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The impact of *Klebsiella quasipneumoniae* inoculation with nitrogen fertilization on baby corn yield and cob quality

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Abstract

In response to the escalating costs and diminishing efficiency of nitrogen fertilizers, the agricultural community is actively seeking sustainable alternatives that leverage natural nitrogen sources derived from biological N-fixation processes to enhance crop yield. This study investigates the combined effects of *Klebsiella quasipneumoniae* inoculation and varying nitrogen fertilizer doses on soil fertility, nutrient availability, and the yield and quality parameters of baby corn (*Zea mays*. L). The study involved the application of five nitrogen levels (0, 75, 150, 225, and 300 kg N ha^{-1}) in conjunction with *Klebsiella quasipneumoniae* inoculum on HM-4 variety of baby corn, employing a comprehensive experimental design with five treatments and four replications. All treatments demonstrated increased ear count and weights of ear, silk, husk, edible cob, and biomass compared to the control. The study highlights the potential of *Klebsiella quasipneumoniae* inoculation in synergy with reduced nitrogen fertilizer to enhance total N contents in soil and positively impact baby corn yield and cob quality parameters. Optimal results were achieved with a 50% reduction in nitrogen fertilizer (150 kg N ha^{-1}), emphasizing the importance of integrated nutrient management. The findings contribute valuable insights to sustainable agriculture, offering a promising strategy for increased baby corn production, improved nutritional quality, and environmental conservation. This integrated approach, involving microbial inoculation and nitrogen management, emerges as a key element in modern agricultural practices, promoting both productivity and nutritional content in baby corn crops.

Keywords: *Klebsiella quasipneumoniae,* inoculation, fertilizer, plant yield, cob quality.

Introduction

Baby corn (*Zea mays*. L), renowned for its high nutritional value, undergoes inoculation with plant growth-promoting rhizobacteria (PGPR) to reduce the dependence on chemical fertilizers. The application of PGPR for plant growth promotion is crucial in enhancing various aspects of crop agronomy, yield traits, and overall yield, offering farmers a sustainable and profitable alternative (Kumar et al., 2014). With a short cultivation period of approximately 70 days from sowing to harvest, baby corn is predominantly utilized as a vegetable, particularly for its fresh ears in global culinary preparations. Its swift growth and minimal susceptibility to pests contribute significantly to the economic gains for farmers (Rani et al., 2015).

In Asian countries such as Vietnam, Thailand, and Taiwan, baby corn cultivation has gained popularity due to its high-income potential, short cultivation period, and robust export market, making it a valuable food source (Gondaliya et al., 2022). Nitrogen (N) nutrient plays a pivotal role in promoting the development of baby corn, enhancing leaf and height growth, reducing senescence, and optimizing essential components for ear formation. The positive impact of N nutrient on corn productivity, including seed number, weight, and seed size, has been well-documented in previous studies (Tolbert et al., 2011). The significance of N nutrient in the agronomy and productivity of baby corn has been emphasized in previous research (McCullough et al., 1994). Notably, the N requirement for baby corn varies based on factors such as farmland type, environmental conditions, and plant rotation practices (Blackmer et al., 1989; Bundy et al., 2011).

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The intricate relationship between PGPR and crops within the farmland has been recognized as crucial for bio-exchange, particularly concerning farmland types (Bever et al., 2013). PGPR, encompassing a diverse range of genera, directly influences soil ecology and nutrient conditions (Liu et al., 2019). Recent studies, such as the work by Chuong et al. (2023), highlight the positive effects of fertilizing animal manures with PGPR on the maturity, productivity, and yield components of groundnuts. This underscores the potential of PGPR to enhance soil fertility and crop output across various plant types. The interaction between PGPR, soil, and crop roots on the root surface contributes significantly to crop growth by facilitating nutrient, salinity and moisture absorption (Riaz et al., 2019; Nguyen, 2023). Additionally, PGPR and legumes can form bio-interactions, with roots secreting compounds that promote vigorous plant growth. PGPR also plays a protective role by producing antibiotics to prevent root rot diseases and contribute to overall plant health (Qureshi et al. 2022). Moreover, PGPR's contribution extends to macronutrient provision, particularly nitrogen, influencing crop growth (Mendes et al., 2013; Lazcano et al., 2021). PGPR has the capacity to promote exudative metabolites and mediate signaling for soil regulation (Korenblum et al., 2020). The ability of PGPR to produce hormones further aids in enhancing nutrient absorption and reducing plant stress in challenging environmental conditions.

