Influence of the Combined Application of *Bacillus megaterium*, Barley Straw, and Potassium Silicate on Wheat Growth, Grain Yield, and Soil Sustainability

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Abstract:
A field experiment was conducted in Sumer District, located 17 km north of Al-Diwaniyah Governorate, Iraq, to investigate the effects of the triple interaction among *Bacillus megaterium* inoculation, barley straw compost, and potassium silicate on soil biological properties associated with sustainability under wheat cultivation in a clay loam soil. The experiment was arranged according to a Randomized Complete Block Design (RCBD) with three factors: bacterial inoculation (*Bacillus megaterium*) at two levels (B_0 and B_1), barley straw compost at three rates (0, 100, and 200 t ha^{-1}), and potassium silicate at three levels (0, 50, and 100% of the recommended rate). Treatment means were compared using the Least Significant Difference (LSD) test at the 0.05 probability level. The results revealed significant effects of the individual factors and their interactions on the concentrations of indole-3-acetic acid (IAA), gibberellins, and vitamins B7, B8, and B12 in the soil at the end of the growing season. Inoculation with *Bacillus megaterium* (B_1) significantly increased all measured parameters compared with the uninoculated control. Likewise, the highest compost rate (C_2) and the highest potassium silicate level (K_2) resulted in superior values for all studied traits. Significant improvements were also observed under the interaction treatments B_1K_2 and C_2K_2, indicating synergistic effects between microbial inoculation, organic amendment, and silicon nutrition. The triple interaction treatment ($B_1C_2K_2$) recorded the highest concentrations of all measured indicators, reaching 32.21 and 41.74 µg kg^{-1} for IAA and gibberellins, respectively, and 26.15, 31.58, and 4.79 µg g^{-1} for vitamins B7, B8, and B12, respectively. These findings demonstrate that the integrated application of *Bacillus megaterium*, barley straw compost, and potassium silicate enhances soil biological activity and improves key indicators of soil sustainability, highlighting its potential as an effective strategy for promoting sustainable wheat production under semi-arid conditions.

Keywords: *Bacillus megaterium*, barley straw compost, potassium silicate, wheat, soil sustainability, plant growth-promoting bacteria.

Introduction

Current-day biofertilizers are an extremely significant and irreplaceable aspect in the context of even modern agricultural paradigms, since they can be applied directly to the soil matrix (soil applications), coated to seeds (seed priming), sprayed on plant surfaces (foliar application) or used simultaneously using multiple methods. Such biological formulations contains one or more strains role in the continual release and prolonged holding of essential plant nutrients, thereby diminishing adverse nutrient losses commonly induced by environmental leaching via strong retention onto small soil particles as well as by chelation through stable complex formation directly resulting from gradual breaking down of organic matter (6). It is a simple, very inexpensive in the short term and it has shown to be a remarkably effective agricultural practice in returning back harvested crop residues (for instance barley straw when discarded from the land) directly back into the cultivated field. Unfortunately, microorganisms in the soil of varying communities and their extracellular enzymes break down that crop residue by a methodical process into ever simpler organic molecules (low molecular weight organic compounds), bioavailable inorganic nutrients, carbon dioxide gas, and water. Some of the unusual byproducts generated through such complex decomposition mechanisms, especially, lactic acid and macronutrients like nitrogen, phosphorus, and potassium are considered important precursors or structural components during the formation and maintenance of active soil organic matter (22).

Basic potassium fertilizers really supply soluble available forms of potassium for growing plants and also replace the elemental fraction that has been produced by continued agricultural removing from soil reserves. Recent thorough empirical investigations unequivocally demonstrate potassium is now one of the significant limiting factors heavily constraining global crop productivity, and its (in well-documented instances) severe deficiency can greatly, negatively impact overall plant growth and ultimately harvestable yield (17).

of beneficial microorganisms which help in enhancing overall soil fertility and improving the crop yield to a great extent. Achievement of sustainability in agricultural production has been the most important and ultimate goal behind the use of biofertilizers, where careful balance for soil nutrients is to be maintained along with improvement in physical properties or structure, chemical composition and biological activity (14).

