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Wheat Productivity as Influenced by Integrated Mineral, Organic and Biofertilization

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EXPONENTIAL population growth and soaring fertilizer prices are among the main challenges threating food security worldwide. Probably, substituting chemical inputs (partially or completely) with organic and/or bio-alternatives are the keys to achieve sustainable development. Thus, a field experiment was conducted for two successive seasons in a randomized block design to achieve this goal, comprising the following treatments: 100% mineral P and K fertilizers (T_1, control), 10 g potassium humate (KH) kg^{-1} (T_2), 10 g humic acid (HA) kg^{-1} (T_3) and 10 g kg^{-1} fulvic acid (FA) (T_4). For treatments from T_2 to T_4, supplementary doses of chemical fertilizers were added to satisfy wheat needs for P and K. Also, a combined treatment of 50% biogas (added on nitrogen bases) plus supplementary PK doses in the form of (i) rock phosphate and feldspars + biofertilizers (*Bacillus megatherium* and *Bacillus circulans*) (T_5) or (ii) chemical P and K fertilizers were included (T_6). All plots were planted with wheat and received 20% of the recommended N requirements via N_2-fixation with *Bacillus polymyxa* while the other 80% was accomplished as ammonium nitrate (after considering the added N in organic additives**)**. Key findings indicate that application of biogas+ supplementary chemical PK fertilizers (T_6) recorded the highest increases in P and K available contents in soil. This in turn significantly raised their concentrations within different plant parts and boosted straw and grain yields during the two seasons of study. Application of 100% mineral PK (T_1) recorded significantly lower values in all abovementioned parameters versus T_6. Nevertheless, these two treatments (T_1 and T_6) recorded comparable increases in 1000-grain weight, plant height, spike lengths and number of grains per spike. Application of KH, HA and FA as partial substitutes for chemical fertilizers (T_2-T_4) lessened significantly nutrient bioavailability and their contents within wheat parts; as a result, plant growth and yield components declined significantly. The least values were recorded for the treatment that received biogas+ rock phosphate and feldspar + biofertilizers (T_5). Overall, straw and grain yields of wheat plants were correlated significantly with P and K contents in both shoots and grains. In conclusion, the combination between biogas and chemical fertilizers seemed to be the optimum selection to satisfy wheat needs for nutrients; hence increase wheat productivity under arid conditions.

Keywords: *Bacillus megatherium; Bacillus circulans*; P and K availability; wheat productivity; biogas manure.

1. Introduction

Continuous increases in human population and improving their living standards threat food security worldwide (Rahman and Zhang 2018; Cai *et al*. 2019; Kumar *et al*. 2022). Vigorous growth path is; therefore needed in food production to meet such increases (Rask and Rask, 2011; Davis *et al*., 2017). Yet, global agri-food production seems to be inefficient (Rodrigues *et al*. 2017). For example, farmers use synthetic fertilizers comprehensively (Rahimi *et al*. 2019) and this undesirably leads to land degradation (Wei *et al*. 2016), soil and water pollution (Rahimi *et al*. 2019; Ye *et al*. 2020), while increasing farm production expenditures (Jayne *et al*. 2018). Thus, the sustainable approach has become an obligation to increase the net agriculture production while minimizing the undesirable impacts of agricultural synthetic inputs on the surrounding ecosystem (Tian *et al*. 2021).

Following a circular economy might be an excellent choice via recycling agricultural products in soil (Diacono *et al*. 2019). Many organics can be used to attain these aims such as manure (Cai *et al*. 2019), compost (Elshony *et al*. 2019; Hussein *et al*. 2022; Elsherpiny 2023; Elsherpiny *et al*. 2023; Nada *et al*. 2023; Sarhan and Shehata 2023), biochar (Mohamed *et al.* 2018; Bassouny and Abbas 2019; Abdelhafez *et al*. 2021b; Tolba *et al*. 2021; Farid *et al*. 2022; Khalil *et al*. 2023) and biogas (Farid *et al*. 2018). During degradation of organic additives,

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nutrients are set free in available forms (Abdelhafez *et al*., 2018; Cai *et al*. 2019) to improve the nutritional status of grown plants (Abbas *et al*. 2020; Farid *et al*., 2021a). Even the relatively resistant biodegradable organic components, named humic substances (El-Shwarby *et al*. 2022) can be used sucessfully to increase crop production. These organics form soluble complexes with soil nutrients (Farid *et al*. 2018) which, in turn, increases nutrient uptake by plants and consequently boost their growth and productivity (Farid *et al*., 2021b).