The taxonomy of the genus Klebsiella has been periodically revised. Currently, this genus includes K. pneumoniae subsp. Pneumoniae and some novel species: *Klebsiella quasipneumoniae*, Klebsiella variicola, and Klebsiella michiganensis (Martínez-Romero et al., 2018). Klebsiella species are ubiquitous in nature, found in water, soil, plants, insects, and other animals, including humans (Bagley, 1985). Although much is known about different free-living nitrogen-fixing organisms' impact on plant yield and soil fertility, very few studies have investigated *Klebsiella quasipneumoniae*'s effects on soil fertility and plant yield. Besides Klebsiella, the genetics of free-living, nitrogen-fixing bacteria remain largely unexplored. The primary objective of this study is to explore the effects of *Klebsiella quasipneumoniae* inoculation with varying nitrogen fertilizer doses on soil fertility, promoting soil nutrient availability, and influencing the yield and cob quality parameters of baby corn.

Material and Methods

Isolation and identification of *Klebsiella quasipneumoniae*: *Klebsiella quasipneumoniae* was isolated from baby corn roots using YEMA (Yeast Extract Mannitol Agar) medium and subsequently identified through the 16S rRNA sequencing method. The sequencing results revealed a 99.74% similarity to the known organisms. The isolation was carried out on the campus of An Giang University - VNU HCMC, utilizing colonies that were initially identified based on morphological and biochemical traits. Further confirmation was achieved through 16S rRNA gene sequencing on the NCBI database, confirming a 99.74% similarity to our target bacteria.

Experimental design and location: The experiment was conducted in an outdoor net house at the An Giang Research Center from August to October. To characterize the soil properties of the experimental site, soil samples were collected from the 0-20 cm depth prior to the experiment, and certain physicochemical attributes of the collected soil sample were determined according to the methodology reported by Carter and Gregoric (2007). The study comprised five treatments labeled BC0 (0 kg N ha^{-1}), BC1 (300 kg N ha^{-1}), BC2 (225 kg N ha^{-1}), BC3 (150 kg N ha^{-1}), and BC4 (75 kg N ha^{-1}), each replicated four times. In BC0, 0% of the required nitrogen for the plant was supplied, BC1 received 100% of the required nitrogen, BC2 received 75% of the required nitrogen, BC3 received 50% of the required nitrogen, and BC4 received 25% of the required nitrogen, all provided through chemical nitrogen fertilizer. In the experiment, alongside seed sowing, phosphorus (355 kg P_2O_5 ha^{-1}) and potassium fertilization (75 kg K_2O ha^{-1}) was applied to all plots. The planting layout consisted of holes spaced at 30 cm x 25 cm, with two seeds sown per hole. The "HM-4" baby corn variety has a growth period of approximately 60 days, ensuring rapid growth, health, and high output. The total research area covered 400 m2 (2 m x 10 m x 4 replicates x 5 plots).

Seed preparation and inoculation: The *Klebsiella quasipneumoniae* strain was cultivated to a quantity of 10^8 colony-forming units per milliliter (10^8 CFU mL^{-1}) on diluted YEMA medium. The "HM-4" variety of baby corn seeds, sourced from a breeding company in southern Vietnam, was utilized for the experiment. Two days prior to sowing in darkness, the baby corn seeds were inoculated with *Klebsiella quasipneumoniae* and subsequently sprayed. The spray inoculation of *Klebsiella quasipneumoniae* was applied to baby corn seeds intended for sowing in all plots, except for the control (BC0) treatment.

