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Increasing Wheat Production in Arid Soils: Integrated Management of chemical, Organic- and Bio P and K-inputs

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THIS study represents a field trial to increase production of wheat grown under arid conditions.To fulfill this purpose, the experiment was conducted for two successive winter seasons comprising the treatments: biogas manure to satisfy 100% of P and K-requirements (organic P and K, T_1), "rock phosphate + feldspar" to fulfill 100% of P and K+ biofertilizers (*Bacillus megatherium* and *Bacillus circulans*, T_2), 50% organic P and K+ the other 50% as rock phosphate and feldspars+ bioagents (T_3), 100% organic-P and K+ biofertiliozers (T_4), rock phosphate and feldspars to satisfy 100% of P and K-needs+ bioagents in presence of either potassium humate (T_5), humic acid (T_6) or fulvic acid (T_7), 50% of P and K as biogas manure + 50% of P and K as mineral fertilizers+ bioagents (T_8) beside of the reference treatment (100% mineral P and K fertilizers) (T_9). Results indicated that the treatment T_8 recorded the highest increases in wheat growth parameters, grain yield and net revenues. These values exceeded even the corresponding ones of the reference treatment. Moreover, T_8 recorded the highest increases in NPK available contents in soil and consequently their contents within grains. Significant-positive correlations were detected between NPK contents in grains and the yield. Additionally, T_8 upraised soil organic matter content and, therefore, decreased soil bulk density. In contrast, bio-fertilizers (solely or with organic additives) did not affect wheat growth and productivity. In conclusion, the treatment T_8 is guaranteed to increase wheat productivity in arid soils.

Keywords: *Bacillus megatherium*; *Bacillus circulans*; biogas; rock phosphate; feldspars.

1. Introduction

Global world population increases drastically overtime and maybe this population surpass 9 billion populations by year 2050 (King *et al*., 2017; Fasusi *et al*., 2021). Such increases threaten food security (Eigenbrod and Gruda, 2015; Igiehon *et al*., 2017; Abdalla and El-Ramady, 2022; Rashed and Hammad, 2023) for many reasons: Firstly, available arable land per person might only be by 2050 one third the accessible area in 1970 (Benke and Tomkins, 2017). Though, there should be a marked increase in food production by at least 70% (King *et al*., 2017). Secondly, intensive use of agrochemicals has been doubled since the last century (Carvalho, 2017) and these inputs contain pollutants that persist in the surrounding environment (Atieno *et al*., 2020) and disturb it (Tomer *et al*., 2016; Kaur and Purewal, 2019; Fasusi *et al*., 2021). Commonly, unmanaged use of agrochemicals leads to unsustainable degradation of soil (Cisse *et al*., 2019; Kopittke *et al*., 2019; Mahapatra, 2022) which may continue in the coming years (Meddich *et al*., 2020).

Sustainable agriculture has become therefore an obligation to increase plant productivity (Odoh *et al*., 2020) and, at the same time, ensure the environmental quality objectives (Meddich *et al*., 2020; Odoh *et al*., 2020). Organic additives may substitute partially synthetic fertilizers (Farid *et al*., 2014; Elshony *et al*., 2019; Abdelhafez *et al*., 2021b; Hussein *et al*., 2022; Farid *et al*., 2023) after being processed and recycled in soil (Bassouny and Abbas, 2019; Diacono *et al*., 2019; Farid *et al*., 2022; Dianatmanesh *et al*., 2022; Lalarukh *et al*., 2022b; Omara and Farrag, 2022). Also, organic extracts, which are relatively stable in soil (Farid *et al*., 2018), may improve and sustain soil health (Farid *et al*., 2021 a and b; Rashwan and Elsaied, 2022).