Biofertilizers may also be a reliable alternative for synthetic fertilizers (Eid *et al*. 2019; Mohamed *et al*. 2019; Rahimi *et al*. 2019; Abdelhafez *et al*. 2021a; Farrag and Bakr, 2023). For instance, a N-fixer named *Bacillus polymyxa* (Hao and Chen 2017) can tolerate adverse conditions (Irina *et al*. 2016) and has a broad range of hosts (Puri *et al*. 2016a). It may fulfill 19-20% of the needed N for oilseed crops (Puri *et al*. 2016a) and this percent increase up to 30% in some crops like wheat (de Freitas *et al*. 2000) and maize (Puri *et al*. 2016b). Another example of biofertilizers is *Bacillus megaterium* that can solubilize soil- P (Massucato *et al*. 2022) via promoting root exudates, and increasing malic, oxalic and acetic acids (An *et al*. 2022). For increasing K availability in soil, inoculation with either of *Paenibacillus polymyxa* or *Bacillus circulans* can be used successfully (Abdel Latef *et al*. 2020). In particular, *Bacillus circulans* solubilize K-bearing minerals like biotite, muscovite, feldspar, mica, iolite, and orthoclase (Rajawat *et al*. 2019); hence increase considerably K-availability in soil (Shaheen and Rashwan 2021).

Wheat is a strategic crop in many parts of the world (De Vita and Taranto 2019; Dianatmanesh *et al*. 2022; Lalarukh *et al*., 2022a, b and c). In Egypt, it is probably the most important one (Saad *et al*. 2023); despite that this country has become the largest wheat importer worldwide (Abdelmageed *et al*. 2019). There is an actual need to increase its productivity to lessen the gap of production-consumption (Saad *et al*. 2023). A point to note is that wheat production is nutrient-dependent (Salim and Raza 2020) and mineral fertilizers still represent the noteworthy economic burden for farmers (Martin *et al*. 2023). Fertilizer prices are increasing continuously, especially after the Russian-Ukraine war (Alexander *et al*. 2022), besides, these chemicals distresses soil fertility and human health (Seenivasagan and Babalola 2021). Maybe, using biofertilizers in wheat production lessen the dependence on chemical fertilizers while preserve high grain production and quality standards (Dal Cortivo *et al*. 2020). Also, organic additives restore soil fertility and sustain its productivity (Hammad *et al*. 2020). Overall organic applications and bio-inoculants are guaranteed in arid and sub-arid regions (Meddich *et al.* 2020) to increase crop productivity and sustain environmental quality (Al-Amri 2021), if managed properly (Abobatta and Al-Azazy 2020; Erfani *et al*. 2020).

The current study aims at investigating the effects of amending a heavily textured soil with organic additives and/or bio-fertilizers to substitute partially the synthetic P and K inputs. Specifically, we assume that application of biogas manure or any of its relatively stable extracts, named K-humate, fulvic and humic acids increase significantly the available contents of P and K in soil (hypothesis one). Likewise, the application of phosphate (*Bacillus megatherium*) and potassium (*Bacillus circulance*) dissolving bacteria increase the bioavailable contents of these two nutrients (hypothesis Two). Thus, application of organic/biofertilizers leads to significant increases in P and K uptake by wheat plants (hypothesis three), which in turn increase plant growth and productivity (hypothesis four). Probably, the combinations between chemical fertilizers and either organic or bio- additives have comparable effects to the usage of chemical fertilizers solely on plant growth and productivity (hypothesis five); yet the former effects on sustaining soils could be superior (hypothesis six). A point to note is that *Bacillus polymyxa* is added as a biooculant to all treatments to satisfy partially 20% of the plant needs for N, while received the other 80% of their needs in the form of synthetic N-fertilizers supplemented with the added N in organic additives. Probably, this is one of the few research projects that considered the integration between biofertilizers, organic additives and mineral NPK forms to improve wheat growth and productivity within the arid region

2. Materials and Methods

2.1. Materials of study

Surface soil samples (30 cm) were collected from a private farm at Moshtohor, Qalyubia Governorate, Egypt prior to wheat cultivation during the winter seasons of 2019 and 2020. These samples were air dried, crashed and sieved via a 2 mm sieve, then analyzed for their physical and chemical characteristics as outlined by Klute (1984) and Sparks *et al*. (1996). The obtained results are presented in Table 1.

Table 1. Physical and chemical characteristics of the investigated soil.