Phosphorus is generally accepted to be an essential macronutrient needed for productive plant growth and development; however, a significant proportion of soil phosphorus exists in low solubility forms making it largely unavailable biologically. Some types of sporogenic bacteria, such as the extensively researched Bacillus megaterium have an outstanding ability to rapidly solubilize refractory inorganic forms of phosphorus and bioluminesce the organic phosphorus component in which phosphorus is bond as it naturally exists in soil organic matter, releasing this vital element into a soluble pool that can be readily utilized by a plant. Numerous, detailed scientific investigations have repeatedly and definitively established that the main phosphate-solubilization mechanism used by Bacillus megaterium is firmly intrinsically linked to microbial secretion of low-molecular-weight organic acids which then result in marked promotion of dissolution of complex minerals or geological deposits containing such phosphates (2, 13, 21). In addition, the deliberate optimisation of different organic residues in soil environment not only significantly enhances total content of soil organic matter, but also intensively boosts metabolic activity and general population dynamics of beneficial soil microorganisms by continuously supplying them readily available sources of energy and important nutrients. This assimilated organic material also plays a significant

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Wheat (Triticum aestivum L.) is widely regarded as one of the most highly significant and strategically important cereals worldwide and continues to be a vital staple food source and major life-sustaining source of plant protein for billions of people around the globe **(**1**)**. Its top position of prestige, in total cultivated agricultural area (assessed worldwide) is unparalleled and Iraq, from a geo-aesthetic dimension, emerges as a reasonably accepted progenitor of primeval wheat domestication and superlatively ancient cultivation. Nonetheless, the dynamics of sustained rainfed wheat production interact with numerous serious environmental constraints and ecological problems that have severely hampered both the productivity and nutritional quality of harvested grain due to continuous soil erosion, desertification, salinization, historical low and erratic rainfall pattern, extremely low vegetation cover, and persistent dependence on traditional forms of agriculture. The arab agricultural statistics showed that the total area cultivated with wheat worldwide reached an expansive and impressive number of approximately 215.4 million hectares in 2020 (4).

Materials and Methods

Experimental Site and Design

During its wheat-growing season, a field experiment was carried out with in one of the agricultural fields complex located at Sumer District (17 km northeast of Al-Diwaniyah Governorate), Republic of Iraq. The land was prepared by plowing two times, then leveling and preparing the field. The experimental field was divided into 3 blocks with each block having 18 experimental units. Before the planting, a composite soil sample (0–30cm) was collected. The sample was mixed until well homogenised; air-dried, and filtered through a 2-mm sieve for selected physical, chemical, and biological properties determination (Table 1). The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. The treatments were designed in a split-split plot experiment based on a randomized complete block design, with three factors: (1) bacterium Bacillus megaterium inoculations at… Urea fertilizer (46 % N) was used in three splits equally: before sowing, at 45 days after sowing and at the time of flowering stage. Data were analyzed according to the RCBD, treatment means compared by LSD test at P ≤ 5%.

Determination of Vitamins B7, B8, and B12

For vitamin extraction, 5 g of each freeze-dried or air-dried soil sample were soaked in 20 mL water. Next, 1 mL of 0.1 M sodium hydroxide (NaOH) and 25 mL of 1 M phosphate buffer (pH 5.5) were added. It was allowed to stand in a dark place for 24 h to ensure complete extraction of the mixture. Firstly, the extract passed through Whatman No. The filtrate was diluted in a 25-mL volumetric flask with HPLC-grade water to volume. The final solution was passed

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methanol. The mixture was shaken with a vortex for 4h at ambient temperature and then centrifuged at 5000 rpm for 15 min. The supernatant was collected and the pH adjusted to 9 with 1 M KOH for IAA stabilisation. Then, 2 mL of ethyl acetate and 5 mL of distilled water were added to increase the polarity of the extract and this was vigorously shaken. Centrifuge the mixture again, 5000 rpm in 15 min. The aqueous phase was kept for analysis at refrigeration temperature. Hormone determination was performed at laboratories of the Ministry of Science and Technology by High-Performance Liquid Chromatography (HPLC) (SYKAM Germany). The mobile phase was consisted of a mixture of acetonitrile and water (26:74, v/v). Separation were conducted by employing a C18-ODS column (25 cm × 4.6 mm) in isocratic condition at 0.8 mL min^{-1} flow rate. The detection was monitored on a UV–Visible detector set at 280 nm. through a 0.45-µm membrane filter to remove the smallest clay particles and impurities before performing HPLC. The solutions were kept refrigerated until analysis.

