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ORGANIC AND BIOFERTILIZERS EFFECTS ON THE RHIZOSPHERE MICROBIOME AND SPRING BARLEY PRODUCTIVITY IN NORTHERN KAZAKHSTAN

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SUMMARY

Organic fertilizers' usage enhances crop productivity and improves soil fertility and the surrounding environment in livestock complexes. The presented study assessed the effect of biofertilizers and poultry-based organic fertilizers on rhizospheric microbial diversity, yield attributes, and productivity of spring barley (*Hordeum vulgare* L.). Conducting field experiments started in 2021 in Northern Kazakhstan's Southern carbonated chernozem of the steppe zone. Poultry manure application had three doses (5, 10, and 15 t ha^{-1}), while four types of biofertilizer of microbial origin consisted of Compo-MIX, Agro-MIX, Agrarka, and Trichodermin-KZ. The poultry-based organic manure resulted in the highest number of nitrogen-fixing bacteria. By treating seeds with biofertilizers, Agrarka and Trichodermin-KZ, the organotrophic bacteria dominated the barley rhizosphere. The seed treatment with Agro-MIX, Trichodermin-KZ, and organic fertilizer (at the rate of 5 and 10 t ha^{-1}) resulted in a predominance of nonsymbiotic nitrogen-fixing bacteria. Combined analysis of variance revealed that, on average, the organic and biofertilizers significantly increased plant viability, 1000-grain weight, and grain productivity. Combined application of poultry manure (10 t ha^{-1}) and biofertilizer Trichodermin-KZ gave the highest average values of grain productivity, i.e., 1,550 and 1,490 kg ha^{-1} (15.5 and 14.9 quintal ha^{-1}), respectively.

Keywords: Spring barley (*Hordeum vulgare* L.), poultry manure, biofertilizers, nitrogen-fixing and organotrophic bacteria, yield components, grain yield

Key findings: The presented study authenticated the positive effects of applying organic manure and biofertilizer on the yield attributes of spring barley. Seed treatment with biofertilizers, Trichodermin-KZ and Agrarka, and poultry-based organic manure (10 t ha^{-1}) significantly improved barley growth and productivity. In general, all treatments with biofertilizers provided better yields than the control.

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INTRODUCTION

Organic farming has become a priority worldwide for safe and healthy food demands, long-run sustainability, and concerns over agrochemicals polluting the environment (Milestad and Darnhofer, 2003). In crop production, the use of chemicals is inevitable to meet the food demand of the world's growing population. However, organic production can get stimulated for certain crops to limit the domestic export market (Aktar *et al*., 2009). According to Food and Agriculture Organization (FAO), barley ranks fifth in grain production globally, following corn, wheat, rice, and soybean (Azimi *et al*., 2013). Therefore, barley grain production stability is a high priority because of its drought resistance and ability to grow even in dry conditions with little rainfall (Thomson, 2009; Lodhi *et al*., 2015).

The grain productivity of this primary dry land barley cultivation varies according to irregular rainfall in Northern Syria (Ceccarelli, 1987). Over the last 14 years, two-thirds of grown barley has provided for fodder, one-third for malt production, and about 2% for food production in Asia and Northern Africa. The main benefit of including barley in various foods and their consumption relates to its potential health benefits because it lowers the cholesterol level in the blood and the glycemic index (Baik and Ullrich, 2008; Kumar *et al*., 2015; Sabra *et al*., 2023).

In barley, to achieve the highest grain production with good quality should practically use edaphic, climatic conditions of the existing area and adequate fertilization. Organic barley grains contain more valuable protein than traditionally grown ones (Biel *et al*., 2016, 2020). The resulting organic products are valued raw materials used to produce cereals and flakes. Organic grain production also requires using organic manure and biofertilizers, minimizing mineral fertilizers' application (Idehen *et al*., 2017). In other words, mineral fertilizers are more soluble and available to plants. However, organic fertilizers release minerals slowly, thus providing plants with decisive nutritional demand periods.