Measurement of agronomic and yield traits: The critical practice of tassel removal, performed at approximately 50 days after sowing (DAS), plays a pivotal role in stimulating the development of baby corn ears, thereby enhancing overall yield and nutrient concentration. Agronomic, yield, and edible cob output traits were systematically assessed from 15 DAS until harvest. The parameters monitored encompassed plant height, total chlorophyll content, biomass weight, fresh pod weight, silk weight, husk weight, and cob weight. Furthermore, for the determination of Baby corn cob quality, moisture, lipid, protein, phosphorus, and potassium contents were quantified following the methodology outlined by Jones (2001). The total chlorophyll content of the plant was determined using a chlorophyll meter.

Soil analysis: At the end of the experiment, soil samples were collected from all plots to determine the effects induced by the implemented treatments on some soil properties. Soil pH was measured using a pH meter with a soil-to-water ratio of 1:2.5. Mineral nitrogen content was analyzed using the Kjeldahl method, while available phosphorus was determined employing the alkaline hydrolysis method (Carter and Gregoric, 2007).

Statistical data: The impact of treatments was assessed through ANOVA using Statgraphics software version XVIII. Means were compared, and all variance analyses were conducted at a significance level of 5% ($P \leq 0.05$).

Results and Discussion

After analyzing the soil sample collected from the experimental site before the commencement of the trial, it was determined that the initial soil composition of the experimental area consisted of sandy loam texture (81% sand, 17.7% silt, and 1.3% clay), exhibited a neutral pH of 6.9, and possessed low levels of soil organic matter (0.790%), total nitrogen (0.075%) and moderate available phosphorus (591 mg kg^{-1}).

At the end of the experiment, changes in soil pH, mineral nitrogen, and available phosphorus content resulting from the applications were determined through soil analysis, as presented in Table 1. According to the obtained results, it was determined that the *Klebsiella quasipneumoniae* inoculation, applied in conjunction with inorganic nitrogen fertilizers, significantly influenced the examined soil properties. Despite the initial soil pH of 6.9, which ranged between 6.47 and 7.22 in all treatments, the highest pH was achieved in the BC1 treatment, where *Klebsiella quasipneumoniae* inoculation was not performed, and all required nitrogen for the plant was supplied through chemical means. Conversely, the lowest pH was observed in the BC4 treatment. However, while the total nitrogen and available phosphorus content of the soils were minimal in the BC1 treatment, the highest total nitrogen was found in the BC3 treatment, and the highest available phosphorus was observed in the control (BC0) treatment.

Table 1. Changes in soil pH, Mineral N, and Available P contents of soil samples collected from plots at the end of the experiment

Treatments	pH	Mineral N (mg kg^{-1})	Available P (mg kg^{-1})
BC0	6.692 ± 0.600	61.0b ± 0.007	573a ± 7.49
BC1	7.221 ± 0.648	41.0c ± 0.005	392b ± 5.12
BC2	6.683 ± 0.600	42.0c ± 0.005	510a ± 6.65
BC3	6.891 ± 0.619	91.0a ± 0.011	553a ± 7.22
BC4	6.471 ± 0.581	71.0b ± 0.009	510a ± 6.66

Sign (±) indicates the mean standard deviation of four repeats; The same letter denotes inadequately different means in a column for each trait.

At 15 and 30 days after sowing (DAS), changes in plant height, leaf count, and total chlorophyll content of baby corn plants due to the treatments are presented in Table 2. According to the obtained results, it was determined that all treatments increased plant height, leaf count, and total chlorophyll content compared to the control (BC0) at 15 DAS. However, by 30 DAS, it was observed that plant height and leaf count in the BC4 treatment were even lower than the control (BC0), indicating a decline in plant development over time. Specifically, plant height was lower in BC4 at 15 DAS, while at 30 DAS, it was lower in BC3. Leaf count was lower in BC4 at 15 DAS, while at 30 DAS, it was lower in BC2 and BC3. The total chlorophyll content was highest in BC1 at 15 DAS, whereas at 30 DAS, it was highest in BC2.