Parameter	Particle size distribution %				Field capacity (%)	Organic matter (g kg^{-1})	$CaCO_3$ (g kg^{-1})	Avail-N (mgkg^{-1})	Avail-P (mgkg^{-1})	Avail-K (mgkg^{-1})
	Sand (%)	Silt (%)	Clay (%)	Textural class						
1st season	33.7	19.5	46.8	Clay	12.7	12.9	19.1	69.0	6.3	174.0
2nd season	32.9	20.4	46.3	Clay	12.5	13.1	18.3	73.0	6.7	185.0
	pH*	EC** dSm^{-1}	Soluble Ions (mmol$_c$ L^{-1})							
			Ca^{2+}	Mg^{2+}	Na^+	K^+	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}
1st season	8.1	1.4	6.6	4.2	2.8	0.6	0.0	4.3	3.5	6.4
2nd season	8.04	1.4	6.7	4.1	2.7	0.5	0.0	4.3	3.3	6.3

pH* was determined in soil:water suspension (1:2.5soil-water suspension). EC** was determined in soil paste extract

Wheat plants (*Triticum aestivum*, Misr l) were obtained from the Field Crops Research Institute, Agricultural Research Center (ARC), Giza, Egypt. A N_2-fixing bacteria (*Bacillus polymyx* EMCCN 1108), a phosphate solubilizing one (*Bacillus megatherium*, HKP-2) and a potassium solubilizer (*Bacillus circulans*, NCAIM B.02324) were kindly obtained from Microbiology Department, Soils, water and Environment Research Institute, Agricultural Research center (ARC), Giza, Egypt then individually grown on nutrient broth medium to attain 1×10^8 CFU mL^{-1} (ALKahtani *et al*. 2020), and applied to the inoculated soil as a foliar spray at a rate equivalent to 24 L ha^{-1} in two equal doses at 30 and 60 days after sowing. Rock phosphate (0.37 g N, 112 g P and 3.2 g K kg^{-1}) and feldspar (0.25 g N, 0.4 g P and 109 g K kg^{-1}) were obtained from Al Ahram Mining Company. Biogas manure was obtained from the Training Center for Recycling of Agricultural Residues at Moshtohor (TCRAR), Soils, water and Environment Research Institute, Agricultural Research Center, Giza, Egypt. Chemical properties of this biogas are presented in **Table 2**. Extraction of different humic substances was carried out according to the protocol described by **Sanchez – Monedero *et al. (2002)***. For example, potassium humate (HK) was extracted by treating the biogas manure with 0.5*N* KOH solution.

Table 3. Chemical characteristics of potassium humate (HK), humic acid (HA) and fulvic acid (FA) extracted from biogas manure.

Characteristics	Biogas manure	K-humate (HK)	humic acid (HA)	fulvic acid (FA)
C (%)	219.00	50.5	52.1	48.4
N (%)	2.20	2.62	3.94	2.76
H (%)	4.11	3.28	4.58	2.85
S (%)	2.97	4.20	2.98	3.79
O (%)	68.82	39.4	36.4	42.2
Total acidity (cmol$_c$ kg^{-1})	530.00	570	620	680
COOH group (cmol$_c$ kg^{-1})	210.00	230	255	270
Phenolic OH group (cmol$_c$ kg^{-1})	310.00	340	355	410
C/N ratio	9.95	19.3	13.2	17.5
C/H ratio	5.33	15.5	11.4	17.0
C/O ratio	0.32	1.28	1.43	1.14
O/H ratio	16.74	12.0	7.94	14.8
N/H ratio	0.54	0.79	0.86	0.97
Alcoholic-OH (cmol$_c$ kg^{-1})	290.00	280	370	140
CEC (cmol$_c$ kg^{-1})	470.00	460	440	320
Total-P (%)	7.80	0.23	0.30	0.27
Total-K (%)	9.30	2.18	2.41	2.32

Humic acid was extracted as a precipitate after being acidifying this manure with HCl to reach pH 2.0 then left overnight and separated from the soluble fulvic acids (FA) via centrifuge at 6000 rpm for 15 minutes. This precipitate was washed several times with 0.05 *N* H_2SO_4 until turned colourless, then purified via electro- dialyses till the ash content decreased to less than 1% (Chen and Schnitzer 1978); thereafter, humic acid was air dried.

On the other hand, the supernatant containing fulvic acid was purified via passing through activated charcoal followed by elution of charcoal and transferred through a membrane filter and electrodialysed to set the dialsate free from chloride (Kononova 1966). Chemical characteristics of HK, HA and FA extracted from biogas manure are presented in Table 3

2.2. Methods of study

A field experiment was carried out at a private farm at Moshtohor (31° 22́ 26́′ E and 30° 36́ 02′ N), Toukh, Qualubia (Egypt) during the winter season of two successive years i.e. 2019 and 2020. This experiment followed a randomized block design with three treatments comprising the following (1) 100% mineral P and K fertilizers (T_1, control), 10 g kg^{-1} potassium humate (KH) plus supplementary doses of the mineral P and K fertilizers to satisfy the recommended PK doses (150 g P and 40 g K kg^{-1}, respectively) of the Egyptian Ministry of Agriculture in the form of calcium superphosphate (67.7 g P kg^{-1}) and potassium sulphate (398.3 g kg^{-1}), respectively (T_2), 10 g humic acid (HA) kg^{-1} plus supplementary doses of the mineral P and K fertilizers (T_3) and 10 g kg^{-1} fulvic acid (FA) plus supplementary doses of the mineral P and K (T_4). Also, a combination between 50% biogas (added on nitrogen bases) plus either (I) supplementary doses of rock phosphate and feldspars +the investigated bioagents i.e *Bacillus megatherium* and *Bacillus circulans* (T_5) or (II) supplementary mineral P and K fertilizers (T_6). All organic and mineral additives were added on soil mass bases.

