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Enhancing Nitrogen Availability and Wheat Productivity in Alluvial Soils by Organic Amendments Combined with Nitrogen Fertilizers and *Azospirillum Brasilense* Bacteria

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Abstract

The objective was to evaluate treatments involving ammonium sulfate (AS), urea and sulfur-coated urea (SCU) mixed with organic amendments such as Moringa seed residues (MSR), biogas manure (BM), and vermicompost (Ver), along with *Azospirillum brasilense* (ASB). Among these treatments, SCU emerged as the most effective nitrogen source, especially when combined with Vermicompost and ASB. Results showed that application of different nitrogen fertilizers *i.e.* ammonium sulphate (AS) or Urea (U) and sulphur coated urea (SCU) combined with organic amendments under *Azospillum brasilense* (ASB) inoculation gave increases in plant height, straw and grains weight, 1000 grain weight, protein content, chlorophyll a, chlorophyll b, and carotenoids, antioxidant enzymes and NPK- uptake of wheat plants compared to untreated plants. Application of SCU + vermicompost (Ver) in the presence ASB gave the highest values of straw, grains, 1000 grain weight and protein content of wheat plants compared to different treatments. The application of SCU plus Ver. under inoculation with ASB was the best treatment in the maximum CAT (70.46 A564 min^{-1} g^{-1} protein), POX (2.08 A564 min^{-1} g^{-1} protein), and SOD (9.11 A564 min^{-1} g-1 protein), while these parameters recorded their lowest values (40.50, 0.620 and 3.40 A564 min^{-1} g^{-1} protein, respectively) as comparing with other combined applications. The treatments of SCU combined with Ver and ASB gave the highest values of available N (41.31 mg kg^{-1}), while the lowest ones (15.35 mg kg^{-1}) were found with untreated soil.

Keywords: Wheat; Alluvial Soil; Organic Amendments; *Azospirillum brasilense*; Nitrogen Fertilizers.

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1. Introduction

Nitrogen is the seventh most abundant element in the universe. It's the single most common element in the earth's atmosphere, comprising about 78% (4,000 trillion tons) of the gas that makes up our atmosphere. Nitrogen is found in all soils, and is required by all living creatures. In plants, nitrogen is the nutrient required in the largest amounts. It is a key constituent of critical organic molecules such as amino acids, nucleic acids, and proteins. Nitrogen is found in marine and freshwaters and is present in some minerals. In short, nitrogen is found in every ecosystem and in every part of the global environment [1,2].

Nitrogen fertilizer application at different growth stages is likely to improve N use efficiency, grain quality and yield of wheat crop. Application of right N fertilizer dose at right time can help to reduce production cost and environmental pollution as well [3]. Nitrogen fertilization has various effects on different processes inside the wheat plant. Increasing nitrogen application rates can improve photosynthetic capacity, delay leaf senescence, and increase dry matter accumulation, ultimately leading to an increase in grain yield [4]. The choice of nitrogen application rate and variety can significantly influence grain yield and physiological traits such as relative water content, proline content, malondialdehyde, superoxide dismutase, catalase, and ascorbate peroxidase activities [5]. The addition of controlled-release nitrogen fertilizer (CRNF) could not only reduce N loss through various pathways, but also promote N absorption and utilization by crops, thus increasing N use efficiency (NUE) and reducing environmental burden compared with urea [6]. Applying S-coated urea at a lower rate of 150 kg N ha^{-1} compared with a higher rate of 200 kg N ha^{-1} may be an effective way to reduce N fertilizer application rate and mitigate NH3 emission, improve NUE, and increase maize yield [7].

Various organic amendments have significantly increased wheat grain yield and yield components [8,9]. Vermicomposting, a type of organic fertilizer derived from red earthworms and cow dung, can enhance soil fertility and promote plant growth [10&11]. Organic fertilizers offer an environmentally friendly alternative to chemical fertilizers, providing beneficial microorganisms, minerals, and nutrients to boost soil fertility and crop growth [12,13]. We hypothesize that combining different nitrogen fertilizers with organic amendments and biofertilizers in alluvial soil can enhance wheat growth, yield, and nutrient uptake while mitigating the environmental impact of conventional nitrogen fertilizers. The objective of this study is to assess how these combined treatments affect wheat growth and yield, focusing on photosynthetic pigments, yield components, and nutrient uptake in a controlled greenhouse setting. This work is novel because it explores the synergistic effects of combining ammonium sulfate, urea, and sulfur-coated urea with organic amendments like Moringa seed residues, biogas manure, and vermicompost, and biofertilizers like *Azospirillum brasilense*.

2. Materials and Methods

A pot experiment was conducted in a greenhouse to study the effect of different nitrogen fertilizers i.e.; ammonium sulphate (205 g N kg^{-1}), Urea (465 g N kg^{-1}) and sulphur coated urea (380 g N kg^{-1}) mixed either with organic amendments {Moringa seed residues (MSR), biogas manure(BM) and vermicompost (VER)} with and without *Azospirillum brasilense* on growth, yield and nutrients uptake of wheat (*Triticum aestivum* L, cv. Sakha 93) plants under alluvial soils. The soil was taken from the surface layers (0-30 cm) from Hehia county, El-Sharkia Governorate, Egypt. The soil was air dried for 6 days, crushed, sieved to pass through 2 mm plastic screen, thoroughly mixed and stored in plastic bags, Main soil properties are given in Table 1. Soil properties were determined according to [14,15,16].

Plastic pots of internal dimensions 25 x 30cm were filled with ten kilograms of the tested soil samples. Previously mentioned treatments were mixed with the tested soil before planting and replicated three times. A randomized complete block design was used. Moringa seed residues, biogas manure and vermicompost were added at a rate of 2% (20 g kg^{-1} soil). Some characteristics of organic amendments are shown in Table (2).