Biofertilizer effectivity is an economically and ecologically rational means of improving grain quantity and quality, which results from stimulating the direct and indirect emission of plant hormones (Osman *et al*., 2010). Biologically active substances released by organic and biofertilizers have a positive impact on yield-related variables, such as, gibberellin, auxin, cytokinins, vitamins, amino acids, polypeptides, antibacterial and antifungal substances, and polymers (Khalid *et al*., 2006; Mumtaz *et al*., 2018). These biological materials interact positively with the soil microflora of the existing area and create effective consortia. In the last decades, seed pretreatment with growth-stimulating microorganisms has become a sustainable means of ensuring nutrient availability in soil (Ahmad *et al*., 2018). Biofertilizers also promote plant growth by improving nutrient-supplying capacity, including biologically fixed nitrogen and its substances, and enhancing available insoluble nutrients in the soil (Ali *et al*., 2017). Microorganisms in a mixed culture of biofertilizers interact synergistically and are stimulated through biochemical activities while simultaneously increasing viability (Vassilev *et al*., 2001).

Rhizospheric and endophytic bacteria are nonsymbiotic bacteria that voluntarily cluster with plant roots and rhizosphere, directly associating with better plant growth and productivity (Khan *et al*., 2021). In the last few years, it has become apparent that beneficial microorganisms can positively affect grain productivity and quality in adverse environmental conditions (Hussain *et al*., 2019; Mumtaz *et al*., 2019). The plant rhizosphere contains different beneficial enzymes that accelerate nutrient absorption and their flow to the upper parts of a plant

(Ashrafuzzaman *et al*., 2009). Some bacteria can also integrate the soluble form of the mineral phosphorus, making them essential for crop production. They also produce other substances, such as siderophores, auxins, cytokines, and vitamins, significantly improving plant growth by increasing phosphorus uptake (Hayes *et al*., 2000; Bulut, 2013). Seed inoculation with phosphorus-solubilizing *Bacillus megaterium,* nitrogen-fixing *B. subtilis,* and *Rhizobium leguminosarum* could enhance crop yields (Elkoca *et al*., 2010). *Trichoderma* spp. is a fungus used in the foliar application, seed treatment, and soil treatment to suppress fungal pathogens causing various fungal plant diseases, and also an effective bio-stimulator in crop production. They also stimulate plant development, including root branching and nutrient uptake, and thus can reasonably enhance productivity with good quality under stressful conditions (Szczałba *et al*., 2019).

Soil microorganisms, essential in the natural soil sub-ecosystem, capable of fixing atmospheric nitrogen and dissolving phosphates, synthesizing growth-promoting substances, and enhancing the decomposition of plant residues to release vital nutrients and enhance soil humus content, will be an environmentally safe approach to nutrient management and ecosystem functions (Thomas and Singh, 2019). Biofertilizers have also minimized mineral fertilizers use and maintained the development of deserts in a less polluted environment, reducing the cost of production and improving crop yields by providing available nutrients to the crop plants better (Singh *et al*., 2011). Apart from contributing available nutrient in the soil to the plants, these also bind soil particles into stable aggregates to further improve the soil structure and reduce soil erosion (Zaeim *et al*., 2017).

At present, scientists worldwide prioritize new technologies, including biofertilizers needing application to ensure stability in crop yields (Mumtaz *et al*., 2018; Chittora *et al*., 2020; Iqbal *et al*., 2022). Plant growth-promoting rhizobacteria (PGPR) improved root development and growth in crop plants by dissolving insoluble phosphorus and releasing growth-stimulating hormones (Kumar *et al*., 2014; Ahmad *et al*., 2017). Currently, the Northern regions of Kazakhstan periodically suffer from droughts in vegetation season, which reduces the productivity of grain crops, especially organically grown spring barley.