The experimental plot was 12.25 m^2 (3.5 m length x 3.5 m width). All plots were planted with wheat (*Triticum aestivum*, Misr l) seeds on November 2019 and 2020 and received 80% of the recommended N requirements which was equivalent to 240 g N kg^{-1} in the form of ammonium nitrate (335 g N kg^{-1}) at three equal doses i.e. during the soil preparation: after 25 and 45 days of seed sowing, supplemented with the added amount of N via organic additives. Plots were also inoculated with *Bacillus polymyx* (nitrogen fixing bacteria) to satisfy the other 20% of the N needs. All agricultural activities were followed as usual until the physiological maturity stage; thereafter, whole plants were harvested, and plant growth parameters, yield and yield components were determined.

2.3. Soil and Plant analyses

Soil samples were collected from the rhizosphere of each plot then analyzed for their available contents of available P and K as outlined by Sparks *et al.* (1996): Available- P was extracted by Olsen then determined by Spectrophotometer (SM1600 UV-VIS Spectrophotometer) after being reduced via Ascorbic acid while available- K was extracted by the ammonium acetate method then measured by flame photometer (*Jenway* model PFP7). Also, soil pH was determined in soil: water (1:2.5) suspension by a glass electrode of Orion Expandable ion analyser EA920. Electrical conductivity was measured in soil paste extract by EC meter (model ICM model 71150) and residual organic matter content was determined by Walkley and Black method as outlined by Sparks *et al.* (1996).

The collected plant materials were divided into shoots and grains then oven dried at 70 C for 48 h and ground in a porcelain mortar. Plant portions, equivalent to 0.5g, underwent wet digested using a mixture of sulphuric and perchloric acids according to Page *et al.* (1982) and analyzed for their contents of P coloremetrically and for K by flame photometer as mentioned above

2.4. Data analyses

All chemicals used in this study were of analytical grade and the obtained data were subjected to one-way ANOVA and Dunken's text via SPSS ver 18. Figures were plotted via Sigma plot 10 software.

3. Results and Discussion

3.1. Effect on plant growth parameters and yield components

Application of biogas+ supplementary PK chemical fertilizers to satisfy the nutrient requirements of wheat recorded the highest increases in straw and grain yields during both seasons of study, followed by application of 100% mineral PK (**Fig. 1**). These results agree with the findings of Farid *et al.* (2021b) who found that the combined use of organic and mineral fertilizers could effectively improve plant growth and productivity versus even 100% mineral fertilizers.