Bio-fertilization is another reliable alternative to synthetic fertilizers (Rahimi *et al*., 2019; Omara *et al*., 2022) that maintain long term soil fertility (Odoh *et al*., 2020). Thus, the bio-approach is considered the

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key towards sustainable production (Reddy *et al*., 2020). The term "biofertilizers" refer to microbial inoculants that can either fix N (Negi *et al*., 2021; Reddy *et al*., 2020) such as *Paenibacillus polymyxa* (previously known by *Bacillus polymyxa*) (Padda *et al*., 2017) or mobilize plant nutrients (Abd El-Wahab, 2016; Igiehon *et al*., 2017; Reddy *et al*., 2020) such as *Bacillus megatherium* (a P solubilizing bacteria) and *Bacillus circulans* (a K solubilizing bacteria) (AbdEl-Nabi *et al*., 2016). Furthermore, beneficial biota plays important roles in restoring hemostasis (Ennab *et al*., 2016; Lalarukh *et al*., 2022b), enhancing formation of soil aggregates and increasing their stability (Yilmaz and Sönmez, 2017), controlling soil-borne pathogens (Mohamed *et al*., 2019; Eid *et al*., 2019; Abdelhafez *et al*., 2021a) and promoting the overall plant health (Elsayed *et al*., 2020). It is then thought that integrated use of synthetic, organic and bio-fertilizers may successfully enhance plant growth and, at the same time, sharply increase the revenues (Jilani *et al*., 2007; Abbas *et al*., 2011).

Wheat is an important strategic crop worldwide (Dianatmanesh *et al*., 2022; Lalarukh *et al*., 2022 a, b and c). It is probably the most important winter crop in Egypt (Elbeltagi *et al*., 2020); yet, this country has become one of the largest wheat importers around the world (Abdelmageed *et al*., 2019). It is therefore important to increase its productivity in Egypt to diminish the gap between production and consumption (Hussein *et al*., 2022; Saad *et al*., 2023). This study is a trial towards evaluating the integrated management of chemical, organo- and bio N, P and K-fertilizers to increase wheat production in arid zones and, at the same time, improve soil characteristics to sustain soil productivity on the long run. We believe that the outcomes of this study might contribute significantly in sustaining soil productivity. Specifically, we anticipate that organic and/or bio-fertilizers applications partially substitute chemical fertilizers in wheat production; thus, increase wheat growth and productivity versus the reference treatment that received the full dose of PK mineral fertilizers (hypothesis 1). Such increases were mostly related to the concurrent increases that occurred in NPK available contents in soil (hypothesis 2); which upraised significantly their contents within wheat plants, particularly within grains (hypothesis 3). Furthermore, organic and/or bio- additives improve significantly soil chemical and physical characteristics, i.e. soil pH, residual organic matter content and bulk density (hypothesis 4).

2. Materials and Methods

2.1. Materials of study

Two soil samples were collected from a private farm at Moshtohor, Qalyubia Governorate, Egypt (31° 22́ 26̋ E and 30° 36́ 02̋ N) prior to wheat cultivation in the winter seasons of 2019 and 2020. Soil physical and chemical characteristics were determined as outlined by Klute (1986) and Sparks *et al*. (1996) (Table 1).

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

Character	1st season	2nd season	Mean	Character	1st season	2nd season	Mean
Particle size distribution				pH*	8.1	8.0	8.1
Sand (%)	33.7	32.9	33.3	EC** (dS m^{-1})	1.4	1.4	1.4
Silt (%)	19.5	20.4	20.0	Avail-N ($mgkg^{-1}$)	69.0	73.0	71.0
Clay (%)	46.8	46.3	46.6	Avail-P ($mgkg^{-1}$)	6.3	6.7	6.5
Textural class	Clay	Clay	Clay	Avail-K ($mgkg^{-1}$)	174.0	185.0	179.5
Organic matter (g kg^{-1})	12.9	13.1	13.0	$CaCO_3$ (g kg^{-1})	19.1	18.3	18.7

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

Wheat seeds (*Triticum aestivum*, Misr l) were kindly obtained from the Field Crops Research Institute, Agricultural Research Center (ARC), Egypt. Three bioagents i.e. a N-fixer (*Bacillus polymyx* EMCCN 1108), a phosphate solubilizing (*Bacillus megatherium*, HKP-2) and a potassium solubilizing (*Bacillus circulans*, NCAIM B.02324) bacteria were obtained from the Microbiology Department at Soils, water and Environment Research Institute, ARC, then grown on nutrient broth media to achieve inoculant cells equivalent to 1×10^8 mL^{-1} according to ALKahtani *et al*. (2020).