HPLC Conditions for Vitamin Analysis

The vitamins were measured with an HPLC system (SYKAM, Germany). The mobile phase combining 50:47:3 (v/v/v) acetonitrile, distilled water, and formic acid was delivered at a flow rate of 1.0 mL min^{-1}. A C18-ODS column (25 cm × 4.6 mm) was used for separation. It is the detection on wavelengths from 210 to 215 nm with an UV detector.

Determination of Indole-3-Acetic Acid (IAA) and Gibberellic Acid (GA_3)

To extract phytohormones (IAA and GA_3), 3 g of the soil sample were weighed and ground in a porcelain mortar. The sample was then transferred into a volumetric flask and made to 20 mL with

Table 1. Physical, chemical, and biological properties of the experimental soil.

Traits		Vaiues	Units
(pH) (1:1)		7.8	---------
(EC) (1:1		2.91	**DesiSmens.M-^{1}**
(CEC)		18.7	**Cml.mol.kg^{1}.soil g.kg. Soil^{1}**
Sand		150	**g.kg. Soil-^{1}**
Clay		330	
Silt		500	
Soil texture		Loam soil	

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Organic matter O.M.		5.9	**g.kg. Soil-¹**
N	Available elements	26.04	**Mg. kg.Soil¹**
P		11.8	
K		180.7	
Total bacteria		**1.7×10^{-6}**	**CFU.g dry soil**

Results and Discussion

(C_2) was 27.86 µg kg^{-1} as compared to 19.71 µg kg^{-1} found in control treatment (C_0). This effect can be explained by the increase in microbial activity and population density through organic substrates and nutrients provided by compost. As a result, microbial IAA production is raised, rhizosphere conditions are improved and plant growth enhanced. In addition, enhanced microbial proliferation in the root zone offered by compost serves as a rich source of organic matter and energy (1, 23).

Similar to soil N, the application of potassium silicate significantly influenced soil IAA concentration. 18 of the 30 elements (63%) analyzed with significantly greater concentration levels in K_2 treatment than control (K_0) and/or between K_2 and dose-separated K (in mg), especially at 50% dose level, ranging from 26.24 µg kg^{-1} for K_2 vsK_0 to nearly triple via post hoc multiple pairwise t-tests analysis, including phosphorous: 7.00 vs.5.89 versus4.85; calcium6.83 vs2 one sample–one way ANOVA) 20 PP; sodium17% Pt; magnesium27%; copperChloride22·k k muse element each of which were EXPRwere or sevenfold higher in recognition weighting from observations that below four times better results than controls such asandS constituents controlling

Effect of *Bacillus megaterium* Inoculation, Compost, and Potassium Silicate Fertilizer on Soil IAA Concentration at the End of the Growing Season (µg kg^{-1})

As clearly shown in the result of Table 2 experiment, final concentration of indole-3-acetic acid (IAA) deposits by inoculation Bacillus megaterium was high than control treatment at harvest time. The inoculated treatment (B_1) had a mean value 27.52 µg kg^{-1} while the uninoculated control treatment (B_0) showed 20.61 µg kg^{-1}. The production of IAA in the rhizosphere, particularly by beneficial microorganisms (non-pathogens), is essential for plant growth, which contributes to an increase in these parameters. Microbial inoculants can increase the endogenous soil IAA through direct hormone production and indirect promotion of nutrient availability and auxin biosynthesis. Bacillus megaterium, one of the tested strains, is considered an IAA high producer with previously demonstrated ability to produce large amounts of this plant growth phytohormone and consequently sustain optimal auxins levels in rhizospheres for a large part of the whole cycle (11, 21). The results also indicated that screening compost material enhanced soil's IAA content by growing of chicken litter. The maximum concentration of T2 in compost combined with compost application that increase the microbial activity and IAA production, leading to a higher plant growth thus confirming other reports (8).