Poultry manure is one of the best organic fertilizers with rich chemical composition, containing all the nutrients and trace elements, including nitrogen (3%–5%), phosphorus (1.5%–3.5%), and potassium (1.5%–3.0%) (Bolan *et al*., 2010). Various crops have shown the effectiveness of poultry manure application. For example, corn productivity increased by 100% with poultry manure application at 2 t/ha compared with the control, fertilizing with bird droppings boosted the average fruit weight of watermelon (Dauda *et al*., 2008; Ojeniyi, 2008). The extensive use of poultry manure as organic fertilizer refers to its positive effects on soil properties, such as, nutrient availability, soil reaction (pH), higher organic matter content, base-exchange capacity, water retention, and maintaining soil structure. Besides increasing crop productivity, poultry manure significantly improves the soil fertility of the said crops (Amanullah *et al*., 2010).

The effectiveness of biological fertilizers depends on their application rate and terms of fertilization, directly affecting crop productivity and soil fertility. The consistent use of organic fertilizers will enhance crop productivity and improve soil fertility and the environmental situation around livestock complexes. Relatedly, limited past findings also exist on the use and effects of organic fertilizers on crop plants in Northern Kazakhstan. Therefore, the presented study determined the impact of organic fertilizers on the rhizosphere microbiome, spring barley productivity, and its structural elements on Southern chernozems.

MATERIALS AND METHODS

Experimental conditions

The experimental site was Village Nauchny, Akmola region, Kazakhstan (51°37'26.9 N latitude and 71°00'57.1 E longitude). The territory lies in dry steppes zone, with its climate characterized by long cold winters and dry and hot summers with average annual temperature and precipitation of 1.7 °C and 325.6 mm, respectively. The duration of the frost-free period was 100–130 days. The identified soil type was Southern carbonate chernozems with heavy loamy granulometric composition, humus content (2.8%), and a pH of 7.5. The said territory also has a low range of mobile phosphorus (9.25 mg/kg) and increased content of exchangeable potassium (500.7 mg/kg), with a high degree of saturation with bases (60%).

Spring barley cultivar Tselinny-2005 seeds came from the A.I. Barayev Research and Production Centre for Grain Farming, District Shortandy, Akmola Province, Republic of Kazakhstan. The variety is a certified and recommended selection for sowing in the Northern regions of Kazakhstan. It is a mid-season cultivar possessing medium resistance to lodging. The experimental site included eight variants in five replicates each. The plot size was one square meter. At 450 germinating seeds per square meter (recommended rate for this area), dropping seeds manually to a depth of 5–6 cm occurred on 24 May 2021, with 1 kg of seeds pre-treated with 200 ml of corresponding microbial fertilizer in suspension. Artificial watering did not happen during the vegetation season.

Types of organic fertilizers

Two types of organic fertilizers were used and studied in the presented research.

a) Biofertilizers containing highly effective microbial strains and the suspension of biofertilizers for seed treatment were Agrarka, Compo-MIX, Agro-MIX, and Trichodermin-KZ.

b) Composted poultry manure applied at doses of 5, 10, and 15 t/ha; organic manure obtained from the "Akmola-Phoenix" Poultry Farm, distributed and spread manually to the soil two weeks before sowing.

Entirely ripped randomly selected 25 plants underwent structural analysis and evaluation for the number of stems, plant height, spike length, spikelet number, and 1000-grain weight. The experiments neither used mineral fertilizers nor herbicides.

Origin and preparation of microbial fertilizers

The biofertilizers used for barley seed pre-treatment were through the kindness of the Department of Soil Science and Agrochemistry, Faculty of Agronomy, Kazakh Agrotechnical University, named after Saken Seifullin, Kazakhstan. The isolates obtained for the study and stored in test tubes on agar media had a temperature of 8 °C. Before pre-treating the seeds, the isolates passed through appropriate agar media several times to recover the viability and metabolic activity of the strains. The bacterial suspension comprised washing three-day-old stock cultures of bacteria with 5 ml of saline. Subsequently, the scraping of microbial cultures with a pipette resulted in 0.5 ml of bacterial suspension inoculated into 100 ml of liquid medium. Depending on microbial properties, growing the liquid cultures on a shaker at 70 pm and 28 °C took 72–120 h.