Biogas manure was brought from the Training Center for Recycling of Agricultural Residues at Moshtohor (TCRAR), ARC. Its chemical properties are presented in Table 2. Potassium humate, humic and fulvic acids were then extracted from biogas according to Sanchez – Monedero *et al .(2002*). Humic acid was purified via washing with 0.05 *N* H_2SO_4 till it becomes colorless, then subjected to electro- dialyses to diminish its ash content (<1%) (Chen and Schnitzer, 1978); thereby this extract was air dried. The supernatant containing fulvic acid was passed through activated charcoal, elution of charcoal then membrane filter and electrodialyses for purification as recommended by Kononova (1966). Chemical properties of the extracted KH, HA and FA are also presented in Table 2.

Table 2. Chemical characteristics of potassium humate, humic and fulvic acids extracted from biogas manure.

Characteristics	Biogas manure	K-humate (HK)	Humic acid (HA)	Fulvic acid (FA)
CEC (cmole$_c$ kg^{-1})	470.00	460	440	320
C (%)	21.90	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
P (%)	7.80	0.23	0.30	0.27
K (%)	9.30	2.18	2.41	2.32
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

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 brought from Al Ahram Mining Company.

2.1. Methods of study

A field study of a randomized block design was accomplished for two successive winter seasons i.e. 2019 and 2020 at the above-mentioned farm. Treatments were as follows: (1) 100% of required P in organic form (biogas, T$_1$), (2) rock phosphate to satisfy 100% of P + feldspar to fulfil 100% of K requirements + biofertilizers (T$_2$), (3) 50% of P and K were applied in the form of biogas+ 50% of P and K as rock phosphate and feldspars + bioagents (T$_3$), (4) 100% of required P and K in organic form (biogas) +biofertiliozers (T$_4$), (5) 24 kg potassium humate (KH) ha^{-1}+100% of P and K as rock phosphate and feldspars+ bioagents (T$_5$), (6) 24 kg humic acid (HA) ha^{-1}+100% of P and K as rock phosphate and feldspars+ bioagents (T$_6$), (7) 24 kg fulvic acid (FA) ha^{-1} +100% of P and K as rock phosphate and feldspars+ bioagents (T$_7$), (8) 50% of P and K as biogas + 50% of P and K as mineral fertilizers+ bioagents (T$_8$) and (9) 100% mineral P and K fertilizers (T$_9$, the reference treatment). For all treatments, P and K were achieved at the recommended doses (10.5 g P and 20 g K kg^{-1} soil, respectively) according to the Egyptian Ministry of Agriculture. Concerning the application of bio-fertilizers, it took place via two equal doses (30 and 60 days after sowing) at a total rate of 24 L ha^{-1}. The experimental plot was 12.25 m^2 (3.5 m length x 3.5 m width) and all treatments were replicated three times. In November (2019 and 2020), wheat seeds were cultivated in all plots at a rate of 120 kg ha^{-1}. Eighty percent of the recommended requirements of N for wheat which is equivalent to 240 g N kg^{-1} were added in the form of ammonium nitrate (335 g N kg^{-1}) at three equal doses after considering the organic N inputs. The other 20% N needs were satisfied via biological nitrogen fixation with *Paenibacillus polymyx*. All agricultural activities were followed as usual. At harvest stage, plant growth parameters and yield were determined.

2.2. Soil and Plant analyses

Soils were sampled from each plot during plant harvest, to estimate their contents of available P and K according to Sparks *et al.* (1996) as follows: available-P by Olsen then reduced by ascorbic acid afterwards determined by Spectrophotometer (SM1600 UV-VIS). Available- K was extracted by ammonium acetate then determined by flame photometer (*Jenway* model PFP7). Available NH_4-N and NO_3-N were determined using Kjeldahl. Soil pH was determined by Orion Expandable ion analyzer (EA920) in 1:2.5 (soil:water suspension). Electrical conductivity was measured in soil paste extract using an EC meter (ICM 71150) and residual organic matter content was assessed according to Walkley and Black method as outlined by Sparks *et al*. (1996). Soil bulk density was estimated using the core method according to Klute (1986). Nitrogenase (N_2- ase) activity was evaluated via acetylene-ethylene assay (Hardy *et al*., 1968), then determined via Gas Chromatography (Hewlett-Packard 5890).