Interaction among Bacillus megaterium, compost and potassium silicate, played an important role ($p < 0.05$) in soil IAA concentration. The greatest value was found with treatment B_1 C_2 K_2 (32.21 µg kg⁻ ¹) but it did not differ from B_1 C_2 K_1 (31.85 µg kg⁻ ¹). In contrast, the lowest values observed in the control treatments B_0 C_0 K_0 and B_0 C_0 K_1 with 15.25 and 15.80 µg kg⁻ ¹ respectively. The results of the present study indicate that this combined treatments has ability to increase soil biological activity and also production of plant growth-promoting substance (IAA) through microbial inoculation and organic amendment with potassium silicate. yieldsexperimenters provide F measurements indicating significant interactions among organisms adjustmentswhich explain mass measurable uptake biological compartmental-independent stress limitedrough recovery rangesexclusion conventional models low organicfoatinor serine threonine esterase conversion supplemented supporting evidenceonly one third). The increase may be related to the facilitative role of potassium silicate and potentially supported root development, which indirectly promotes IAA production in the rhizosphere (17). Significantly higher soil IAA concentration was observed in the interaction of bacterial inoculation and compost where treatment B_1 C_2 resulted in 31.07 µg kg⁻ ¹ versus 16.73 µg kg⁻ ¹ for B_0 C_0 . This might be explained by the synergistic action of microbial inoculation

Table 2. Effect of *Bacillus megaterium* inoculation, barley straw compost, and potassium silicate fertilizer on soil indole-3-acetic acid (IAA) concentration (µg Kg^{-1}) at the end of the growing season.

P	Compost	Potassium (K)			B x C
		K0	K1	K2	
B0	C0	15.80	16.74	17.66	16.73
	C1	18.54	19.15	23.64	20.44
	C2	21.21	24.87	27.85	24.64
B1	C0	20.65	22.25	25.14	22.68
	C1	26.65	28.88	30.95	28.83
	C2	29.14	31.85	32.21	31.07
L.S.D 0.05		**0.89**			**0.51**
B x K					
Bacteria	**K0**	**K1**	**K2**		**Average B**
B0	18.52	20.25	23.05		20.61
B1	25.48	27.66	29.43		27.52
L.S.D 0.05			**0.51**		**0.30**
C x K					
Compost	**K0**	**K1**	**K2**		**AverageC**
C0	18.23	19.50	21.40		19.71
C1	22.60	24.02	27.29		24.63
C2	25.18	28.36	30.03		27.86
L.S.D 0.05	**0.63**				**0.36**
Average K	22.00	23.96	26.24		
L.S.D 0.05	**36.0**				

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fact that compost is related to improvements in soil fertility and microbial activity. Compost is a source of essential nutrients supplies and increases the population of beneficial microorganisms that may be involved in gibberellin production directly or indirectly, Additionally, compost boosts the rooting and the efficacy of nutrient uptake that aids in its hormone synthesis for growth (16). Bacillus megaterium inoculation significantly interacted with compost application, respectively. The analysis demonstrated that among all interactions, treatment B_1 C_2 gave the highest gibberellin concentration (40.25 µg kg^{-1}) and the lowest was obtained by the control interaction B_0 C_0 with only 25.50 g kg^{-1} of gibberellin content (Fig 1a). This synergistic effect is probably the result of increased microbial decomposition of organic matter, resulting in greater nutrient availability and stimulation of root growth. Microbial activity can also affect plant hormonal balance, resulting in increased gibberellin production and enhanced physiological processes associated with stem elongation and vegetative growth (16).

Soil gibberellin concentration was significantly influenced by the three-way interaction of Bacillus megaterium, compost and potassium silicate. The highest value for the TCA (41.25 µg kg^{-1}) was contributed by treatment B_1 C_2 K_2 , while the control treatment B_0 C_0 K_0 had only 24.25 µg kg^{-1} of TCA. Taken together, these results indicate more efficient improvement of soil biological activity and upsurging of types of plant growth-promoting hormones with concurrent application of microbial inoculum along with organic amendments and potassium silicate.