Table 2. Effects of treatments on plant height, leaf count, and total chlorophyll content of baby corn plants in measurements taken at 15 and 30 days after sowing (DAS)

Treatment	Crop height (cm)		Number of leaves (leaf $plant^{-1}$)		Total chlorophyll (µg mL^{-1})	
	Days After Sowing (DAS)					
	15	30	15	30	15	30
BC0	33.53b ± 1.37	95.81 ± 4.51	6.51c ± 0.577	12.51ab ± 0.577	34.47c ± 1.00	34.92c ± 2.27
BC1	42.75a ± 5.35	97.70 ± 2.27	7.76ab ± 0.500	12.80a ± 0.957	43.31a ± 4.56	39.77b ± 2.58
BC2	40.38a ± 4.95	96.00 ± 9.22	7.01bc ± 0.816	13.31a ± 0.500	37.44bc ± 2.58	43.97a ± 2.16
BC3	38.75ab ± 4.13	102.00 ± 7.56	7.51ab ± 0.577	13.30a ± 0.500	39.40ab ± 2.88	39.80b ± 1.30
BC4	41.58a ± 3.25	90.92 ± 3.41	8.01a ± 0.001	11.81b ± 0.500	36.88bc ± 2.12	39.74b ± 2.22
F*test*	*	ns	*	*	**	**
CV (%)	12.42	16.70	10.1	16.31	10.6	18.86

ns: not significant; *: $p \leq 0.05$; **: $p \leq 0.01$; CV (%) expresses the coefficient of variation; Sign (±) indicates the mean standard deviation of four repeats; The same letter denotes inadequately different means in a column for each trait.

The effects of treatments on ear number, fresh weights of certain corn ear components (ear, silk, husk, and edible cob), and fresh plant biomass of baby corn plants are presented in Table 3. According to the obtained results, it was observed that all nitrogen (N) fertilizer and N fertilizer with *Klebsiella quasipneumoniae* inoculation treatments (BC1, BC2, BC3, and BC4) significantly increased ear count, as well as the fresh weights of ear, silk, husk, edible cob, and biomass compared to the control (BC0). The highest ear count and silk weight were recorded in the BC1 treatment, while the highest weights for ear, husk, and plant biomass were observed in the BC2 treatment, and the highest edible cob weight was achieved in the BC3 treatment.

Table 3. Effects of treatments on ear number, fresh weight of ear, silk, husk, edible cob and biomass of baby corn plants

Treatments	Ear number (ears plant-1)	Fresh weingt (t ha-1)				
		Ear	Silk	Husk	Edible cob	Biomass
BC0	2.52d ± 0.016	6.32e±0.016	0.531d±0.001	3.50c±0.408	1.69d±0.008	26.8d±0.163
BC1	5.00a±0.817	14.8b±0.150	1.82a±0.007	9.80a±0.163	2.45b±0.041	34.8c±0.163
BC2	4.37b±0.057	15.3a±0.245	1.35b±0.040	10.1a±0.082	3.15a±0.041	42.2a±0.163
BC3	4.32b±0.016	10.8c±0.653	0.65c±0.041	6.23b±.0.025	3.30a±0.245	34.8c±0.163
BC4	3.48c±0.065	9.90d±0.082	0.65c±0.041	6.43b±0.025	2.23c±0.025	37.2b±0.163
Ftest	**	**	**	**	**	**
CV(%)	23.8	21.5	19.1	25.1	24.2	14.5

ns: not significant; *: p ≤ 0.05; **: p ≤ 0.01; CV (%) expresses the coefficient of variation; Sign (±) indicates the mean standard deviation of four repeats; The same letter denotes inadequately different means in a column for each trait.

The effects of treatments on baby corn cob quality parameters (moisture, lipid, protein, phosphorus, and potassium) are presented in Table 4. According to the obtained results, it was determined that the BC2 treatment predominantly increased the cob lipid and potassium content of the baby corn plant, while the BC3 treatment was found to enhance the cob protein and phosphorus content of baby corn plant.

