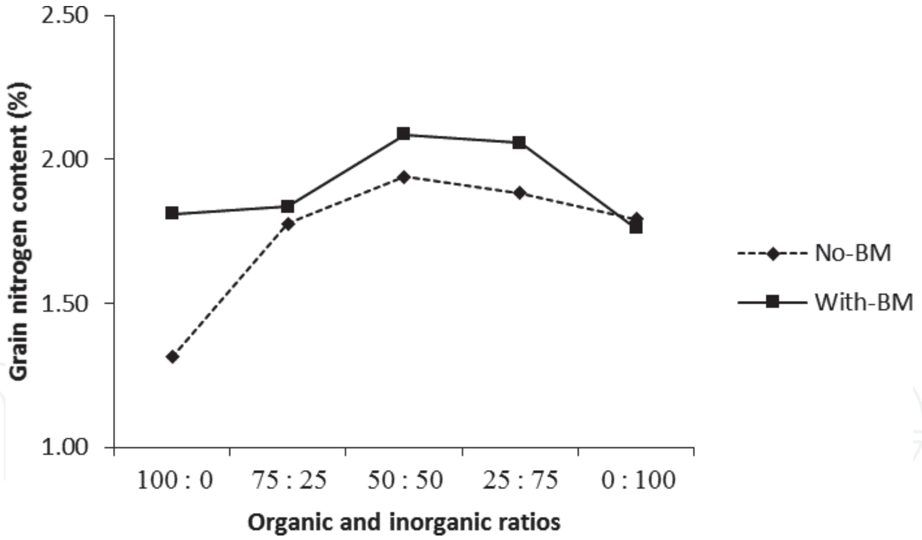

Figure 6.
Grain nitrogen content as affected by beneficial microbes and organic and inorganic ratios.

production [28]. Our results indicated that organic and inorganic N ratios significantly influenced N stover content in maize crop. The application of a 50:50 ratio of organic and inorganic nitrogen resulted in higher stover N content (1.11%), whereas lower stover nitrogen content (0.89%) was attained with the application of 100% N from inorganic source. It might be due to the reason that inorganic fertilizer was quickly available, while organic fertilizer was slowly available to crop. The N, P, and K concentration in straw was significantly increased with the combined application of 10 t N ha^{-1} from poultry manure (PM) and 200 kg N ha^{-1} from NPK as compared to control [40]. N, P, and K uptake by straw and grains was significantly influenced by organic and inorganic fertilizer [41–43]. The application of chemical fertilizers, FYM, green manures, and compost to the soil resulted in improved uptake of N, P, and K [44, 45].

Beneficial diazotrophic bacteria significantly increase grain nitrogen content (**Table 3**). Highest grain nitrogen content (1.91%) has been perceived with the application of beneficial microbes as compared to without beneficial microbes. This may be due to beneficial microbes increase the speed of decomposition and increase mineralization, and more nitrogen content was transferred to grain [28]. Organic and inorganic ratios significantly improved grain nitrogen content, and higher grain nitrogen content (2.01%) was achieved with the application of a 50:50 organic and inorganic N ratio, whereas less grain nitrogen content (1.56%) was achieved with the application of 100% inorganic fertilizer. It may be due to the quick availability of inorganic fertilizer, whereas organic fertilizer is slowly available to the crop. Nitrogen and phosphorus are higher in grains than straw, while potassium content was higher in straw as compared to grains. N, P, and K content was significantly improved by organic fertilizer both in straw and grain [46]. Growth, yield, and NPK concentrations were significantly increased with integrated organic and inorganic fertilizers [3]. Macro- and micronutrients in the grains and straw of wheat were significantly improved with the application of FYM as inorganic N fertilizer [47]. Higher N, P, and K uptake by crop was observed with organic N sources [48].

The graph showed that grain nitrogen increased with organic and inorganic N ratio from 0:100 to 50:50. This trend was declined with N ratio from 50:50 to 100:0 for both beneficial microbes (**Figure 6**). This might be due to the reason that beneficial microbes rapidly decomposed organic matter, provided nutrients, and also increased availability of nitrogen from both organic and inorganic sources [28].

4. Conclusion

High maize yield and nitrogen content was better observed with the application of beneficial microbes and organic and inorganic nitrogenous fertilizer with a ratio of 50:50. Soil bulk density, soil organic matter, and soil total nitrogen were significantly improved with beneficial microbes combinedly apply with organic and inorganic nitrogenous fertilizer in a ratio of 100:0. Therefore, the application of beneficial microbes and organic and inorganic nitrogenous fertilizer with a ratio of 50:50 has been recommended for better nitrogen uptake and higher yield of spring maize in Peshawar valley.

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