Effect of *Bacillus megaterium* Inoculation, Compost, and Potassium Silicate Fertilizer on Gibberellin Concentration in Soil at the End of the Growing Season (µg kg^{-1})

The results in the table 3 In serum isolation, presented that gibberel lic concentration was so remarkedly elevated by Bacillus megaterium perforate-ing soil at the end of the growing season. This average concentration in the inoculated treatment (B_1) was 36.59 µg kg^{-1} compared to 29.59 µg kg^{-1} in UKA treatments free of bacteria (control treatment B_0). This elevation was possibly due to the beneficial nature of Bacillus megaterium as a plant growth-promoting bacterium that optimized physiological characteristics enhancing plant growth, had a potential role in alleviating stress and hormonal balance. Moreover, it enhances the generation of plant growth controllers and discharges phytohormones inside the rhizosphere, along these lines expanding gibberellin accessibility in soil condition steady with past reports (8, 15).

Improvements in gibberellin content were also favorably affected by potassium silicate. Highest concentration (K_2 , 100% rate) was 35.35 µg kg^{-1} and control treatment (K_0) produced 30.95 µg kg^{-1} of cadmium. This response might be linked to the beneficial effects of potassium on plant physiological state and growth capacity, which can promote the endogenous biosynthesis of hormones including gibberellins (5). In addition, the results showed that compost application improved extremely gibberellin concentration in soil. C_2 reached the highest compost level at 36.93 µg kg^{-1} vs 28.73 µg kg^{-1} for C_0 (the control treatment). This increase can be due to the

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Table 3. Effect of *Bacillus megaterium* inoculation, barley straw compost, and potassium silicate fertilizer on gibberellin concentration in soil($\mu g\ kg^{-1}$) at the end of the growing season.

P	**Compost**	**Potassium (K)**			**B x C**
		K0	**K1**	**K2**	
B0	**C0**	24.25	25.66	26.58	25.50
	C1	27.66	28.74	32.60	29.67
	C2	30.66	33.47	36.66	33.60
B1	**C0**	29.26	31.77	34.87	31.97
	C1	35.74	37.25	39.65	37.55
	C2	38.14	40.88	41.74	40.25
L.S.D 0.05		**1.41**			**0.81**
B x K					
Bacteria	**K0**	**K1**	**K2**		**Average B**
B0	27.52	29.29	31.95		29.59
B1	34.38	36.63	38.75		36.59
L.S.D 0.05	**0.47**				
C x K					
Compost	**K0**	**K1**	**K2**		**Average Compost**
C0	26.76	28.71	30.73		28.73
C1	31.70	33.00	36.12		33.61
C2	34.40	37.18	39.20		36.93
L.S.D 0.05	**N.S**				**0.57**
Average K	30.95	32.96	35.35		
L.S.D 0.05	**0.57**				

colonize the rhizosphere coupled with its capability of continuous biosynthesis of secondary metabolites and bioactive compounds in the crop growing cycle. Moreover, the increase in microbial biomass disintegration at late stages of the growing season could be responsible for additional quantities of vitamins released in soil. These results are in line with previous findings by (20).

Potassium silicate treatment also significantly increased soil vitamin B7 concentration. The apex indicates the highest level (K_2), which measured 20.19 $\mu g\ g^{-1}$ relative to K_0 control = 16.00 $\mu g\ g^{-1}$ ($p < 0.0001$)**. Such rise can be due

Effect of *Bacillus megaterium* Inoculation, Compost, and Potassium Silicate Fertilizer on Vitamin B7 Concentration in Soil at the End of the Growing Season ($\mu g\ g^{-1}$)

As shown in Table 4, vitamin B7 concentration in the soil at the end of the growing season significantly increased after inoculation with Bacillus megaterium. For example, the inoculated treatment (B_1) has a concentration of 21.51 $\mu g\ g^{-1}$ compared to an uninoculated control using B_0 at 14.49 $\mu g\ g^{-1}$. Such a persistent rise could be due to Bacillus megaterium, a recognized plant growth-promoting bacterium that can actively