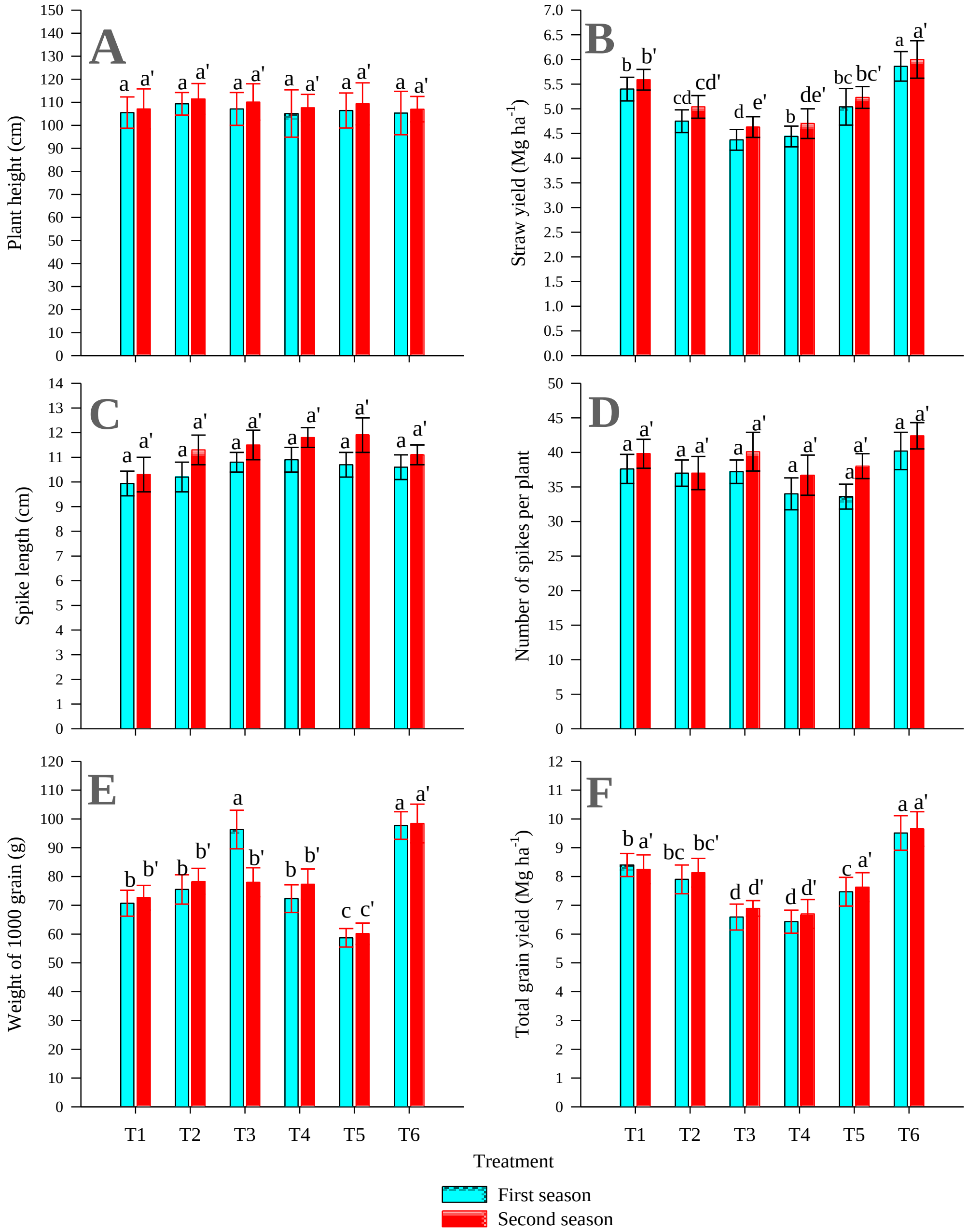

Fig 1. Wheat growth, grain yield and yield components (mean± standard deviation) as affected by organic and bio treatments. Treatments were as follows: 100% mineral P and K fertilizers (T_1, control), 10 g kg^{-1} KH plus supplementary PK mineral fertilizers (T_2), 10 g HA kg^{-1} plus supplementary PK fertilizers (T_3), and 10 g kg^{-1} FA plus supplementary PK fertilizers (T_4), 50% biogas plus supplementary doses of rock phosphate and feldspars and biofertilizers (T_5) and a 50% biogas+ supplementary mineral P and K fertilizers (T_6). Similar letters indicate no significant variations among treatments.

Although, the organic additive (biogas) supply plants with nutrients at relatively slower rates versus mineral fertilizers; yet it lessen their fixation in soil via forming soluble complexes (Abbas *et al*. 2020; Hussein *et al*. 2022). Moreover, organic additives stimulate soil beneficial bacteria (Farid *et al*., 2018) and soil enzymes forming aggregates (Mohamed *et al*., 2021). Regarding to weights of 1000 grain, the two treatments ("100% mineral PK" and "50% mineral+50% organic forms") recorded the highest increases in these weights, with superiority for the latter treatment in the second growing season. Variations in plant height and spike lengths as well as the number of grains per spike were almost insignificant among treatments.

The least straw and grain yields were noted for plants that received half of their PK requirements in inorganic forms while the other half was added as rock phosphate and feldspar + biofertilizers. Such unexpected findings were lower than the outcomes of many researchers (Eid *et al*. 2019; Mohamed *et al*. 2019; Thomas and Singh 2019; Abdelhafez *et al*. 2021a). Others found that bio-inoculation recorded comparable plant growth and productivity with the usage 100% synthetic mineral fertilizer (Zainuddin *et al*. 2022). Despite these results, dependence on chemical fertilizers solely to satisfy plant needs for nutrients may damage both human health and the ecosystem (Kumar *et al*. 2022).

A point to note is that the application of humic and fulvic acids as partial substitutes for mineral fertilizers may effectively increase crop productivity (Man-hong *et al*, 2020; El-Shwarby *et al.* 2022); yet these organics decreased both straw and grains yields versus application of 100% PK in the results obtained herein. Probably, these organic components bound nutrients forming complexes that plants cannot breakdown and utilize (Farid *et al.* 2021a).