Biofertilizer 'Agrarka' is a concentrated liquid fertilizer including effective strains of actinomycetes, such as, *Streptomyces xantholiticus* spp.7, *Streptomyces microspores* spp.12, and *Streptomyces sioyaensis* spp.41. These strains produce complex biologically active substances possessing antifungal properties and growth-promoting effects. Biofertilizer 'Compo-MIX' includes growth-promoting, nitrogen-fixing, cellulose-decomposing, and antifungal microbes isolated from the soils of Northern Kazakhstan. The microbes were *Streptomyces sindenensis* spp.PM9, *Streptomyces griseus* spp.PM25, *Bacillus aryabhattai* spp.PM62, *Bacillus aryabhattai* spp.PM68, *Bacillus aryabhattai* spp.PM69, *Bacillus megaterium* spp.PM80B, and *Lentzea violacea* spp.PM86B. Biofertilizer

'Agro-MIX' comprised of growth-promoting, nitrogen-fixing, and preserving microorganisms, such as *Bacillus* spp., *Saccharomyces* spp., *Acetobacter* spp., *and Streptomyces* spp. Biofertilizer 'Trichodermin-KZ' consists of the most promising fungal strains T134, T115, and T200, identified as *Tr. lignorum* and *Tr. album*, possessing the highest antagonistic and hyperparasitic properties.

Soil sampling analysis

Soil sampling of the barley rhizosphere had 15 randomized points ranging from 0 to 20 cm depths using stainless steel soil tube. Mixing the collected soil samples resulted in one variant after removing the roots, weeds, soil animals, and other impurities. Then, placing soil samples in a sterile sealed bag prepared these for delivery to the laboratory. The samples passed through a 2 mm sieve before equally dividing into two parts. One part underwent immediate analysis for microbial populations, including bacteria and fungi, while the other for chemical analysis after air-drying.

Quantitative analysis of bacterial and fungal communities

For microbiological analysis, soil sampling proceeded in three periods, i.e., a) germination, b) barley earring, and c) full ripeness. Sterilizing the soil tubes used 96% ethanol before sampling each point. Immediately after sampling, each specimen gained thorough mixing with sterility.

The microbial populations' analysis continued in fresh soil samples of natural moisture. Soil suspension of each sample's inoculation was on selective nutrient media for quantitative microbial analysis, where meat-peptone agar (Accumix, India) accounted for organotrophic bacteria (Scrimgeour, 2008), starch-ammonia agar used for mineral nitrogen-fixing bacteria (Küster, 1959), and Ashby mannitol agar specified atmospheric nitrogen-fixing bacteria (diazotrophs) (Aquilanti *et al*., 2004). The nutrient media received sterilizing (ST-85G Jeiotech) at 121 °C for 20 min; after cooling to 45 °C–50 °C, pouring the media into sterile Petri dishes. The soil suspension serially diluted to 10^{-5} had 0.1 ml of suspension plated in five replicates. Accounting heterotrophic bacteria went on after 72 h of growth at 30 °C. Colony-forming (CFU) of heterotrophic bacteria scaled for one g of soil followed the method of Carter and Gregorich (Scrimgeour, 2008).

Statistical analysis

Analysis of variance (ANOVA) ($P < 0.05$) proceeded to use the software Statistical Package for Social Sciences (SPSS 16.0 for Windows). The data shown comprised a mean of three replications ± standard deviation.

RESULTS

The number of different microbial populations

The presented study compared the quantitative data on soil microorganisms between different biofertilizers to assess the distribution of the most active microbes. Organic fertilizers' application ensued in spring 2021 after pre-sowing tillage. The treatment of seeds used biofertilizers. The abundance of the numerous microbial populations varied during the growing season of 2021.