Table 4. Effects of treatments on cob quality parameters of baby corn plants

Treatments	Cob quality parameters of baby corn plant				
	Moisture, %	Lipid, %	Protein, %	Phosphorous, %	Potassium, %
BC0	81.9d±0.082	0.165d±0.004	2.00b±0.817	0.040d±0.008	0.237c±0.002
BC1	86.6b±0.163	0.175c±0.004	2.32ab±0.016	0.061b±0.008	0.241b±0.003
BC2	85.6c±0.245	0,.215b±0.004	2.62a±0.016	0.049c±0.008	0.274a±0.004
BC3	87.9a±0.082	0.125e±0.004	2.74a±0.033	0.212a±0.002	0.245b±0.002
BC4	77.3e±0.245	0.245a±0.004	2.37ab±0.016	0.047c±0.067	0.237c±0.015
Ftest	**	**	*	**	**
CV(%)	4.70	23.1	17.4	12.2	5.86

*: p ≤ 0.05; **: p ≤ 0.01; CV (%) expresses the coefficient of variation; Sign (±) indicates the mean standard deviation of four repeats; The same letter denotes inadequately different means in a column for each trait.

Discussion

Sustainable agricultural practices are imperative for ensuring food security and environmental protection (McLaughlin and Kinzelbach, 2015). Chemical fertilizers have been extensively employed to boost food production. Conversely, the use of microbial inoculants presents a strategy to enhance soil quality and plant nutrition (Pylak et al., 2019). Microorganisms possess the ability to fix nitrogen from the atmosphere (Kızılkaya, 2008) and produce organic acids, enzymes, and hormones, thereby regulating the soil environment (Bai et al., 2021), fostering the proliferation and activities of soil microorganisms (Guo et al., 2023). These microorganisms can establish a symbiotic relationship with plant root systems, augmenting the nutrient uptake capacity of crops (Mi et al., 2022). *Klebsiella quasipneumoniae* is a bacterium with the ability to fix atmospheric nitrogen (Haahtel and Kari, 1986; Pishchik et al., 1998; Liu et al., 2018). In this study, it was observed that the application of *Klebsiella quasipneumoniae* to soils, in conjunction with chemical nitrogen fertilizers at varying doses, increased both the total nitrogen content of the soil and the yield and yield components of baby corn (Table 1-4), similar to previous findings (Yan et al., 2021; Brooks et al., 2022). This is primarily due to the superior release of organic acids in the combination of chemical fertilizer and microorganism inoculation (Morales-Santos et al., 2023), leading to increased microbial activity and a greater number of microorganisms. Consequently, the fertilizer and water become more readily available for uptake and utilization (Yusefi-Tanha et al., 2023). The combined approach proves more effective in meeting the nutritional needs of baby corn plants consistently, facilitating increased yields, while the microorganisms aid in organic matter decomposition and nitrogen release, thereby enhancing soil fertility.

Recent studies underscore the significant impact of jointly applying chemical fertilizers and microbial inoculants (Bargaz et al., 2018). A study conducted by Ye et al. (2020) demonstrated that an inoculant containing Trichoderma species, when combined with a reduced rate of chemical fertilizer, increased tomato yield and improved soil microbial activity. Additionally, Assainar et al. (2018) found that a well-balanced combination of microbial inoculants with rock-based fertilizer enhanced grain yield in maize under greenhouse conditions. However, limited research exists on the effects of the simultaneous application of chemical fertilizer and microbial inoculant on soil quality and plant nutrition. Ortega (2015) referred to this strategy as integrated nutrient management, encompassing organic matter application, adjusted chemical fertilization, and microbial inoculants.