Wheat grains were oven dried at 70°C for 48 h, ground in a porcelain mortar and plant portions, equivalent to 0.5g dried samples, were wet using a mixture of sulphuric and perchloric acids according to Page *et al.* (1982) then analysed for their contents of N by Kjeldahl, P colormetrically and K by flame photometer as mentioned above.

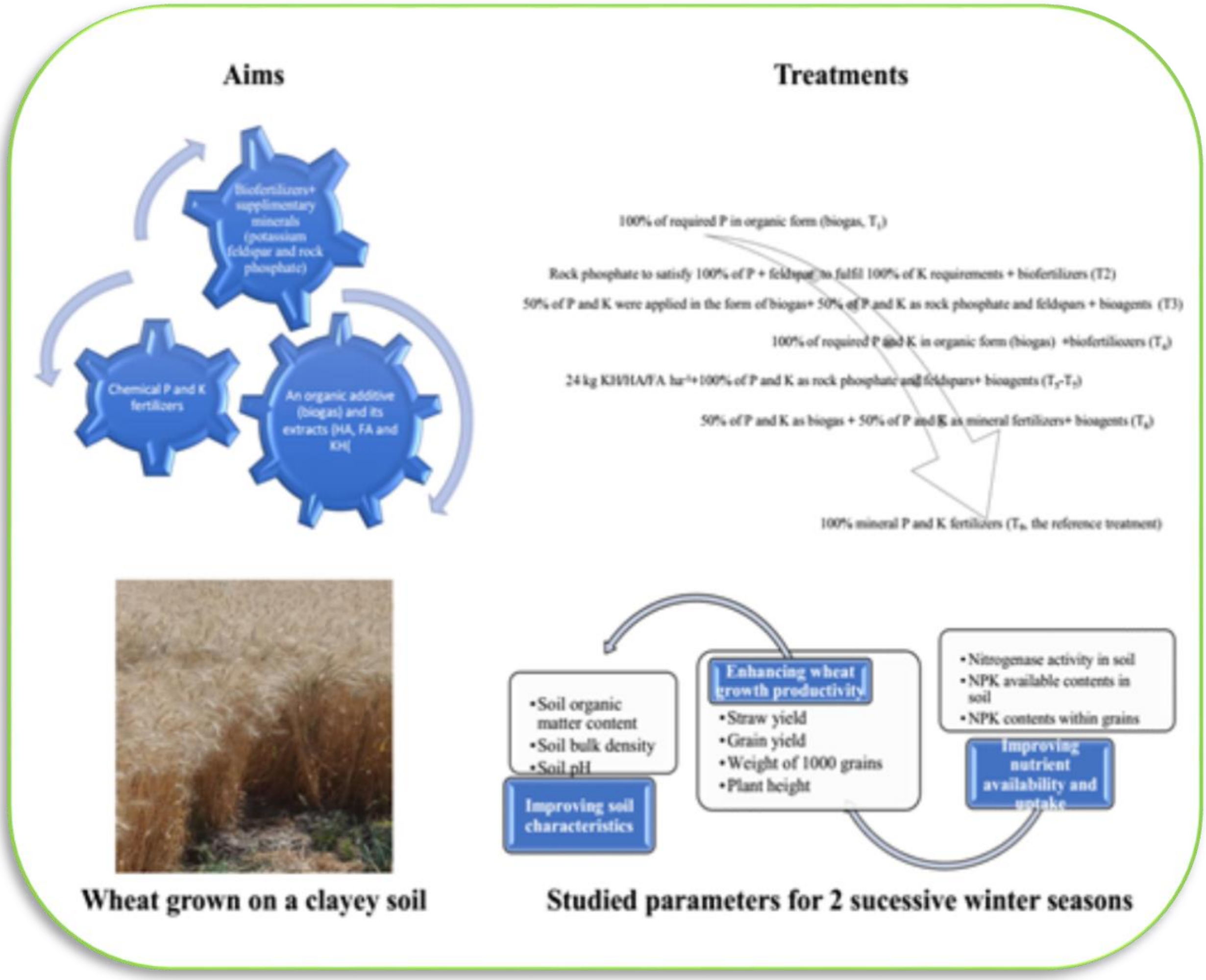

Fig. 1. Scheme of the experiment.