Accounting for the number of ammonifiers on meat-peptone agar media took place. These microorganisms can actively decompose the proteins of plant and microbial origin. Amino acids released during protein decomposition were the source of ammonium formation, providing plant-available nitrogen. However, a significantly enhanced number of ammonifiers emerged at the beginning of the growth and development of spring barley for all treatments compared with the control. The bacterial number did not significantly differ between treatments of spring barley at tillering and full ripeness stages. Though, the average colony-forming (CFU) of ammonifiers raised dramatically, especially for treatments with Agro-MIX, Trichodermin-KZ, and poultry manure (5 t/ha) (Table 1).

Table 1. The number of ammonifiers colonizing barley rhizosphere during the vegetation period.

Treatments	Seedling (CFU 10^6)	Tillering (CFU 10^6)	Full ripeness (CFU 10^6)	Average (CFU 10^6)
Compo-MIX	74.5	14.0	10.5	33.0
Agrarka	43.0	18.0	3.0	21.3
Agro-MIX	61.0	45.0	13.0	39.7
Trichodermin-KZ	112.5	11.0	8.0	43.8
Poultry manure (5 t/ha)	64.0	38.0	18.5	40.2
- do - (10 t/ha)	51.0	4.0	24.5	26.5
- do - (15 t/ha	61.0	12.0	15.5	29.5
Control	5.5	15.0	6.5	9.0

Table 2. Mineral nitrogen-fixing bacteria count colonizing barley rhizosphere.

Treatments	Seedling (CFU 10^6)	Tillering (CFU 10^6)	Full ripeness (CFU 10^6)	Average (CFU 10^6)
Compo-MIX	6.0	11.0	3.0	6.7
Agrarka	83.0	5.0	2.5	30.2
Agro-MIX	40.0	10.0	10	10.0
Trichodermin-KZ	379.0	3.0	5.0	129.0
Poultry manure (5 t/ha)	96.0	14.0	10	40.0
- do - (10 t/ha)	161.0	4.5	3.5	56.3
- do - (15 t/ha	76.0	10.0	15.5	33.8
Control	14.0	3.5	7.5	5.5

Table 3. The number of nonsymbiotic nitrogen-fixing bacteria colonizing barley rhizosphere.

Treatments	Seedling (CFU 10^6)	Tillering (CFU 10^6)	Full ripeness (CFU 10^6)	Average (CFU 10^6)
Compo-MIX	6.0	6.0	1.5	4.5
Agrarka	5.5	4.0	1.0	3.5
Agro-MIX	66.0	-	2.5	34.3
Trichodermin-KZ	64.5	2.0	3.0	23.2
Poultry manure (5 t/ha)	114.0	4.0	3.0	40.3
- do - (10 t/ha)	19.5	15.0	44.5	26.3
- do - (15 t/ha	6.5	1.5	15.0	7.7
Control	4.5	2.5	5.0	4.0

Microorganisms grown on SAA (starch-ammonia agar) can be a zymogenic microflora and can decompose plant residues and simpler carbohydrates (starch). The application of Agrarka, Trichodermin-KZ, and poultry manure (with three doses) resulted in the highest CFU and active immobilization of easily accessible carbon. However, on SAA media, the lowest colony growth appeared in treatments of Agro-MIX and Compo-MIX, with the CFU not significantly different from the control (Table 2). Although, nitrogen transformation processes are essential for microflora development and agricultural plants. It explains why this study considered microbial groups involved in soil nitrogen accumulation. Nitrogen-fixing bacteria count on the Ashby medium was higher at the beginning of barley development for all treatments than the control (Table 3).