Furthermore, in this study, it was identified that the most effective application for increasing the yield and yield components of baby corn involved reducing the nitrogen fertilizer by 50% after inoculation with *Klebsiella quasipneumoniae* (BC3). Similarly, Ren et al. (2021) demonstrated that a 50% organic and 50% inorganic nitrogen management strategy resulted in the most significant yield and efficiency increase, aligning with the outcomes of this experiment. Fertilization with microbial inoculations varied across trials due to differences in crop species, types of microorganisms inoculated, trial locations, and climates (Kızılkaya, 2009; Imran and Amanullah, 2023). Nevertheless, field experiments in this study revealed that chemical fertilizer combined with *Klebsiella quasipneumoniae* inoculation significantly boosted yields, primarily due to increased plant fresh weight (Table 3) and improved baby corn cob quality parameters such as lipids, proteins, phosphorus, and potassium (Table 4). Therefore, maintaining or increasing plant weight and cob quality parameters is crucial for enhancing baby corn yield and yield parameters.

Conclusion

In conclusion, this study elucidates the synergistic impact of *Klebsiella quasipneumoniae* inoculation and a strategic reduction in nitrogen fertilizer application, showcasing remarkable outcomes in soil fertility, baby corn yield, and cob quality. The findings underscore the nitrogen-fixing capabilities and soil nutrient enhancement potential of the *Klebsiella quasipneumoniae* genus. Notably, the optimal efficacy was achieved with a 50% reduction in nitrogen fertilizer, revealing a substantial impact on both productivity and qualitative attributes. The study's significant contributions lie in revealing the positive effects of *Klebsiella quasipneumoniae* inoculation on productivity and qualitative attributes, including moisture content, lipid levels, raw protein content, as well as phosphorus (P) and potassium (K) concentrations in the edible cob. Moreover, the identification of the optimal nitrogen rate at 150 kg N per hectare, combined with *Klebsiella quasipneumoniae* inoculation, stands out for its ability to amplify edible cob weight. This signifies substantial potential for enhancing both the yield and nutritional content of baby corn cobs.

The pivotal role of an appropriate nitrogen fertilizer rate, when coupled with *Klebsiella quasipneumoniae* inoculation, is highlighted in elevating all nutritional traits and output parameters of baby corn. This combination emerges as a crucial component in sustainable agricultural practices, providing a pathway for enhanced food security and environmental protection. As a result, the study positions the integration of *Klebsiella quasipneumoniae* inoculation with nitrogen fertilizer reduction as a valuable strategy in modern agricultural landscapes, promising increased yields and improved nutritional quality for baby corn production.

References

Assainar, S.K., Abbott, L.K., Mickan, B.S., Whiteley, A.S., Siddique, K.H.M., Solaiman, Z.M., 2018. Response of wheat to a multiple species microbial inoculant compared to fertilizer application. *Frontiers in Plant Science* 9: 1601.

Bai, Y., Feng, P., Chen, W., Xu, S., Liang, J., Jia, J., 2021. Effect of three microbial fertilizer carriers on water ınfiltration and evaporation, microbial community and alfalfa growth in saline-alkaline soil. *Communications in Soil Science and Plant Analysis* 52(20): 2462–2470.

Bargaz, A., Lyamlouli, K., Chtouki, M., Zeroual, Y., Dhiba, D., 2018. Soil microbial resources for improving fertilizers efficiency in an integrated plant nutrient management system. *Frontiers in Microbiology* 9: 1606.

Bever, J.D., Broadhurst, L.M., Thrall, P.H., 2013. Microbial phylotype composition and diversity predicts plant productivity and plant–soil feedbacks. *Ecology Letters* 16(2): 167–174.

Blackmer, A.M., Pottker, D., Cerrato, M.E., Webb, J., 1989. Correlations between soil nitrate concentrations in late spring and corn yields in Iowa. *Journal of Production Agriculture* 2(2): 103-109.

Brooks, K., Mourtzinis, S., Conley, S.P., Reiter, M.S., Gaska, J., Holshouser, D.L., Irby, T., Kleinjan, J., Knott, C., Lee, C., Lindsey, L., Naeve, S., Ross, J.,Singh, M.P., Vann, R., Matcham, E., 2022. Soybean yield response to sulfur and nitrogen additions across diverse U.S. environments. *Agronomy Journal* 115(1): 370–383.