2.3. Data analyses

Chemicals used in this study were of analytical grade. Data were subjected to analyses of variance using a one- way ANOVA and Dunken's texts via SPSS statistical software (ver 18). Figures were plotted by Sigma plot 10 software.

To calculate the net revenues of the used treatments in local currency payment (1$≈ 30 Egyptian pound, EGP), the following calculations were considered per hectare for each season:

a. **Non-changeable expenses (fixed for all treatments):** land rental = 25400 L.E., seeds = 1200 L.E., urea = 4800 EGP, the N- fixer (*Paenibacillus polymyx*) =480 EGP ha^{-1}, hired labor and machinery (soil preparation, cropping, irrigation, fertilization, yield cutting and packing) = 7860 EGP (total costs= 39740 EGP).

b. **Changeable expenses (differ among treatments)**: (1) calcium super-phosphate valued 320 EGP for a pack of 100 kg, (2) Potassium sulphate was 400 EGP per pack of 50 kg. Potassium feldspar and rock phosphate valued 1950 and 1200 EGP (per megagram), respectively. Biogas was worth 500 EGP per megagram. P and K biofertilizers expensed 950 EGP, while humic, fulvic and K-humate additives valued approximately 140 EGP per one kilogram.

c. **Selling prices** were 10,000 EGP per every mega gram of wheat grains in addition to 4800 EGP for the straw yield of the hectare.

The net profit was then estimated as a difference between the selling prices of both seeds and straw minus all costs (Saad *et al*., 2023).

3. Results and Discussion

3.1. Effect of integrated organic and biofertilizers on wheat growth parameters and productivity

The highest increases in straw and grain yields of wheat during both seasons of study as well as the weight of 1000 grain were achieved when wheat plants received T_8 (50%organic+50%synthetic PK+bioagents), exceedingly even the reference treatment i.e. T_9 (Fig 2). These results signify the importance of the integration between different forms of nutrients to increase crop productivity (Abbas *et al*., 2020; Farid *et al*., 2021c). On the other hand, T_7 (24 kg FA ha^{-1} +P-input in the form of rock phosphate and K-input in the form of feldspars+ bioagents) recorded the least records related to plant growth parameters and productivity within both seasons of study. It is worthy to mention that there were no significant variations among treatments in plant height.

Generally, the full dose of biogas application (T_1) recorded significantly higher increases in all plant growth parameters and grain yield versus the treatment that received both rock phosphate and feldspar as sole sources for P and K plus biofertilizers. Although, phosphate solubilizing (*Bacillus megatherium*) (Hu *et al*., 2006) and potassium solubilizing (*Bacillus circulans*) (Yadav and Sidhu, 2016) bacteria exhibited high efficiencies for increasing nutrient availability in soil while reducing the use of agrochemicals in crop production (Etesami *et al*., 2017); yet their efficiencies might not be enough if they are used solely to improve crop productivity (Etesami *et al*., 2017). A point to note is that the first type (*Bacillus megatherium*) is an acidifying bacteria while the second one (*Bacillus circulans*) is a saprophytic one (Meena et al., 2014).

Partial substitution of these minerals by organic application (biogas) was not enough to increase plant growth and yield component i.e. T_3 versus T_9. On the contrary, this treatment recorded significantly lower records versus either T_1 or T_2. Probably these bioagents, particularly *B. circulance* satisfy their needs from the readily available forms of nutrients or those released upon organic matter decomposition (Hou *et al*., 2017; Chhetri *et al*., 2022) rather than mineralizing rock phosphate and feldspars. This explains reasonably the reductions that occurred in plant growth and productivity owing to application of 50% or 100 % biogas (to a lower extent) doses +the biofertilizers (T_4).