Application of poultry manure (5 t/ha) caused a twenty-five-fold enhancement in nitrogen-fixing bacteria. However, during barley ear formation, there was a slight drop in nitrogen fixers except for biofertilizer Agro-MIX, explaining the presence of nitrogen-fixing bacteria. At full ripeness, their numbers fluctuated, with treatments of Compo-MIX, Agrarka, Agro-MIX, and Trichodermin-KZ yielding the lowest count of nitrogen fixers.

Table 4. The effect of organic fertilizers on barley yield attributes.

Treatments	PV (pcs)	NSP (pcs)	NPS (pcs)	PH (cm)	SL (cm)	SN (pcs)	TW (g)	Y (kg/ha)
Compo-MIX	421±19.8	2.73±0.05	2.57±0.15	40.6±2.1	6.87±0.2	15.6±0.4	53.91±1.6	12980±2227
Agrarka	327±33.9	2.28±0.12	1.94±0.17	36.56±0.6	6.93±0.2	15.8±0.64	52.96±1.5	14460±834
Agro-MIX	250±16.2	2.12±0.42	1.8±0.12	36.7±2.3	6.43±0.3	15.17±0.85	55.8±1.15	9470±1059
Trichodermin-KZ	287±5.9	2.13±0.21	1.6±0.18	33.83±3.8	6.7±0.5	14.5±0.25	49.3±1.56	15460±2129
Poultry manure (5 t/ha)	277±12.3	1.46±0.08	1.32±0.02	39.62±2.5	7.32±0.4	19.2±0.97	50±0.65	12260±1791
- do - (10 t/ha)	437±20.7	1.96±0.18	1.96±0.21	37.6±1.7	6.02±0.3	14.42±0.65	52.46±1.1	14870±1052
- do - (15 t/ha_	278±21.4	1.62±0.17	1.32±0.14	39.02±1.1	6.1±0.3	14.32±1.2	45.13±1.9	8160±671
Control	330±15.4	1.45±0.03	1.21±0.05	38.1±1.9	6.18±0.4	14.6±0.07	46.45±1.9	77050±1239
$LSD_{0.05}$	49.6	0.3	0.4	6.1	0.93	1.46	4.8	4456

Note: PV – plant viability, NSP – number of stems, NPS – number of productive stems, PH – plant height, SL – spike length, SN – spikelet number, TW – thousand kernel weight, Y – yield.

The poultry manure applied at the rate of 5 and 10 t/ha caused extensive growth of nitrogen-fixing bacteria. Nitrogen fixers reflect soil fertility with high demand for neutral pH, a favorable water regime, and a sufficient supply of phosphorus and trace elements. In the presented study, the most effective growth conditions for nitrogen-fixing bacteria resulted from the application of biofertilizers Agro-MIX and Trichodermin-KZ and poultry manure (5 and 10 t/ha).

Effect of organic fertilizers on grain productivity and quality

The growing conditions significantly affected the grain yield and its quality. The said study investigated the growth, morphological, and yield parameters, such as, plant viability (PV), number of stems (NSP), number of productive stems (NPS), plant height (PH), spike length (SL), spikelet number (SN), 1000-kernel weight (TW), and yield (Y) (Table 4).

Plant viability

Plant viability varied in organic fertilizer treatments, obtaining the highest value in poultry manure application at 10 t/ha (437 pcs/m^2), and the lowest was from Agro-Mix (250 pcs/m^2). However, the treatment's differences were nonsignificant in plant viability (F: 2.618; $P > 0.05$).

Tillers per plant

According to the results, biofertilization positively affects the number of tillers and significantly (F: 3.154; $P < 0.05$) stimulated tillers formation in barley. Poultry manure (5 t/ha) enhanced tillers, and Compo-Mix application obtained the highest value for tillers per plant. However, the control group showed the lowest number of stems.

Plant height

In barley treatments, the plant heights ranged from 33.83 to 40.60 cm. However, the biofertilizer applications were not significantly (F: 0.979; $P > 0.05$) effective for the plant height. The tallest plants resulted from biofertilizer Compo-Mix, whereas the lowest was from Trichodermin-KZ treatment.