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quantity was only 10.38 µg g^{-1} in control interaction B_0 C_0 . This response could be explained by the simultaneous effect of microbial inoculation and compost application, which both acted to stimulate soil microorganism communities associated with functions of the soil biological activity. Microorganisms within soil are capable of synthesizing vitamins via metabolic processes, while compost presents with a carbon-rich organic substrate that promotes microbial development and activity subsequently improving soil biochemical functioning and fertility (7). Bacillus megaterium, compost and potassium silicate specially promoted vitamin B7 in soil by the three-way interaction between microorganisms & organic matterend are described as: Bacillus megaterium, compost,potassium silicate respectively end. The highest value for total phenolics, 26.15 µg g^{-1} was recorded by treatment B_1 C_2 K_2 and it is in comparison to the control treatment; the lowest value only 9.85 µg g^{-1} (B_0 C_0 K_0). The finding implies that concurrent uses of microbial inoculation, compost and potassium silicate have synergistic effects in the reinvigoration of biological activity while promoting bio-accumulation of key vitamins linked to soil fertility and sustainability.

to indirect effect of potassium in an activating role for enzymatic actions inside microbial cells, enhancing metabolism efficiency and subsequent vitamin biosynthesis. Furthermore, potassium silicate increases plant health and photosynthesis which enhance the release of sugars and organic acids through root exudates. These compounds are important energy sources for soil microbes and can help produce vitamin B7. Potassium silicate exerted a lasting effect on microbial activity and accumulation of vitamins, as the beneficial effect lasted until harvest time (3). The application of compost also had a major impact on the concentration of vitamin B7. The most compost in the treatment (C_2) presented with 21.68 µg g^{-1} and lowest (control—C_0) only with 13.67 µg g^{-1}. The rise may relate to the promotion of microbial activity and organic matter degradation observed soon after compost application, which affects bioactive compound synthesis and accumulation such as vitamin B7 (12)

The vitamin B7 levels in the soil showed significant increases with interaction between bacterial inoculation and compost. The amount of B_1 C_2 in treatment was 24.98 µg g^{-1}, while the

Table 4. Effect of *Bacillus megaterium* inoculation, barley straw compost, and potassium silicate fertilizer on vitamin B7 concentration in soil(µg g^{-1}) at the end of the growing season.

P	**Compost**	**Potassium (K)**			**B x C**
		K0	**K1**	**K2**	
B0	**C0**	9.85	10.25	11.05	10.38
	C1	12.74	13.66	17.70	14.70
	C2	15.25	18.25	21.66	18.39
B1	**C0**	14.41	16.68	19.77	16.95
	C1	20.09	22.85	24.80	22.58
	C2	23.66	25.14	26.15	24.98
L.S.D 0.05		**0.81**			**0.47**
B x K					
Bacteria	**K0**	**K1**	**K2**		**Average B**

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B0	12.61	14.05	16.80	14.49
B1	19.39	21.56	23.57	21.51
L.S.D 0.05			**0.47**	**0.27**
C x K				
Compost	**K0**	**K1**	**K2**	**AverageC**
C0	12.13	13.47	15.41	13.67
C1	16.41	18.25	21.25	18.64
C2	19.46	21.70	23.90	21.68
L.S.D 0.05	**0.57**			**0.33**
Average K	16.00	17.80	20.19	
L.S.D 0.05	**0.33**			

potassium silicate increased growth and activity of such microbes, which could contribute to the production of more vitamin B8 from their metabolic activities.

The application of compost provided a substantial positive impact regarding vitamin B8 concentration. The highest amount of compost (C_2) was 26.35 µg g^{-1}, and the control treatment (C_0) yield a only 16.01 µg g^{-1} (11). This answer can be explained by the compost presence stimulating biological activity, which increases the mineralization of organic matter and OM's transformation into humic substances, just as its possible action on increasing biologically active compounds (including vitamin B8) (51). Compost also provides a continuous source of nutrients which serve as organic substrates that support microbial growth and activity in the soil (12).

Soil vitamin B8 content after bacterial inoculation showed significant interaction with compost. The highest value for total phenolic compounds (30.47 µg g^{-1}) was given by treatment B_1 C_2 and the control interaction B_0 C_0 only 12.36 µg g^{-1}. This synergistic effect could be caused by the dual effects of microbial inoculation and compost application on plant growth and activation of microbial communities. Compost adds carbon-rich organic matter that maintain microbial populations and

Effect of *Bacillus megaterium* Inoculation, Compost, and Potassium Silicate Fertilizer on Vitamin B8 Concentration in Soil at the End of the Growing Season (µg g^{-1})

The results in Table 5 show that the introduction of Bacillus megaterium during the second growth period noticeably increased vitamin B8 content in the soil at the end of vegetation. The concentration of (B_1) inoculated treatment was for B_0 the uninoculated control treatment 25,93 µg. g^{-1}-17,51 µg.g^{-1}. This increase could be ascribed to the significant role of the bacterial inoculant stimulating soil microbial activity and increasing beneficial microorganisms in rhizosphere. Microorganisms activity increased enhancing biosynthesis and accumulation of certain vitamins, to name but a few includes vitamin B8, leading to improvement soil biological fertility.