In presence of relatively resistant biodegradable organic products (potassium humate, humic and fulvic acids), fulvic acid (T_7) exhibited higher efficiencies in increasing wheat grain yield and the weight of 1000 grains versus other organic extracts. Probably, these bioagents dissolve P and K bearing minerals (Etesami *et al*., 2017) and FA specifically increased their mobility in soil to reach the roots of the grown plants (Yang *et al*., 2013). Moreover, HA might retain partially some of the soluble ions against leaching (Piri *et al*., 2019). These treatments recorded relatively lower consequences on wheat straw yield, versus its impacts on grain yield. This probably indicates that the chelated nutrients via FA were utilized mainly in enhancing plant productivity rather than increasing wheat vegetative growth.

Application of 100% biogas set nutrients free at relatively slow rates and this was not enough to attain proper plant growth (Farid *et al*., 2021b); in spite of that this treatment decreased the rate of nutrient leaching from the top soil (Barthod *et al*., 2018). Overall, this treatment recorded significantly lower growth parameters and yield components versus the reference one. Based on the above results, organic applications (-/+ bio-fertilizers) partially and not totally substitute chemical fertilizers in wheat production thus increased wheat growth and productivity. Consequently, the first hypothesis becomes valid.

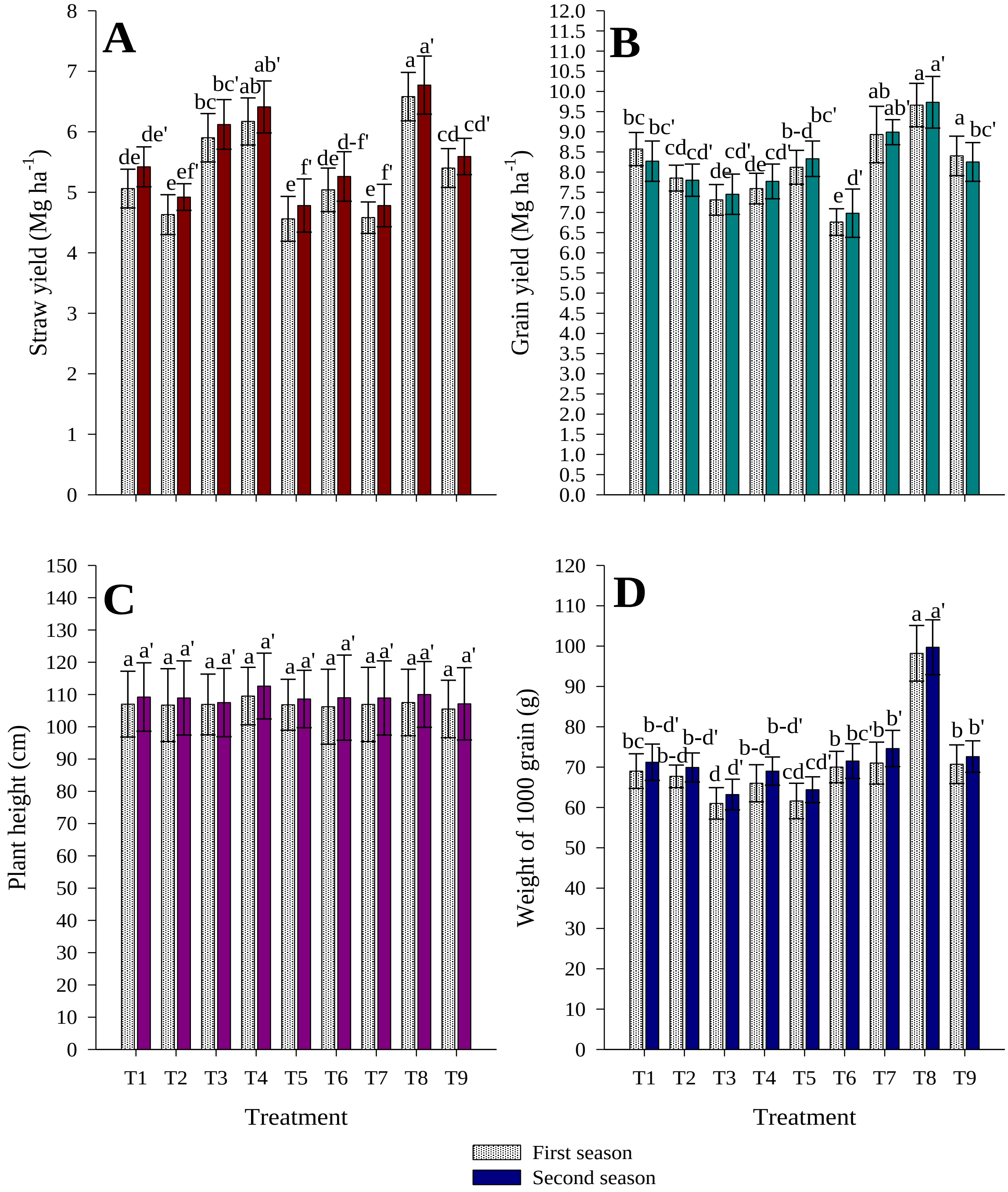