Table 1: Some physical and chemical properties of the investigated soil

Soil characteristics	Values
Soil particles distribution	
Sand ,%	17.31
Silt,%	34.39
Clay,%	48.30
Textural class	Clay
Field capacity (FC),%	21.28
$CaCO_3$, (g kg^{-1})	5.0
Organic matter,(g kg^{-1})	9.87
pH*	7.91
EC,(dSm^{-1}) **	0.79
Soluble cations and anions, (mmolc L^{-1})**	
Ca^{++}	1.72
Mg^{++}	2.95
Na^{+}	1.54
K^{+}	1.69
$CO_3^{=}$	0.00
HCO_3^{-}	3.81
Cl^{-}	1.55
$SO_4^{=}$	2.54
Available nutrients (mg kg^{-1}soil)	
Available N	45.32
Available P	19.16
Available K	234

* Suspension of 1:2.5 soil:water ** Soil paste extract

Table 2: Some characteristics of organic residues

Organic residues	EC**, dSm^{-1}	pH*	Organic matter, (%)	Total nutrients, %			C/N ratio
				N	P	K	
Moringa seed residues	1.34	7.45	40.23	1.96	0.60	1.53	11.93
Biogas manure	2.51	7.85	30.56	1.76	0.27	1.96	10.10
Vermicompost	2.27	7.56	40.1	2.91	0.75	1.65	8.01

*Organic residues -water suspension 1: 5 ** Organic residues water extract 1:10

Different nitrogen fertilizer was added at the rate of 100 mg N kg^{-1} soil at three equal splits. The first was 15 days after seeding, the second and third doses were added at tillering (45 day after seeding) and booting (75 day after seeding). Before seeding, Phosphatic fertilizers were added to the soil samples as ordinary super phosphate (67.6 g P kg^{-1}) at a rate of at 13 mg P kg^{-1}. Potassium fertilizers as potassium sulphate (400 g K kg^{-1}) was thoroughly mixed with the soil at a rate of 40 mg K kg^{-1}. Twenty seeds of wheat were seeded per pot. The pots were daily weighed and the soil moisture content was adjusted nearly the field capacity. After germination, plants were thinned to ten plants. Seeds were inoculated with *Azospirillum brasilense* inoculum, which has activity in N_2 fixation in the soil; and is produced commercially by the Soil Microbiology Unit of the Soil, Water and Environments Research Institute of the Agriculture Research Center, Giza, Egypt. At 80 days, two plants were randomly selected for the measurement of growth (plant height) and photosynthetic pigments (chlorophyll a, chlorophyll b and carotenoids) were determined spectrophotometrically [17]. Porline was determined according to [18]. After enzymes extraction following [19] . the contents of catalase (CAT),) and Peroxidase (POD) enzymes were determined by spectro-photochemically [20,21,22]. Superoxide dimutase (SOD) activity was measured based on the absorbance peak of superoxide-nitro blue tetrazolium complex [23]. Plants were harvested, dried at 70°C for 72 hours, and weighed to determine yield and yield components. The plant samples were digested with concentrated H_2SO_4 and $HClO_4$ (4:1), with total N and P determined as per [24]. Phosphorus was analyzed colorimetrically [25]. Data were entered into the Statistical Package for Social Sciences ver. [26] . Arithmetic means and standard errors has been calculated as well as and Tow-way ANOVA test was performed.

3. Results and Discussion

3.1. Straw, grain dry weight and biological yield (straw and grains) of wheat plants (g plant^{-1}) as affected by nitrogen fertilizers and organic amendments with or without Azospirillum brasilense bacteria under alluvial soil conditions

The data are given in Table (3) show the effect of applying nitrogen fertilizers and organic amendments with or without *Azospirillum brasilense* bacteria (ASB) on plant height(cm) straw, grain and biological yield (straw and grains), 1000 grains weight (g $plant^{-1}$) and protein content (%) of wheat plants grown on alluvial soil. Application of different nitrogen fertilizers *i.e.* ammonium sulphate (AS) or urea (U) and sulphur coated urea (SCU) combined with organic amendments under ASB inoculation gave increases in straw and grains dry weight of wheat plants compared to untreated plants. Application of SCU + vermicompost (Ver) in the presence ASB gave the highest values of straw, grains, and biological yield and protein content of wheat plants compared to different treatments. These results are similar to those of [27, 28 & 29]. Mineral fertilizers with the combination of vermicompost help to enhance the nutrients and yield of major crops and help to improve soil health [30]. The wheat growth and phenology significantly improved by using coated fertilizers [31] .The crop reached maturity earlier with the application of bioactive sulfur-coated urea than others. The highest values of plant height, straw, grain weight, biological yield and protein content of wheat plants were found to be 138 cm, 1.80 g $plant^{-1}$, 1.70 g $plant^{-1}$, 3.50 g $plant^{-1}$ and 17.17%, respectively, in the SCU plus Ver. under inoculation with ASB. Regarding the impact of nitrogen fertilizers source addition, data indicate that the application of individual SCU or combination with organic amendments and ASB gave the higher values of straw and grains yield of wheat than Uera or AS application. Similar results were obtained [6, 28,32] confirmed that the application of Controlled-release nitrogen fertilizer (CRNF) could not only reduce N loss through various pathways, but also promote N absorption and utilization by crops, thus increasing N use efficiency (NUE) and reducing environmental burden compared with urea. As for the average effect of organic amendments addition, the data show that using Ver. combined with different nitrogen fertilizers in the presences of ASB. gave higher values than Moringa seed residues (MSR) or biogas manure (BM) application. This finding stands in well agreement with those of [33,34] Results show that the addition of Ver. increased grains yield compared to the untreated ones. These increases represent 21, 15,15 and 15% in the case of different for untreated, AS, U, and SCU, respectively. These results are in agreement with those of [35] . Vermicompost stimulates to influence the microbial activity of soil, increases the availability of oxygen, maintains normal soil temperature, increases soil porosity and infiltration of water, improves nutrient content and increases growth, yield and quality of the plant [36]. Nitrogen (N) is a vital element found in all living things. Crops require nitrogen in relatively large amounts, making it the nutrient most often deficient in crop production [37]. Managing nitrogen inputs to achieve a balance between profitable crop production and minimizing nitrogen loss to the environment should be every producer’s goal. The behavior of nitrogen in the soil system is complex, yet understanding the basic processes can lead to a more efficient nitrogen management program [38].

Table 3: Plant height (cm), Straw, grain dry weight, biological yield (g plant^{-1}) and protein of wheat plants as affected by nitrogen fertilizers and organic amendments with or without Azospirillum brasilense bacteria under alluvial soil conditions