Spike length

The results showed no significant (F: 2.197; $P > 0.05$) effects of organic manure and biofertilizer treatments on the spike lengths in barley. However, in various treatments, the spike length varied from 6.02 (poultry manure 5 t/ha) to 7.40 (poultry manure 10 t/ha).

Spikelet number

The treatments for spikelet number in barley showed significant (F: 3.249; $P < 0.05$) differences. Although spikelet numbers varied along with doses showing the highest spikelet number from poultry manure (5 t/ha), the lowest was in biofertilizer Trichodermin-KZ.

A thousand-kernel weight

For 1000-kernel weight, the differences were statistically significant among the barley treatments (F: 4.93; $P < 0.01$). In comparison, microbial fertilizers performed better than poultry manure by producing bolder grains and the highest 1000-kernel weight. Except for poultry manure at 15 kg/ha treatment, 1000-kernel weight showed an increasing trend due to various treatments. The highest 1000-kernel weight showed from biofertilizers Agro-MIX, followed by Compo-MIX, Agrarka, and poultry manure (10 kg/ha and 5 kg/ha), then by Trichodermin-KZ, respectively.

Spring barley yield (quintal/ha) (hundred kilograms per hectare)

Differences among the various treatments of biofertilizers and poultry manure for barley yield were statistically significant (F: 4.338, $P < 0.01$), and the application of organic fertilizers significantly enhanced the grain yield of barley cultivar Tselinny 2005. The maximum grain yield occurred with the poultry manure (15 t/ha) and biofertilizer Trichodermin-KZ applications, whereas the lowest harvest was the control.

DISCUSSION

Top-dressing with organic fertilizers initially increased the number of ammonifiers (organotrophic bacteria). Later, especially at the end of the vegetative season, it boosted the count of nitrifying bacteria and became more capable of fixing mineral nitrogen (Bakšienė *et al*., 2014). The presented results demonstrated the domination of organotrophic bacteria at the sprouting. The proportion of organotrophic bacteria was the highest in all the treatments compared with the control; however, applying biofertilizers Trichodermin-KZ and Compo-MIX ensured the highest count. Poultry manure fertilization also significantly increased ammonifier count at the full ripeness stage. The population expressed considerable variation among the various treatments, with seed pre-treatment with biofertilizer Agrarka and poultry manure application causing the highest bacterial count at the full ripeness stage. Organic fertilizers significantly increased diazotroph variety by introducing *Pseudacidovorax* and *Rhodopseudomonas*, which provided the highest potential for molecular nitrogen fixation (Shi *et al*., 2021).

The results further demonstrated the predominance of nitrogen-fixing bacteria upon poultry manure fertilization. Seed pre-treatment with biofertilizers Agrarka and Trichodermin-KZ yielded the highest count of organotrophic bacteria. At the same time, the biofertilizers Agro-MIX and Trichodermin-KZ and poultry manure (5 and 10 t/ha) significantly enhanced the nonsymbiotic nitrogen-fixing bacteria.

The findings demonstrated that all treatments with organic fertilizers significantly affected barley's yield attributes and grain yield. The percent viable plants upon application of Compo-MIX and poultry manure (10 t/ha) exceeded the control by 27.6% and 32.4%, respectively. It is because biofertilizers include growth-promoting, nitrogen-fixing, cellulose-degrading, and antifungal strains, such as, *Streptomyces sindenensis* spp. *PM9, Streptomyces griseus* spp.*PM25, Bacillus aryabhattai* spp.*PM62, Bacillus aryabhattai* spp.*PM68, Bacillus aryabhattai* spp.*PM69, Bacillus megaterium* spp.*PM80B,* and *Lentzea violacea* spp.*PM86B* isolated from soils of Northern Kazakhstan. The given results for the number of productive tillers per plant were in analogy with the past studies by assessing the effect of organic fertilizers on the yield attributes of several crops (Shirani *et al*., 2002).