Fig. 2. Wheat growth parameters and grain yield (means ± standard deviations) as affected by the integral management of P and K synthetic, organic and bio-inputs. No statistical difference among treatments sharing same Dunkin's letters. For T_1 to T_9: 100% of P and K as biogas (T_1), rock phosphate to satisfy 100% of P + feldspar to fulfill 100% of K requirements + biofertilizers (T_2), 50% of P and K as biogas + 50% of P and K as rock phosphate and feldspars + bioagents (T_3), 100% of P and K as biogas +biofertilizers (T_4), 24 kg KH ha^{-1} +100% of P and K as rock phosphate and feldspars+ bioagents (T_5), 24 kg HA ha^{-1}+100% of P and K as rock phosphate and feldspars+ bioagents (T_6), 24 kg FA ha^{-1} +100% of P and K as rock phosphate and feldspars+ bioagents (T_7), 50% of P and K as biogas + 50% mineral fertilizers+ bioagents (T_8) and 100% mineral P and K fertilizers (T_9).

3.2. Effect of integrated organic and bio fertilizers on available N, P and K in soil as well as the activity of nitrogenase enzyme

Fig 3 reveals that T_8 recorded the highest increases in N, P and K available contents in soil. Their values were even higher than the reference treatment that received the full dose of PK as mineral fertilizers. Although, application of biogas was not enough to stimulate considerably the biological oxygen fixation versus the reference treatment because this additive was of slow release rate; yet this additive increased significantly available NH_4-N that released during its degradation (Farid *et al*., 2021a and b). Consequently, this nitrogen probably underwent oxidation in soil forming NO_3-N (Glaser *et al*., 2010).