NS	OR+ASB	Plant height (cm)	Straw weight (g plant $^{-1}$)	Grain weight (g plant^{-1})	Biological Yield (g plant^{-1})	Protein content (%)
Untreated	Without	92.55 r ± 0.279	0.653 p ± 0.005	0.547 o ± 0.005	1.20 o ± 0	2. 78 q ± 0
	ASB	94.82r ± 0.153	0.723 o ± 0.012	0.627 n ± 0.009	1.35 n ± 0.022	3.44 pq ± 0.046
	MSR	98.63 q ± 0.05	0.800 n ± 0.014	0.703 m ± 0.017	1.50 m ± 0.031	7.06 n ± 0
	MSR+ ASB	100 q ± 0.509	0.930 l ± 0.028	0.827 l ± 0.026	1.76l ± 0.054	8.29 kl ± 0.5
	BM	104 p ± 1.7	1.13 j ± 0.014	1.03 j ± 0.012	2.16 j ± 0.026	8.29 kl ± 0
	BM+ ASB	107 no ± 2.357	1.19 i ± 0.005	1.09 i ± 0.008	2.28 i ± 0.012	8.90 jk ± 0
	Ver	111kl ± 2.625	1.29 g ± 0.009	1.19 g ± 0.009	2.47 g ± 0.019	9.82 hi ± 0.25
	Ver+ ASB	112 kl ± 5.888	1.39 f ± 0.008	1.29 f ± 0.008	2.68 f ± 0.016	10.74 g ± 0
AS	Without	106 op ± 0.816	1.03 k ± 0.005	0.927 k ± 0.005	1.95 k ± 0.009	3.39 pq ± 0
	ASB	108 mno ± 0.943	1.15 j ± 0.005	1.05 ij ± 0.005	2.21 ij ± 0.009	4.00 p ± 0.5
	MSR	109 lmn ± 0.943	1.23 h ± 0.012	1.13 h ± 0.012	2.37 h ± 0.025	7.98 lm ± 0.25
	MSR+ ASB	112 kl ± 0.471	1.31 g ± 0.012	1.21 g ± 0.012	2.53 g ± 0.025	8.90 jk ± 0
	BM	114 jk ± 0.471	1.37 f ± 0.025	1.27 f ± 0.025	2.63 f ± 0.05	9.82 hi ± 0.25
	BM+ ASB	116 ij ± 0.816	1.45 e ± 0.037	1.35 e ± 0.037	2.80 e ± 0.075	10.43 gh ± 0.25
	Ver	118 hi ± 0.471	1.52 d ± 0.033	1.42 d ± 0.033	2.95 d ± 0.066	11.04 fg ± 0.25
	Ver+ ASB	122 fg ± 1.633	1.59 c ± 0.009	1.49 c ± 0.009	3.09 c ± 0.019	12.88 e ± 0.25
Urea	Without	111klm ± 0.471	0.890 m ± 0.008	0.790 l ± 0.008	1.68 l ± 0.016	2.78q ± 0
	ASB	113 jk ± 0.471	1.01 k ± 0.073	0.907 k ± 0.073	1.91 k ± 0.146	5.12 o ± 1.665
	MSR	116 ij ± 0.816	1.12 j ± 0.005	1.02 j ± 0.005	2.15 j ± 0.009	7.37 mn ± 0.25
	MSR+ ASB	118 hi ± 0.471	1.23 h ± 0.005	1.13 h ± 0.005	2.37 h ± 0.009	8.29 kl ± 0
	BM	120gh ± 0.471	1.30 g ± 0.022	1.20 g ± 0.022	2.50 g ± 0.043	8.59 kl ± 0.25
	BM+ ASB	123fg ± 0.816	1.36f ± 0.025	1.26 f ± 0.025	2.61 f ± 0.05	9.51 ij ± 0
	Ver	126 de ± 0.471	1.43 e ± 0.009	1.33 e ± 0.009	2.77 e ± 0.019	10.43 gh ± 0.25
	Ver+ ASB	128 cd ± 0.471	1.50 d ± 0	1.40 d ± 0	2.90 d ± 0	11.66 f ± 0.25
SCU	Without	120gh ± 0.471	1.25 h ± 0.005	1.15 h ± 0.005	2.39 h ± 0.009	6.76 n ± 0.25
	ASB	122. fg ± 0.471	1.30 g ± 0.005	1.20 g ± 0.005	2.5 1g ± 0.009	7.37 mn ± 0.25
	MSR	124 ef ± 0.471	1.39 f ± 0.005	1.29 f ± 0.005	2.69 f ± 0.009	13.49 de ± 0.25
	MSR+ ASB	126.de ± 0.471	1.45 e ± 0.005	1.35 e ± 0.005	2.79 e ± 0.009	14.11 cd ± 0.25
	BM	128 cd ± 0.471	1.60 c ± 0.005	1.50 c ± 0.005	3.09 c ± 0.009	14.72 c ± 0.25
	BM+ ASB	130 c ± 0.471	1.66 b ± 0	1.56 b ± 0	3.22 b ± 0	15.94 b ± 0.25
	Ver	135 b ± 0.471	1.70 b ± 0.005	1.60 b ± 0.005	3.29 b ± 0.009	15.94 b ± 0.25
	Ver+ ASB	138a ± 0.471	1.80 a ± 0	1.70 a ± 0	3.50 a ± 0	17.17 a ± 0.25

NS: Nitrogen source, OR:Organic Residues;AS:Ammonium sulphate; SCU: Sulphur cotated urea; ASB: Azospirillum brasilense; MSR: Moringa Seed Residues; BM: Biogas Manure; Ver: Vermicompost.

Table 4: Chlorophyll a, chlorophyll b, carotenoids (mg g^{-1}f wt) and free proline (µg g^{-1} DW) of wheat plants as affected by nitrogen fertilizers and organic amendments with or without Azospirillum brasilense bacteria under alluvial soil conditions