Applying organic fertilizers increases soil nutrient supply, helping improve crop productivity (Koutroubas *et al*., 2016; Markoni *et al*., 2017). In addition, poultry manure fertilization benefits physical and chemical structure and biological soil stability. Poultry manure applied at 5 t/ha stimulated the plant growth, where barley plants were also 1.52 cm taller than the control. Other researchers who studied the effect of organic fertilizers on crop plants revealed similar results (Mahajan *et al*., 2008). Demissie *et al*. (2017) demonstrated that the complex application of lime, balanced fertilizers, and compost resulted in significantly taller barley plants than the control. It was also true when applying organo-mineral fertilizers at 5 t/ha on barley (Tadesse *et al*., 2018).

A significant improvement and gain in 1000-kernel weight showed for all treatments with organic fertilizers in wheat (Ibrahim *et al*., 2008). Similarly, Ayalew and Dejene (2012) reported the highest 1000-kernel weight in barley when applied with organic fertilizers at 5 t/ha. Biofertilizer Agro-MIX consists of bacteria capable of biological nitrogen fixation. Some biofertilizers also include microorganisms producing nitrogenase, enhancing the nitrogen assimilation efficiency in yellow lupine (*Lupinus luteus* L.) and other grain crops (Niewiadomska *et al*., 2018).

Barley's grain productivity was lowest in control at 7,700 kg/ha (7.7 quintal/ha), indicating the unsustainable development of barley production. Oppositely, the biofertilizer treatment of Trichodermin-KZ ensured a two-fold increase in grain productivity. Similar studies utilizing seed pre-treatment with *Trichoderma spp.* also reported an increase in barley productivity by 17% (Taghavi *et al*., 2015), rice productivity by 30% (Doni *et al*., 2018), and beetroot and cabbage productivity by 29% (Topolovec-Pintaric *et al*., 2013).

Grain productivity of about 1,490 kg/ha (14.9 quintal/ha) resulted from poultry manure application at 10 t/ha. According to the study results, all treatments with organic fertilizers demonstrated higher grain productivity than the control. The results were consistent with a similar increase in grain and straw productivity of grain crops upon fertilization with poultry manure at 10 t/ha (Chowdhury *et al*., 2019; Hammad *et al*., 2020). A typical application of organic and mineral fertilizers revealed better barley productivity than solely used mineral fertilizers (Tadesse *et al*., 2018). Similarly, the combined use of organo-mineral fertilizers significantly increased barley productivity and improved its quality (Mahajan *et al*., 2008).

This study has some theoretical and practical implications. The theoretical results of the research are justifiable with the use of various doses of organic fertilizer from bird droppings and biofertilizers by agricultural producers for spring barley in the conditions of southern chernozems from Northern Kazakhstan. The research is feasibly essential for developing organic farming, replacing synthetic fertilizers with organic and biofertilizers, increasing crop yields, and improving soil fertility.

CONCLUSIONS

As a result of microbiological analysis of the rhizosphere of barley, a positive effect on the number of ammonifiers and nonsymbiotic nitrogen-fixing bacteria occurred by using biofertilizers Agro-MIX, Trichodermin-KZ, and poultry manure (5 t/ha). Active immobilization of readily available carbon is characteristic when using Agrarka, Trichodermin-KZ, and poultry manure in all the recommended doses. On average, during the growing season, counting the most rhizospheric bacteria was during the period of barley seedlings. The latest study also confirmed the positive effects of organic fertilizer on the yield attributes of spring barley. Seed pretreatment with Trichodermin-KZ, Agrarka, and poultry manure (10 t/ha) significantly improved barley growth and productivity. Generally, all the treatments with biofertilizers provided better barley yields than the control. The study was limited to poultry manure in three doses and four types of biofertilizers of microbial origin. Further research needs implementation on studying the effects of organic fertilizers with various dosages on barley productivity.

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