3.2. Effect on PK available contents in soil, and distribution within different plant parts

Application of biogas manure plus supplementary doses of mineral PK fertilizers to satisfy the recommended doses of these two nutrients recorded the highest increases in available PK contents in soil, exceeding even the application of 100% synthetic fertilizers (**Fig 2**). Also, the former additives recorded the highest increases in P and K concentrations within shoots, followed by the application of PK in mineral forms (100%). On the other hand, the organic + biotreatments (T_5) recorded the least PK available contents and also exhibited the lowest concentrations of these two nutrients within plant shoots. In this context, *Bacillus megaterium* can survive under adverse conditions and solubilize triple calcium phosphate (Abdelmoteleb and Gonzalez-Mendoza 2020) via acidifying the media with organic acids (Saeid *et al*. 2018) such as succinic acid to increase the solubility and availability of soil-P (Ortiz and Sansinenea 2020); hence increase its uptake by plants as occurred in common beans (Abdelmoteleb and Gonzalez-Mendoza 2020) and tomato (Jahil and Kamal 2021). Moreover, this type of bacteria can solubilize K-bearing minerals (Verma *et al*. 2015)

In case of *Bacillus circulance*, this biofertilier improves K^+ availability via formation of solubilizing acids (Sattar *et al*. 2019), that increase its availability in soil (Ali *et al*. 2021) and raised its uptake by plants (Ali *et al*. 2019; Hassan 2020; Ali *et al*. 2021). The discouraging results of this combined treatment indicate that this combination is not appropriate to substitute the chemical fertilizers.

Application of humic and fulvic acids as partial substitutes for both P and K mineral fertilizers significantly lessened their available indices in soil and also their contents within wheat shoots versus 100% synthetic PK fertilizers. These organics are not easily bio-diogradable in soil (Machado *et al*. 2020; Farid *et al*. 2021c; Anielak *et al*. 2022) nevertheless they chelate nutrients via carboxyl (COOH−) and phenolic (OH−) groups forming soluble complexes (Sootahar *et al*. 2019). On the other hand, the mineralization of humic acids, in presence of high nutrients as in our case, may slow down considerably (Bottino *et al*., 2019). This may vary for a soil to another as found by Sootahar *et al.* (2019) who recorded significant increases in available P and K contents by 80%–90% and 20%–45% in Aridisols and Vertisols, respectively owing to the application of fulvic acids derived from different materials, whereas in Mollisols P and K decreased by 60%–70%. In case of P and K in grains, our results indicate no significant variations detected among the investigated treatments.