NS	OR+ASB	Cho. a (mg g^{-1}f wt),	Cho. B (mg g^{-1}f wt),	Chrotein (mg g^{-1}f wt),	Proline (µg g^{-1} DW)
Untreated	Without	0.452 y ± 0.004	0.350 y ± 0.004	0.113 u ± 0	18.87 w ± 0.552
	ASB	0.510 x ± 0.002	0.408 x ± 0.002	0.119 u ± 0	20.62 v ± 0.181
	MSR	0.540 w ± 0.006	0.438 w ± 0.006	0.210 t ± 0.001	21.41 u ± 0.103
	MSR+ ASB	0.574 v ± 0.017	0.472 v ± 0.017	0.219 st ± 0.001	22.78 t ± 0.16
	BM	0.688 u ± 0.034	0.586 u ± 0.034	0.228 rs ± 0.002	23.71 s ± 0.204
	BM+ ASB	0.775 t ± 0.01	0.673 t ± 0.01	0.240 r ± 0.005	25.06 r ± 0.649
	Ver	0.839 s ± 0.004	0.737 s ± 0.004	0.253 q ± 0.002	26.70 q ± 0.139
	Ver+ ASB	0.920 r ± 0.004	0.818 r ± 0.004	0.272 op ± 0.005	29.41 p ± 0.351
AS	Without	1.23 o ± 0.008	1.13 o ± 0.008	0.344 m ± 0.001	30.90 n ± 0.019
	ASB	1.31 n ± 0.016	1.21 n ± 0.016	0.391 k ± 0.029	31.29 n ± 0.037
	MSR	1.38 l ± 0.008	1.28 l ± 0.008	0.439 i ± 0.004	32.67 m ± 0.083
	MSR+ ASB	1.44 j ± 0.009	1.34 j ± 0.009	0.509 g ± 0.001	34.14 k ± 0.504
	BM	1.50 i ± 0.005	1.40 i ± 0.005	0.536 f ± 0.004	35.24 ij ± 0.066
	BM+ ASB	1.60 h ± 0.016	1.50 h ± 0.016	0.563 e ± 0.003	36.22 gh ± 0.029
	Ver	1.66 fg ± 0.008	1.56 fg ± 0.008	0.615 d ± 0.004	37.25 ef ± 0.248
	Ver+ ASB	1.70 de ± 0.005	1.60 de ± 0.005	0.623 d ± 0.001	38.17 d ± 0.045
Urea	Without	0.772 t ± 0.007	0.670 t ± 0.007	0.231 rs ± 0.005	27.08 q ± 0.086
	ASB	0.822 s ± 0.008	0.720 s ± 0.008	0.259 pq ± 0.003	30.28 o ± 0.545
	MSR	0.907 r ± 0.007	0.805 r ± 0.007	0.278 o ± 0.004	31.14 n ± 0.118
	MSR+ ASB	0.949 q ± 0.003	0.847 q ± 0.003	0.293 n ± 0	32.29 m ± 0.067
	BM	1.16 p ± 0.031	1.06 p ± 0.031	0.351 m ± 0.006	33.48 l ± 0.033
	BM+ ASB	1.31 n ± 0.005	1.21 n ± 0.005	0.370 l ± 0.004	34.76 j ± 0.401
	Ver	1.35 m ± 0.009	1.25 m ± 0.009	0.387 k ± 0.001	36.13 h ± 0.11
	Ver+ ASB	1.41 kl ± 0.005	1.31 kl ± 0.005	0.454 h ± 0.009	37.22 ef ± 0.066
SCU	Without	1.41 jk ± 0.008	1.31 jk ± 0.008	0.408 j ± 0.004	34.02 k ± 0.068
	ASB	1.51 i ± 0.029	1.41 i ± 0.029	0.436 i ± 0.006	35.73 hi ± 0.184
	MSR	1.64 g ± 0.005	1.541 g ± 0.005	0.466 h ± 0.002	36.71 fg ± 0.459
	MSR+ ASB	1.68 ef ± 0.012	1.58 ef ± 0.012	0.510 g ± 0.002	37.60 e ± 0.332
	BM	1.71 d ± 0.005	1.61 d ± 0.005	0.622 d ± 0.007	38.32 d ± 0.022
	BM+ ASB	1.78 c ± 0.017	1.68 c ± 0.017	0.657 c ± 0.004	39.39 c ± 0.23
	Ver	1.85 b ± 0.022	1.75 b ± 0.022	0.710 b ± 0.003	40.21 b ± 0.07
	Ver+ ASB	1.92 a ± 0.016	1.82 a ± 0.016	0.807 a ± 0.001	41.61 a ± 0.069

NS: Nitrogen source, OR:Organic Residues;AS:Ammonium sulphate; SCU: Sulphur cotated urea; ASB: Azospirillum brasilense; MSR: Moringa Seed Residues; BM: Biogas Manure; Ver: Vermicompost.

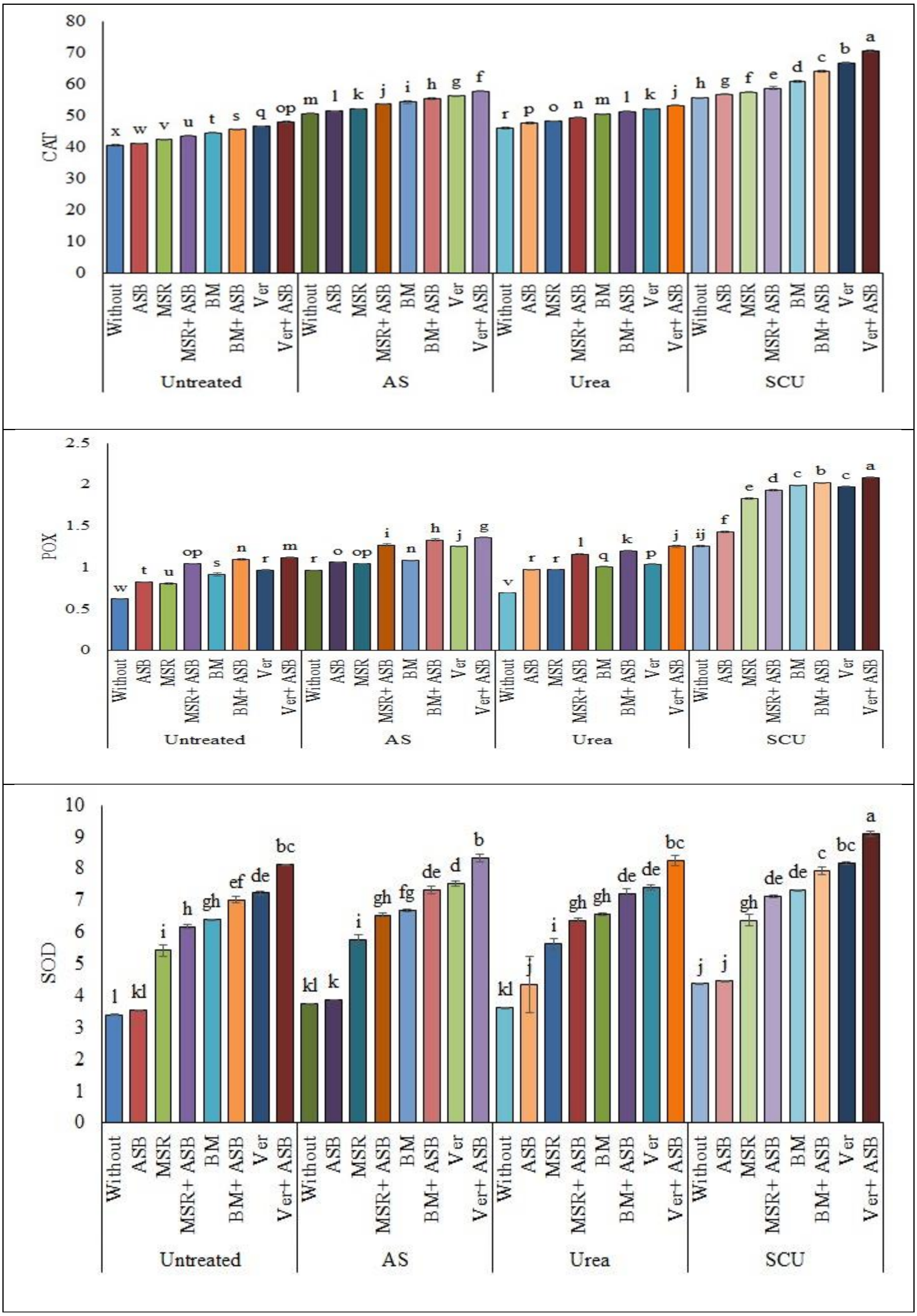

Fig. 1: The content of antioxidant enzymes i.e., catalase (CAT), peroxidase enzymes (POx) and superoxide dimutase activity (SOD), (A564 min^{-1} g^{-1} protein) of wheat plants as affected by nitrogen fertilizers and organic amendments with or without Azospirillum brasilense bacteria under alluvial soil conditions.