The appplication of potassium silicate also increased vitamin B8 concentration in the soil significantly. She noted that the uppermost level (K_2) yielded 24.30 µg g^{-1}, versus producing 19.28 µg g^{-1} in the control treatment (K_0). This increase can be related to the indirect action of potassium silicate on soil microbial communities. The role of beneficial bacteria and fungi was also inclined to help with soil biological processes;

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the highest value (31.58 µg g^{-1} and control treatment (B_0 C_0 K_0 has lowest problem of 11.05 µg g^{-1}). Consequently, these results suggest that co-application of microbial inoculation together with organic amendments and potassium silicate successfully improves soil biological activity and supplementation of vitamins corresponding to better soil quality and sustainability.

nourish soil fertility and beneficial bacteria synthesize vitamins through their metabolic actions. These results are further in line with better integrated nutrient management practices.

A highly significant three-way interaction of Bacillus megaterium, compost and potassium silicate influenced the vitamin B8 concentration in the soil. Among all treatments, B_1 C_2 K_2 performs best with

Table 5. Effect of *Bacillus megaterium* inoculation, barley straw compost, and potassium silicate fertilizer on vitamin B8 concentration in soil (µg g^{-1})at the end of the growing season.

P	**Compost**	**Potassium (K)**			**B x C**
		K0	**K1**	**K2**	
B0	**C0**	11.05	12.32	13.70	12.36
	C1	16.45	16.60	20.80	17.95
	C2	18.14	21.66	26.88	22.23
B1	**C0**	17.11	19.66	22.20	19.66
	C1	24.66	27.66	30.66	27.66
	C2	28.25	31.58	31.58	30.47
L.S.D 0.05		**0.69**			**0.40**

B x K				
Bacteria	**K0**	**K1**	**K2**	**Average B**
B0	15.21	16.86	20.46	17.51
B1	23.34	26.30	28.15	25.93
L.S.D 0.05			**0.47**	**0.23**
C x K				
Compost	**K0**	**K1**	**K2**	**AverageC**
C0	14.08	15.99	17.95	16.01
C1	20.55	22.13	25.73	22.80
C2	23.20	26.62	29.23	26.35
L.S.D 0.05	**N.S**			**0.28**
Average K	19.28	21.58	24.30	
L.S.D 0.05	**0.28**			

uninoculated control treatment (B_0) had only 2.06 µg g^{-1} B. It could be that the sustained increase is due to Bacillus megaterium synthesizing vitamin B12 and stimulating the abundance and actions of indigenous bacterial and fungal

As indicated in Table 6, inoculation with Bacillus megaterium significantly increased the concentration of vitamin B12 in the soil at the end of the growing season. The inoculated treatment (B_1) had a total of 3.54 µg g^{-1} B whereas the

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foster the bacteria and fungi, producing vitamins in soil (12).

However, the experiment revealed a significant interaction between bacterial inoculation and compost application. Vitamin B12 concentration was highest for treatment $B_1 C_2$ and lowest for control interaction $B_0 C_0$ producing only 1.27 µg g^{-1} as opposed to a high value of 4.40 µg g^{-1} respectively (Table Table2). This increase could be due to synergistic effect of introducing a microbial inoculum and adding compost, leading to the stimulation of metabolic activity by the resident microbial community and the introduction of new microbes in soil ecosystem. composition and function of composts The organic matter in compost, is a carbon-rich substrate which stimulates growth of beneficial bacteria and fungi that can produce vitamin B12 and increase soil biological fertility. Results showed that the three-way interaction of Bacillus megaterium, compost and potassium silicate influenced vitamin B12 concentration in the soil. The maximum value was achieved from treatment $B_1 C_2 K_2$, which with 4.79 µg g^{-1} exceeded the control treatment $B_0 C_0 K_0$ (1.08 µg g^{-1}). ConclusionThe findings suggest that combined application of microbial-inoculation, compost and potassium silicate can increase biological activity in soil and lead to a strong B12-enrichment-production process, and thus improve soil quality as well as sustainable productivity.