Bundy, L.G., Andraski, T.W., Ruark, M.D., Peterson, A.E., 2011. Long-term continuous corn and nitrogen fertilizer effects on productivity and soil properties. *Agronomy Journal* 103(5): 1346-1351.

Carter, M.R., Gregorich, E.G., 2007. Soil sampling and methods of analysis. Second Edition, CRC Press. 1264p.

Chuong, N.V., 2023. Response of peanut quality and yield to chicken manure combined with Rhizobium inoculation in sandy soil. *Communications in Science and Technology* 8(1): 31–37.

Gondaliya, B.R., Desai, K.D., Ahlawat, T.R., Mangroliya, R.M., Mandaliya, J.V., 2022. Effect of chemicals on growth and yield of baby corn (*Zea mays* L.). *The Pharma Innovation Journal* 11(9): 2761-2764.

Guo, K., Yang, J., Yu, N., Luo, L., Wang, E., 2023. Biological nitrogen fixation in cereal crops: Progress, strategies, and perspectives. *Plant Communications* 4: 100499.

Haahtel, K., Kari, K., 1986. The role of root-associated Klebsiella pneumoniae in the nitrogen nutrition of Poapratensis and Triticum aestivum as estimated by the method of ^{15}N isotope dilution. *Plant and Soil* 90(1-3): 245-254.

Imran, Amanullah, 2023. Soybean quality and profitability improved with peach (*Prunus persica* L;) remnants, phosphorus, and beneficial microbes. *Journal of Plant Nutrition* 46(3): 370–385.

Jones, J.B., 2001. Laboratory guide for conducting soil tests and plant analyses. CRC Press, New York, USA. 363p.

Kızılkaya, R., 2008. Yield response and nitrogen concentrations of spring wheat (*Triticum aestivum*) inoculated with *Azotobacter chroococcum* strains. *Ecological Engineering* 33(2): 150-156.

Kızılkaya, R., 2009. Nitrogen fixation capacity of Azotobacter spp. strains isolated from soils in different ecosystems and relationship between them and the microbiological properties of soils. *Journal of Environmental Biology* 30: 73-82.

Korenblum, E., Dong, Y., Szymanski, J., Panda, S., Jozwiak, A., Massalha, H., Meir, S., Rogachev, I., Aharoni, A., 2020. Rhizosphere microbiome mediates systemic root metabolite exudation by root-to-root signaling. *PNAS* 117(7): 3874–3883.

Kumar, A., Maurya, B.R., Raghuwanshi, R. 2014. Isolation and characterization of PGPR and their effect on growth, yield and nutrient content in wheat (Triticum aestivum L.). *Biocatalysis and Agricultural Biotechnology* 3(4): 121–128.

Lazcano, C., Boyd, E., Holme,s G., Hewavitharana, S., Pasulka, A., Ivors, K., 2021. The rhizosphere microbiome plays a role in the resistance to soil-borne pathogens and nutrient uptake of strawberry cultivars under field conditions. *Scientific Report* 11: 3188.

Liu, D., Chen, L., Zhu, X., Wang, Y., Xuan, Y., Liu, X., Chen, L., Duan, Y., 2018. Klebsiella pneumoniae SnebYK mediates resistance against Heterodera glycines and promotes soybean growth. *Frontiers in Microbiology* 9: 1134.

Liu, J., Cui, X., Liu, Z., Guo, Z., Yu, Z., Yao, Q., Siu, Y., Jin, J., Liu, X., Wang, G., 2019. The diversity and geographic distribution of cultivable bacillus-like bacteria across black soils of Northeast China. *Frontier Microbiology* 10: 1424.

McCullough, D.E., Mihajlovic. M., Aguilera, A., Tollenaar, M., Giradin, P., 1994. Influence of N supply on development and dry matter accumulation of an old and new maize hybrid. *Canadian Journal of Plant Science* 74(3): 471-477.

McLaughlin, D.; Kinzelbach, W. 2015. Food security and sustainable resource management. *Water Resourse Research* 51(7): 4966-4985.