3.2. Chlorophyll a, chlorophyll b, carotenoids (mg g^{-1}f wt) and free proline (µg g^{-1} DW) of wheat plants as affected by nitrogen fertilizers and organic amendments with or without Azospirillum brasilense bacteria under alluvial soil conditions

The data are given in Table (4) show the effect of applying nitrogen fertilizers and organic amendments with or without *Azospirillum brasilense* bacteria (ASB) on chlorophyll a, chlorophyll b, carotenoids (mg g^{-1}f wt) and free proline (µg g^{-1} DW) grown on alluvial soil. Application of different nitrogen fertilizers *i.e.* ammonium sulphate (AS) or Urea (U) and sulphur coated urea (SCU) combined with organic amendments under ASB inoculation gave increases in chlorophyll a, chlorophyll b , carotenoids and free proline of wheat plants compared to untreated plants. Application of SCU + vermicompost (Ver) in the presence ASB gave the highest values of chlorophyll a and b , carotenoids and free proline of wheat plants compared to different treatments. These results are similar to those of [39**,**40**,**41]. Incorporating vermicompost as an organic amendment can enhance the physiological characteristics of the soil. This includes increased moisture retention, enhanced hydraulic conductivity, and reduced bulk density, biomass production and nitrogen contents, thereby benefiting overall plant growth and soil fertility management [42] .The high inorganic N concentration of vermicompost makes it a more effective source of plant-available nitrogen compared to conventional organic fertilizers [43]. Nitrogen is a macronutrient that contributes significantly to sustainable agriculture by maintaining productivity and plant growth in both optimal and stressful environments. Significant progress has been made in comprehending the fundamental physiological and molecular mechanisms associated with N-mediated plant responses to salt stress [44]. Regarding the impact of nitrogen fertilizers source addition, data indicate that the application of individual SCU or combination with organic amendments and ASB gave the higher values of chlorophyll a, b, carotenoids and free proline of wheat than AS or Uera application. Similar results were obtained [45, 4647]. Coated urea fertilizers increase nitrogen supply while lowering nitrogen losses in the form of leaching, volatilization, and N2O emission [48]. Normal urea is less efficient as compared to nutrient-coated urea whose NUE is 30–60% less than coated urea [49] . With coating, 20–30% dose of urea can be saved than normal urea application while increasing its uptake and higher yield production. It increases nitrogen agronomy efficiency (NAE; 23.4%), reduces nitrogen fertilizer utilization rate (NUR; 34.65%), and enhances 25.83% nitrogen physiological efficiency (NPE; 25.83%) [43] .

As for the average effect of organic amendments addition, the data show that using Ver. combined with different nitrogen fertilizers in the presences of ASB. gave higher values than Moringa seed residues (MSR) or biogas manure (BM) application. This finding stands in well agreement with those of [33,34]**.**Vermicompost stimulates to influence the microbial activity of soil, increases the availability of oxygen, maintains normal soil temperature, increases soil porosity and infiltration of water, improves nutrient content and increases growth, yield and quality of the plant [49]. Results show that the addition of Ver. Increased free proline compared to the untreated ones. These increases represent 56, 27,37 and 22% in the case of different for untreated, AS;U and SCU, respectively. These results are in agreement with those of [50,51].

3.3. The content of antioxidant enzymes i.e., catalase (CAT), peroxidase enzymes (POx) and superoxide dimutase activity (SOD), (A564 min^{-1} g^{-1} protein) of wheat plants as affected by nitrogen fertilizers and organic amendments with or without Azospirillum brasilense bacteria under alluvial soil conditions

The data are illustrated in Figs. (1) show the effect of applying nitrogen fertilizers and organic amendments *i.e.*, (Moringa seed residues (MSR), biogas manure (BM) and vermicompost(Ver) with or without *Azospirillum brasilense* (ASB) on the content of antioxidant enzymes *i.e.*, catalase (CAT), peroxidase enzymes (POx) and superoxide dimutase activity (SOD)**,** (A564 min^{-1} g^{-1} protein) of wheat plants grown on alluvial soil. Application of different nitrogen fertilizers *i.e.* AS, U and SCU combined with organic amendments under ASB inoculation gave increases in catalase, peroxidase enzymes and and superoxide dimutase activity of wheat plants compared to untreated plants. Application of SCU+ vermicompost (Ver) in the presence ASB gave the highest values of antioxidant enzymes of wheat plants compared to different treatments. These results are similar to those of [52,53].

The application of SCU plus Ver. under inoculation with ASB was the best treatment in the maximum CAT (70.46 A564 min^{-1} g^{-1} protein), POX (2.08 A564 min^{-1} g^{-1} protein), and SOD (9.11 A564 min^{-1} g^{-1} protein), while these parameters recorded their lowest values (40.50, 0.620 and 3.40 A564 min^{-1} g^{-1} protein, respectively) as comparing with other combined applications The application of compost and plant growth-promoting rhizobacteria (PGPR)enhanced chlorophylls, carotenoids, stomatal conductance, and the relative water content (RWC) whilst reducing ESP, proline content, which eventually increased the yield-related traits of wheat plants under deficient irrigation conditions. Moreover, the coupled application of compost and PGPR reduced the uptake of Na and resulted in an increment in superoxide dismutase (SOD), catalase (CAT), and peroxidase (POX) activities that lessened oxidative damage and improved the nutrient uptake (N, P, and K) of deficiently irrigated wheat plants under soil salinity [52]

Regarding the impact of nitrogen fertilizers source addition, data indicate that the application of individual SCU or combination with organic amendments and ASB gave the higher values of antioxidant enzymes of wheat than AS or U application. Similar results were obtained [5]. Nitrogen fertilization has various effects on different processes inside the wheat plant. Increasing nitrogen application rates can improve photosynthetic capacity, delay leaf senescence, and increase dry matter accumulation, ultimately leading to an increase in grain yield [53] The choice of nitrogen application rate and variety can significantly influence grain yield and physiological traits such as relative water content, proline content, malondialdehyde, superoxide dismutase, catalase, and ascorbate peroxidase activities [5]. Nitrogen fertilization also enhances photosynthetic efficiency, chlorophyll content, and canopy photosynthetically active radiation, leading to increased photosynthetic rate, stomatal conductance, and transpiration rate [54].