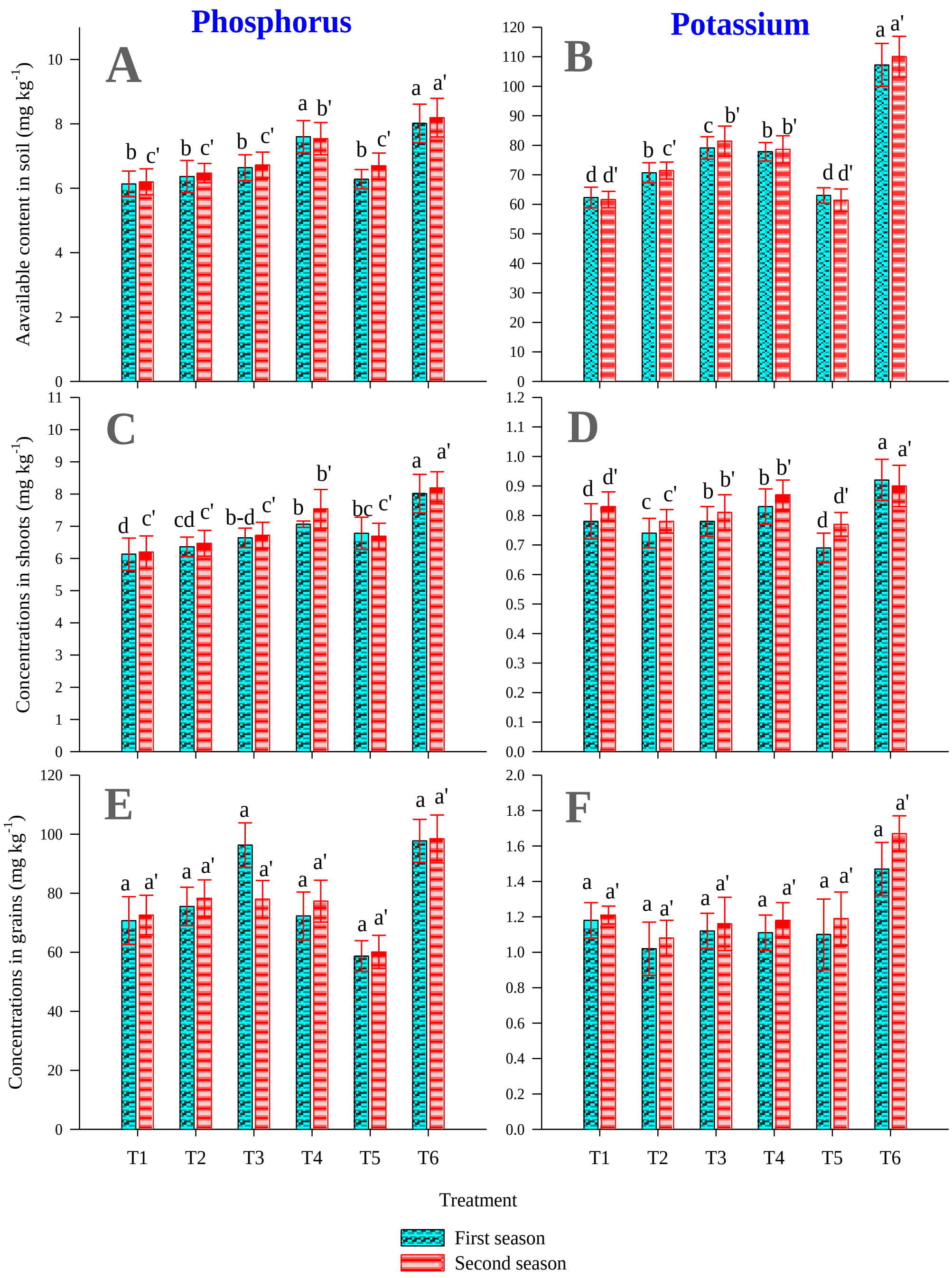

Fig. 2. Available P and K contents in soil, and the corresponding contents within wheat shoots and grains (mean± standard deviation) as affected by organic and bio treatments. See footnote Fig 1. Similar letters indicate no significant variations among treatments.

3.3. Effect on the chemical characteristics of the soil

Data presented in Fig 3 reveal that no significant variations in soil pH were detected in soil pH owing to application of studied additives; however, these applications affected significantly both soil EC and organic matter content. In this concern, treatments including K-humate, humic and fulvic acids raised significantly soil organic matter content during both seasons of study exceeding that attained for the application of mineral PK solely (T_1), while the reductions in soil EC owing to these treatments were detectable only in the first season only. These results confirm that humic and fulvic acids form relatively stable complexes in soil (Lipczynska-Kochany 2018) that may hinder the solubility of salts in soil (Huang 2022). On the other hand, the buffering capacity of the soil (rich in clay content) could resist the changes that occur in pH, especially in soils of high clay content (Jeon and Nam 2019). Regarding to the application of 50%biogas+ rock phosphate and feldspars + biofertilizers, this treatment recorded the least values in soil EC and soil organic matter content among the studied treatments during both seasons of study.