Mendes, R., Garbeva, P., Raaijmakers, J.M., 2013. The rhizosphere microbiome: significance of plant beneficial, plant pathogenic, and human pathogenic microorganisms. *FEMS Microbiology Reviews* 37(5): 634–663.

Mi, S., Zhang, X., Wang, Y., Ma, Y., Sang, Y., Wang, X., 2022. Effect of different fertilizers on the physicochemical properties, chemical element and volatile composition of cucumbers. *Food Chemistry* 367: 130667.

Morales-Santos, A., García-Vila, M., Nolz, R., 2023. Assessment of the impact of irrigation management on soybean yield and water productivity in a subhumid environment. *Agricultural Water Management 284*: 108356.

Ortega, R., 2015. Integrated nutrient management in conventional intensive horticulture production systems. *Acta Horticulturae* 1076: 159-164.

Pishchik, V.N., Chernyaeva, I.I., Kozhemaykov, A.P., Vorobyov, N.I., Lazarev, A.M., Kozlov, L.P., 1998. Effect of inoculation with nitrogen-fixing *Klebsiella* on potato yield. In: Nitrogen Fixation with Non-Legumes. Malik, K.A., Mirza, M.S., Ladha, J.K. (Eds.). Developments in Plant and Soil Sciences, vol 79. Springer, Dordrecht. pp. 223–235.

Pylak, M.; Oszust, K.; Frac, M. 2019. Review report on the role of bioproducts, biopreparations, biostimulants and microbial inoculants in organic production of fruit. *Reviews in Environmental Science and Bio/Technology* 18(3): 597-616.

Qureshi, M.A., Iqbal, M.Z., Rahman, S., Anwar, J., Tanveer, M.H., Shehzad, A., Ali, M.A., Aftab, M., Saleem, U., Ehsan, S., 2022. Relative potential of Rhizobium sp for improving the rice-wheat crop in the semi-arid regions. *Eurasian Journal of Soil Science* 11(3): 216-224.

Rani, P.L, Sreenivas, G., Katti, G.S., 2015. Baby corn based inter cropping system as an alternative pathway for sustainable agriculture. *International Journal of Current Microbiology and Applied Sciences* 4(8):869-873.

Ren, T., Li, Z., Du, B., Zhang, X., Xu, Z., Gao, D., Zheng, B., Zhao, W., Li, G., Ning, T., 2021. Improvement of photosystem performance and seed yield of summer soybean in Huanghuaihai region by organic fertilizer application and rational planting. *Journal of Plant Nutrition and Fertilizers* 27: 1361–1375.

Riaz, A., Rafique, M., Aftab, M., Qureshi, M.A., Javed, H., Mujeeb, F., Akhtar, S., 2019. Mitigation of salinity in chickpea by Plant Growth Promoting Rhizobacteria and salicylic acid. *Eurasian Journal of Soil Science* 8(3): 221-228.

Torbert, H.A., Potter, K.N., Morrison, J.E., 2001. Tillage system, fertilizer nitrogen rate and timing effect on corn yield in the taxes black land prairie. *Agronomy Journal* 93(5): 1119-1124.

Yan, Z., Chunqiao, X., Sheng, Y., Yin, H., Yang, Z., Chi, R., 2021. Life cycle assessment and life cycle cost analysis of compound microbial fertilizer production in China. *Sustainable Production and Consumption* 28: 1622–1634.

Ye, L., Zhao, X., Bao, E., Li, J., Zou, Z., Cao, K., 2020. Bio-organic fertilizer with reduced rates of chemical fertilization improves soil fertility and enhances tomato yield and quality. *Scientific Reports* 10: 177.

Yusefi-Tanha, E., Fallah, S., Pokhrel, L.R., Rostamnejadi, A., 2023. Addressing global food insecurity: Soil-applied zinc oxide nanoparticles promote yield attributes and seed nutrient quality in Glycine max L. *Science of The Total Environment* 876: 162762.