As for the average effect of organic amendments addition, the data show that using Ver. combined with different nitrogen fertilizers in the presences of ASB. gave higher values than Moringa seed residues (MSR) or biogas manure (BM) application. This finding stands in well agreement with those of [33,34]. Results show that the addition of Ver. increased CAT, POX and SOD compared to the untreated ones. These increases represent 18,14, 16 and 27 for CAT; 80, 66, 93 and 65% for POX and 138, 126, 128 and 172% for SOD in the case of different for untreated, AS,U and SCU respectively. These results are in agreement with those of [55,35]. Applying vermicompost, either through foliar or edaphic methods, bolsters the activity of antioxidant enzymes, namely SOD, POD, and CAT[56] . This leads to a decrease in EL and oxidative stress and benefits maize seedling growth [57] . Furthermore, applications of FYM + biogas manure under salinity stress notably enhance antioxidant activities, elevating CAT and APX levels by 59.9% and 68.8%, respectively. This also boosts grain protein and Fe and Zn contents in rice[58] .The antioxidants improve the complex antioxidants defense systems of plant such as cellular defense strategies against oxidative stress of heavy metals that would relieve and fix the damage from ROS overproduction [59] . The increase of growth characteristics, chlorophyll content and antioxidant enzymes of wheat plants grown alluvial soil conditions reflected in increasing shoot system that might be attributed to more assimilation which correlated with macro and micro nutrients as well as amino acids [11]. While the increased in chlorophyll may be attributed to organic amendments *i.e.*, Moringa seed residues, biogas manure and vermicompost prevents the premature leaf senescence and resulting in more leaf area which increased photosynthetic pigments [60] . The application of vemicompost can improve chlorophyll contents owing to altering the leaf senescence by its contents of mineral nutrients, phytohormones, and antioxidants [11].

3.4. Nitrogen, phosphorus and potassium uptake (mg plant^{-1}) by straw and grains of wheat plants as affected by nitrogen fertilizers and organic amendments with or without Azospirillum brasilense bacteria under alluvial soil conditions

The data are given in Table (5) show the effect of applied nitrogen fertilizers and organic amendments with or without *Azospirillum brasilense* bacteria (ASB) on N, P and K-uptake by wheat plants grown on alluvial soil. Application of various nitrogen fertilizers combined with organic amendments *i.e.* MSR or BM or Ver in the presence of ASB gave increases in N, P and K-uptake by straw and grains of wheat plants as compared to untreated plants. Similar results were obtained by [59&52]. The highest N, P and K-uptake of wheat were obtained under application of SCU combined with Ver in the presences of ASB, while the lowest ones were obtained with untreated soils in absence of organic amendments in the absence of ASB.

Regarding the impact of nitrogen fertilizers sources addition, data indicate that the application of individual SCU or combination with organic fertilizers and ASB. gave the highest values of straw and grain N, P and K-uptake than AS or U. Similar results were obtained by [28,6].

Data showed that the application of *Azospirillum brasilense* bacteria (ASB) to AS , U and SCU increased straw and grains NPK-uptake of wheat compared to the untreated ones under application different organic amendments. These increases represent 17, 26, 73 and 12% of straw N-uptake; 18, 25, 20 and 38% of straw P-uptake and 37, 22, 38 and 11of straw K-uptake for the treatments of untreated, AS, U and SCU, respectively and 41, 34, 117 and 100% of grains N-uptake; 19, 19,18 and 30% of grain P-uptake and 41,24,39 and 13of grains K-uptake for the same treatments, respectively. These results are in agreement with those of [61,62]. *Azospirillum* bacteria, which are gram-negative, are in the Spirillaceae family and are unable to produce internal spores [63] . Potential benefits of Azospirillum are primarily attributed to biochemical and anatomical improvements throughout the host plant roots contributing to the enhancement of water and mineral absorption [64] . Azospirillum affects the rate, and length of the hairy root, increasing the development of the lateral roots that enhance the root area [65] .

[66] observed that in (co-inoculation with *Azotobacter* spp. and *Azospirillum* spp in 100 ppm N showed significantly increase in NPK-uptake of plants. [67] indicated that the treatment of adding bio-fertilizer as *Azospirillum.brasilense* was significantly superior to the comparison treatment. The plants of wheat grown in the disinfected soil with *Azospirillum* showed a higher biomass, N concentration , N-uptake and available nitrogen than those in the non-disinfected soil, and in both soils the inoculation stimulated plant growth, N accumulation, and N and NO_3^- concentration in the tissues [68]. [63] reported an average NUE and available N increase of 51.2 and 60% when the inoculation with *Azospirillum brasilense* was associated with N application rates varying between 50 and 200 kg ha^{-1}. Bacteria with multiple plant-growth promoting traits (PGPB, plant-growth promoting bacteria) can improve NUE , available N and increase the growth and grain yields of cereal crops under tropical conditions [69] , [70 & 72] Plant-growth-promoting rhizobacteria (PGPR) are a group of microbes that play a vital role in nitrogen fixation, improving soil fertility, enhancing nutrient uptake by plants, and increasing the amounts of growth hormones in the plants, helping to improve crop yield. PGPR also improve the tolerance of plants to water stress and pests [71].

The promotive effect of various organic amendments on NPK-uptake by straw and grains of wheat plants grown on alluvial soil may follow the order: Ver> BM>MSR>untreated under the application of various nitrogen fertilizers in the presences or absence of ASB. The favourable effect of various organic amendments on nutrient content is mainly due to the positive effect of this material on increasing the available moisture content and hence increasing the availability of nutrients in the soil solution [50,51,55,72,73,74].