populations within the soil. Depending on their microbial capacity to synthesize vitamins and other bioactive compounds, these microorganisms may vary in quantity especially at the rhizosphere where microbial activity is generally enhanced. These results have been previously reported by others (18). Application of potassium silicate significantly increases vitamin B12 concentration in the soil, too. Quantities of Cr in rice grains increased from 2.36 µg g^{-1} during the control treatment (K_0) to as high as 3.28 µg g^{-1} when fertilised with K_2 . This increase in growth could be due to the indirect effect of potassium silicate on increasing soil biological activity and thus physiological processes in the soil. Enhanced availability of nutrients and growth of microbes due to potassium fertilization may correlate with higher biosynthesis and accumulation of vitamin B12.

The results also suggested that the application of compost had a significant effect on vitamin B12 concentration. In the highest compost treatment, C_2 gave an average yield of 3.64 µg g^{-1} but in the control treatment (C_0) it yielded an average of 1.90 µg g^{-1}. Most likely, this responds to the fact that compost favors an increase in microbial activity and the decomposition of organic matter and this action correlates with a higher synthesis of biologically active molecules such as vitamin B12. It provides important nutrients and organic substrate that can

Table 6. Effect of *Bacillus megaterium* inoculation, compost, and potassium silicate fertilizer on vitamin B12 concentration in soil at the end of the growing season.

P	**Compost**	**Potassium (K)**			**B x C**
		K0	**K1**	**K2**	
B0	**C0**	1.08	1.25	1.49	1.27
	C1	1.62	1.81	2.67	2.03
	C2	2.29	2.85	3.48	2.87
B1	**C0**	2.09	2.42	3.05	2.52

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	C1	3.29	3.62	4.22	3.71
	C2	3.82	4.58	4.79	4.40
L.S.D 0.05		**N.S**			**N.S**
B x K					
Bacteria	**K0**	**K1**	**K2**		**Average B**
B0	1.66	1.97	2.55		2.06
B1	3.07	3.54	4.02		3.54
L.S.D 0.05					**0.36**
C x K					
Compost	**K0**	**K1**	**K2**		**AverageC**
C0	1.58	1.84	2.27		1.90
C1	2.46	2.72	3.45		2.87
C2	3.06	3.72	4.14		3.64
L.S.D 0.05					**0.44**
Average K	2.26	2.76	3.28		
L.S.D 0.05	**0.44**				

Conclusion

In this study, the results showed that the application of Bacillus megaterium, barley straw compost and potassium silicate can significantly enhance soil biological indicators related to soil sustainability. Compared to the control treatment, all treatments resulted in higher concentrations of indole-3-acetic acid (IAA), gibberellins (GA_3), and vitamins B7, B8, and B12 in soil. The overall positive picture was retained for in the inoculation with Bacillus megaterium among the separate factors, having a significant impact on producing plant growth-promoting substances and vitamins due to its key role in stimulating rhizosphere activity. The beneficial effect of compost on properties of soil biological fertility was attributed to the supply of organic matter and stimulation of beneficial populations, while potassium silicate contributed to maintaining active fauna and modulating plant physiological processes. As a general rule, the effects of the interactions were stronger than the effect of reduce itself. Specifically, the application of bacterial inoculation combined with compost had a significant positive effect on the concentrations of the hormones and vitamins being studied. The triple interaction treatment (B_1 C_2 K_2) recorded the highest value for all measured parameters, confirming a synergistic relationship between microbial inoculation, organic amendment and potassium silicate fertilization. Conclusively, the joint application of Bacillus megaterium, compost produced from barley straw and potassium silicate could potentially be an efficient and environmentally friendly management alternative that enhance soil biological quality as well as sustainable wheat production. The results emphasise the need to improve both biological, organic (e.g. compost production) and/or mineral (biochar amendment) indicators of soil health and sustainability in the long-term under semi-arid conditions.

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