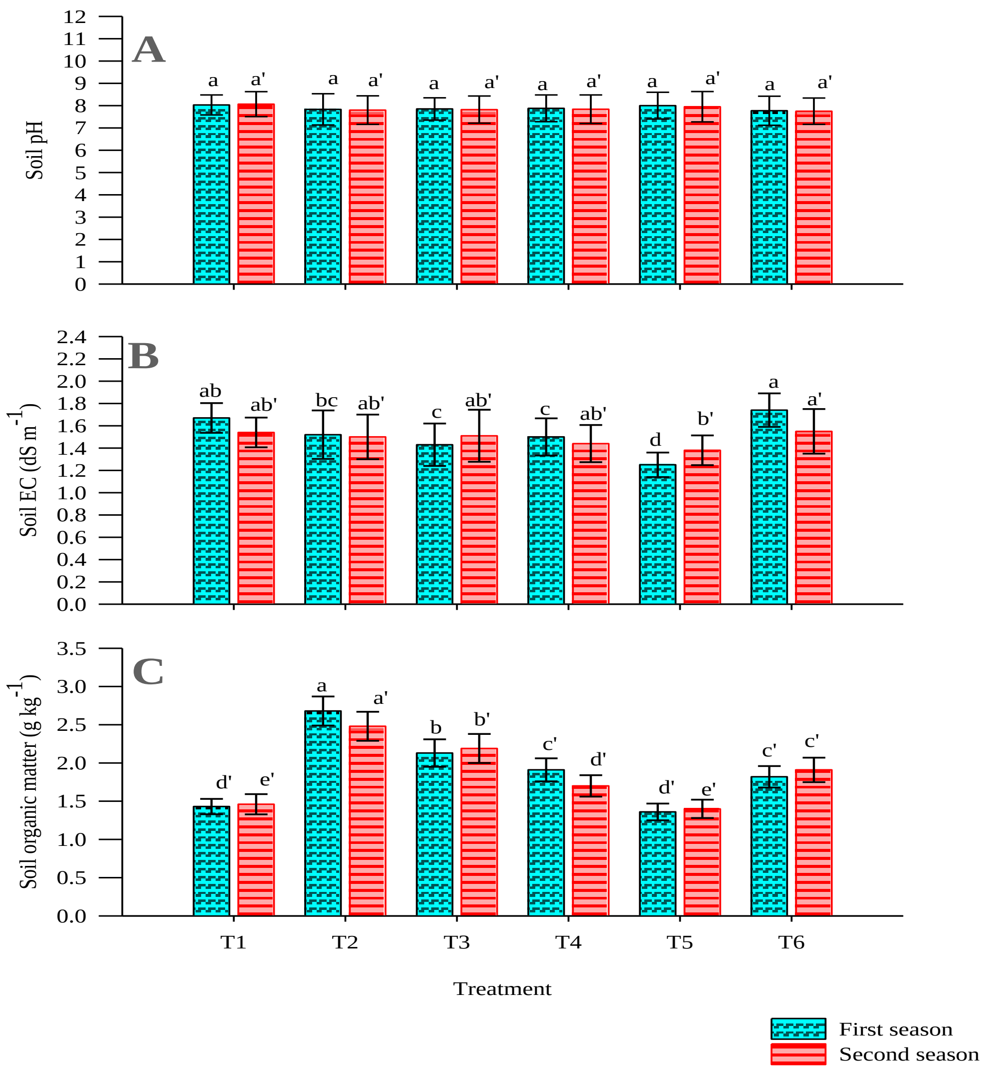

Fig. 3. Soil pH, EC and organic matter content (mean± standard deviation) as affected by organic and bio treatments. See footnote Fig 1. Similar letters indicate no significant variations among treatments.

3.4. Correlations between wheat straw and grain yields in relation to the available contents of P and K in soil, their uptake and distribution with different plant parts

Table 4 shows that both straw and grain yields of wheat plants were correlated significantly with P and K contents within wheat shoots and grains. Moreover, the weight of "1000 grains" was affected significantly by their content of P and K. Moreover, concentrations of these two nutrients in plant shoots and grains were correlated significantly with their corresponding available contents in soil. These results signify that selecting suitable K and P fertilizers are the keys to increase wheat growth and productivity.

Table 4. Coefficients of determination (r^2) calculated for the relation between wheat growth and yield components, PK available contents in soil and the corresponding contents within plant tissues.

	Straw yield	1000 grain weight	Grain yield	P-available content	P-shoot	P-grain	K-available content	K-shoot	K-grain
Straw yield									
1000- grain weight	0.283								
Grain yield	0.942**	0.414*							
P-available content	0.348*	0.629**	0.329*						
P-shoot	0.445**	0.612**	0.419*	0.958**					
P-grain	0.388*	0.571**	0.353*	0.677**	0.613**				
K-available content	0.405*	0.854**	0.494**	0.871**	0.876**	0.643**			
K-shoot	0.405*	0.854**	0.494**	0.871**	0.876**	0.643**			
K-grain	0.548**	0.468**	0.540**	0.510**	0.544**	0.602**	0.623**	0.623**	

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

4. Conclusions

Application of biogas manure or any of its relatively stable extracts (K-humate, fulvic and humic acids) did not successfully increase the bioavailable contents of P and K in soil versus the treatment that received 100% mineral P and K inputs (the reference treatment). Nevertheless, the treatment that received 50% biogas plus supplementary doses of P and K chemical fertilizers did. Such a result supports partially the first hypothesis. On the contrary, application of bioagents+ rock phosphate and potassium feldspar recorded the least P and K bioavailable values and for this reason we cannot accept the second hypothesis.

Generally, the increases in bioavailable contents of P and K in soil lead to concurrent significant increases in their uptake by wheat plants and this in turn enhanced wheat straw and grain yields. Accordingly, the third and fourth hypotheses become valid. A point to note is that the combined 50% biogas+50% mineral P and K fertilizers recorded significantly higher increases in straw and grain yield than the reference treatment; yet there were no significant variations between these two treatments on soil characteristics after the two growing seasons, particularly on soil pH, soil EC and soil organic matter. These results justify the fifth hypothesis while could not prove the sixth one regarding the effects of the combined treatments on soil sustainability. Probably, long term experiments are needed to test this hypothesis.

Application of K-humate, humic and fulvic acids reduced significantly nutrient contents within wheat shoots and grains and this in turn lessened plant growth and productivity. Likewise, application of organic+biotreatments did not successfully improve plant growth and productivity. In conclusion, the combination between biogas and chemical fertilizers seemed to be the most appropriate one to satisfy wheat needs for nutrients hence increase its productivity under arid conditions.

5. Conflicts of interest

There are no conflicts to declare.

6. Formatting of funding sources

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7. Acknowledgments

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