Table 5: Nitrogen, phosphorus and potassium uptake (mg plant^{-1}) by straw and grains of wheat plants as affected by nitrogen fertilizers and organic amendments with or without *Azospirillum brasilense* bacteria under alluvial soil conditions

NS	OR+ASB	Straw (mg plant^{-1})			Grains(mg plant^{-1})		
		N-uptake	P-uptake	K-uptake	N-uptake	P-uptake	K-uptake
Untreated	Without	4.81 s ± 0.035	0.667 u ± 0.015	4.09 s ± 0.001	2.43 r ± 0.021	0.941 t ± 0.005	2.74 t ± 0.044
	ASB	5.68 s ± 0.271	0.785 u ± 0.012	5.57 r ± 0.196	3.45 r ± 0.096	1.12 t ± 0.013	3.86 s ± 0.136
	MSR	11.38 q ± 0.201	1.16 t ± 0.051	7.60 q ± 0.193	7.99 p ± 0.192	1.51 s ± 0.064	5.35 r ± 0.165
	MSR+ ASB	15.03 p ± 0.418	2.21 q ± 0.042	10.25 p ± 1.026	10.94 o ± 0.359	2.54 p ± 0.06	7.29 q ± 0.732
	BM	18.28 mn ± 0.229	3.10 n ± 0.033	14.01 o ± 0.232	13.70 mn ± 0.165	3.55 mn ± 0.04	10.25 p ± 0.193
	BM+ ASB	20.48 kl ± 0.081	3.35 l ± 0.014	15.67 mn ± 0.144	15.52 kl ± 0.116	3.83 l ± 0.007	11.45 no ± 0.071
	Ver	23.97 hi ± 0.541	3.69 k ± 0.03	17.63 kl ± 0.481	18.64 hi ± 0.495	4.23 k ± 0.036	13.01 klm ± 0.361
	Ver+ ASB	27.94 g ± 0.164	4.27 ij ± 0.046	20.48 j ± 0.428	22.16 g ± 0.14	4.87 ij ± 0.049	15.20 j ± 0.317
AS	Without	8.56 r ± 0.039	2.08 q ± 0.022	13.35 o ± 0.206	5.02 q ± 0.026	2.53 p ± 0.024	9.64 p ± 0.153
	ASB	10.75 q ± 0.921	2.50 p ± 0.028	16.30 lm ± 0.193	6.74 p ± 0.841	3.02 o ± 0.029	11.91 mn ± 0.14
	MSR	19.35 lm ± 0.584	2.87 o ± 0.016	18.21 k ± 0.223	14.47 lm ± 0.524	3.43 n ± 0.024	13.39 kl ± 0.173
	MSR+ ASB	22.54 ij ± 0.214	3.29 lm ± 0.121	20.49 j ± 0.278	17.28 ij ± 0.178	3.89 l ± 0.123	15.14 j ± 0.217
	BM	25.46 h ± 0.819	3.71 k ± 0.153	22.92 i ± 0.692	19.90 h ± 0.728	4.33 k ± 0.161	16.99 i ± 0.537
	BM+ ASB	28.44 g ± 1.064	4.15 j ± 0.225	26.22 g ± 1.557	22.54 g ± 0.94	4.80 j ± 0.241	19.53 g ± 1.197
	Ver	31.37 f ± 0.907	4.72 h ± 0.092	29.51 f ± 0.945	25.15 f ± 0.809	5.41 h ± 0.115	22.06 f ± 0.738
	Ver+ ASB	37.49 d ± 0.458	5.46 g ± 0.022	36.38 d ± 0.416	30.77 d ± 0.439	6.16 g ± 0.028	27.28 d ± 0.316
Urea	Without	6.55 s ± 0.06	1.54 s ± 0.036	8.28 q ± 0.129	3.51 r ± 0.036	1.92 r ± 0.038	5.88 r ± 0.098
	ASB	11.38 q ± 3.59	1.83 r ± 0.135	11.36 p ± 1.546	7.62 p ± 3.114	2.28 q ± 0.186	8.19 q ± 1.182
	MSR	16.53 op ± 0.511	2.16 q ± 0.052	14.27 no ± 0.379	12.07 o ± 0.459	2.68 p ± 0.047	10.40 op ± 0.275
	MSR+ ASB	19.96 klm ± 0.076	2.60 p ± 0.029	16.69 lm ± 0.388	15.03 klm ± 0.063	3.19 o ± 0.031	12.27 lmn ± 0.289
	BM	21.67 jk ± 0.57	3.16 mn ± 0.132	18.59 k ± 0.66	16.50 jk ± 0.51	3.75 l ± 0.14	13.73 k ± 0.503
	BM+ ASB	24.61 h ± 0.452	3.63 k ± 0.188	20.86 j ± 1.099	19.13 h ± 0.38	4.25 k ± 0.196	15.46 j ± 0.837
	Ver	28.10 g ± 0.423	4.42 i ± 0.065	24.70 h ± 0.597	22.25 g ± 0.404	5.05 i ± 0.062	18.38 h ± 0.443
	Ver+ ASB	32.36 f ± 0.6	4.79 h ± 0.019	27.25 g ± 0.187	26.11 f ± 0.56	5.45 h ± 0.017	20.35 g ± 0.14
SCU	Without	17.12 no ± 0.555	3.17 mn ± 0.064	18.91 k ± 0.224	12.40 no ± 0.503	3.72 lm ± 0.055	13.91 k ± 0.169
	ASB	19.17 lm ± 0.583	4.35 i ± 0.077	21.42 j ± 0.148	14.19 lm ± 0.531	4.85 j ± 0.076	15.82 j ± 0.105
	MSR	34.15 e ± 0.568	6.07 f ± 0.031	24.29 hi ± 0.253	27.92 e ± 0.526	6.54 f ± 0.032	18.04 hi ± 0.193
	MSR+ ASB	36.88 d ± 0.685	6.64 e ± 0.1	27.15 g ± 0.361	30.40 d ± 0.632	7.12 e ± 0.098	20.22 g ± 0.273
	BM	42.26 c ± 0.534	7.79 d ± 0.026	33.27 e ± 2.153	35.25 c ± 0.505	8.35 d ± 0.022	24.95 e ± 1.619
	BM+ ASB	47.19 b ± 0.664	8.36 c ± 0.039	38.46 c ± 1.026	39.80 b ± 0.624	8.95c ± 0.037	28.91 c ± 0.772
	Ver	48.24 b ± 0.797	8.59 b ± 0.112	40.89 b ± 0.179	40.73 b ± 0.745	9.21 b ± 0.11	30.78 b ± 0.139
	Ver+ ASB	54.70 a ± 0.72	10.02 a ± 0.085	46.08 a ± 0.147	46.70 a ± 0.68	10.65 a ± 0.08	34.82 a ± 0.111

NS: Nitrogen source, OR:Organic Residues;AS:Ammonium sulphate; SCU: Sulphur cotated urea; ASB: Azospirillum brasilense; MSR: Moringa Seed Residues; BM: Biogas Manure; Ver: Vermicompost.

3.5. Available nitrogen (mg kg⁻¹) as affected by nitrogen fertilizers and organic amendments with or without Azospirillum brasilense bacteria under alluvial soil conditions

Under investigation, the values of available nitrogen (mg kg^{-1}) as affected by the application of nitrogen fertilizers AS, U and SCU) and organic amendments (MSR, BM and Ver) with or without *Azospirillum brasilense* bacteria(ASB) are illustrated in Fig. (2). The treatments of SCU combined with Ver with ASB gave the highest values of available N (41.31 mg kg^{-1}), while the lowest ones (15.35 mg kg^{-1}) were found with untreated soil. These results are in agreement with those obtained by [65,75**,**76**,**77,78]**.**

Data showed that the application of *Azospirillum brasilense* bacteria to AS, U and SCU increased available N in alluvial soil compared to the untreated ones under application organic amendments *i.e.*, without, MSR, BM and Ver (Fig. 2). These increases represent 8, 6, 6,7 and 9%, respectively for the treatments of untreated ; 9,4, 5,4 and 5%, respectively for AS treatments and 5,4,7,2 and 7% for urea treatments and 7,3.5,6 and 2% for SCU. These results are in agreement with those of [65**,**63]**.**Micro-organisms *i.e.*, *Azospirillum brasilense* are very beneficial to crop production and nitrogen availability in the soil [79]. Although the most prevalent reported benefit of *Azospirillum* has been its capacity of fixing N_2, an increasing number of studies describes other properties that imply growth-promotion. One main property of *Azospirillum* relies on the synthesis of phytohormones and other compounds, including auxins [80]. Cytokinins, Gibberellins, abscisic acid [81] Ethylene and Salicylic acid [82]. Phytohormones greatly affect root growth, resulting in improvements in uptake of moisture and nutrients [83]. Some *Azospirillum* strains can solubilize inorganic phosphorus, making it more readily available to the plants and resulting in higher yields [84].

The promotive effect of different organic amendments on available nitrogen in alluvial soil may follow the order: Ver> BM> MSR> without under the application of AS, U and SCU in the presence or absence of ASB. The favourable effect of organic amendments on nutrient content is mainly due to the positive effect of this material on increasing the available moisture content and hence increasing the availability of nutrients in the soil solution [85] .

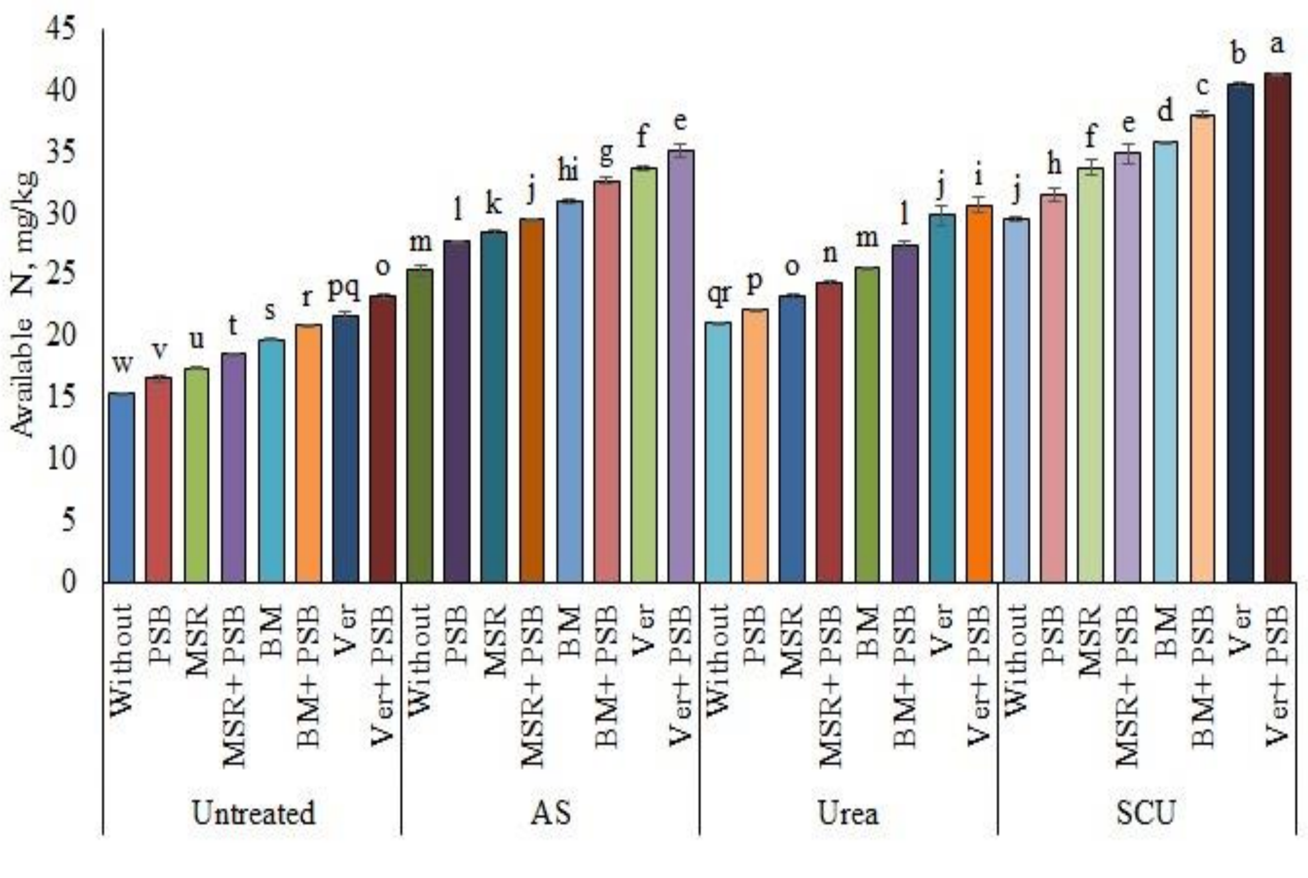

Fig.2: Available nitrogen (mg kg^{-1}) as affected by nitrogen fertilizers and organic amendments with or without *Azospirillum brasilense* bacteria under alluvial soil conditions.

4. Conclusions

The present study successfully demonstrated that the integration of organic amendments (MSR, BM, Ver) with *Azospirillum brasilense* bacteria (ASB), in conjunction with ammonium sulfate (AS), urea and sulfur-coated urea (SCU) fertilizers, significantly enhances nitrogen availability, leading to improved growth, yield, and nutrient uptake in wheat plants grown under alluvial soil conditions. The combined treatment of SCU+ Ver with ASB emerged as the most effective strategy, showing marked improvements in key physiological parameters, and overall plant productivity.

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