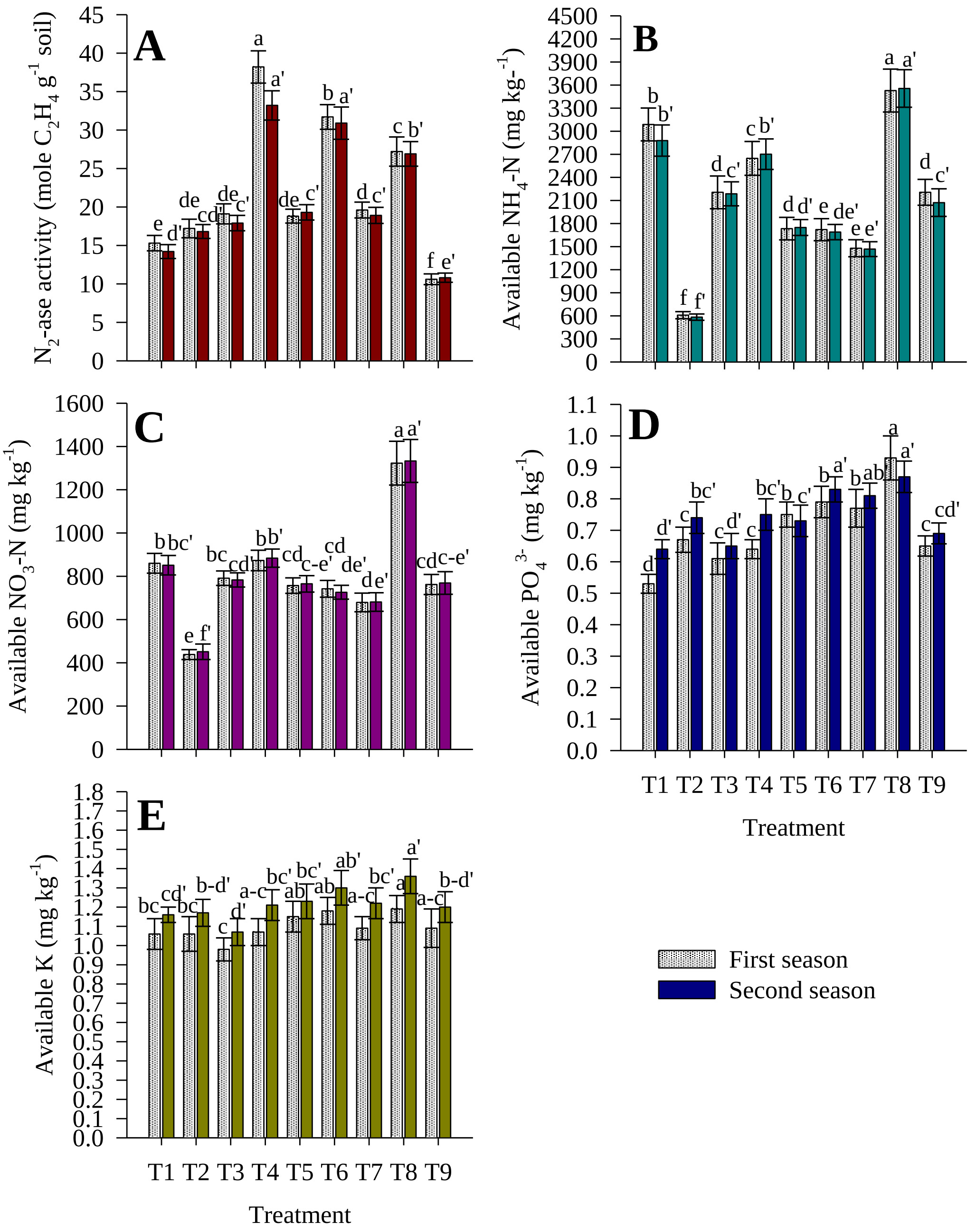

Fig. 3. Available NPK contents in soil and the activity of nitrogenase enzyme (means±standard deviations) as affected by the integral management of P and K synthetic, organic and bio-inputs. No statistical difference among treatments sharing same Dunkin's letters. See footnote Fig. 2.

Likewise, application of 50% mineral+50% organic+ bioagents (T_8) increased N_2-ase yet to a lower extent versus T_4 during the two seasons of study as the latter treatment probably released bioactive components needed to stimulate the activities of N-fixers.

Significant reductions were noticed in activities of N_2-ase enzyme owing to application of bioagents+ P and K bearing minerals (rock phosphate and feldspar). It is well known that soil biota converts atmospheric nitrogen to ammonium via this enzyme (Bellés-Sancho *et al*., 2021); yet they also need nutrients, and these nutrients were relatively low in the soil that was supplied with both feldspar and rock phosphate. Thus, bioagents take part in organic matter degradation (Chhetri *et al*., 2022) to utilize organic nutrients to stimulate their bioactivities. This might explain why the application of 100% organic +bioagents raised considerably the activity of this enzyme versus the application of biogas solely.

Addition of either KH, HA or FA significantly raised the activity of N_2-ase enzyme versus the that of the reference treatment with superiority of HA among the organic extracts. Its high molecular weight (HA) probably retained nutrients longer in soil (Yang *et al*., 2020) hence stimulated the activities of N-fixing micro-organisms.

Generally, the investigated additives significantly raised P and K available contents in soil and these results support the second hypothesis.

3.3. Effect of organic and bio fertilizers on NPK contents within grains

The highest increases in N and P contents within wheat grains were attained for T_8 treatment, followed by T_9 (the reference treatment), while the variations in K content between these two treatments were almost insignificant (Fig 4).

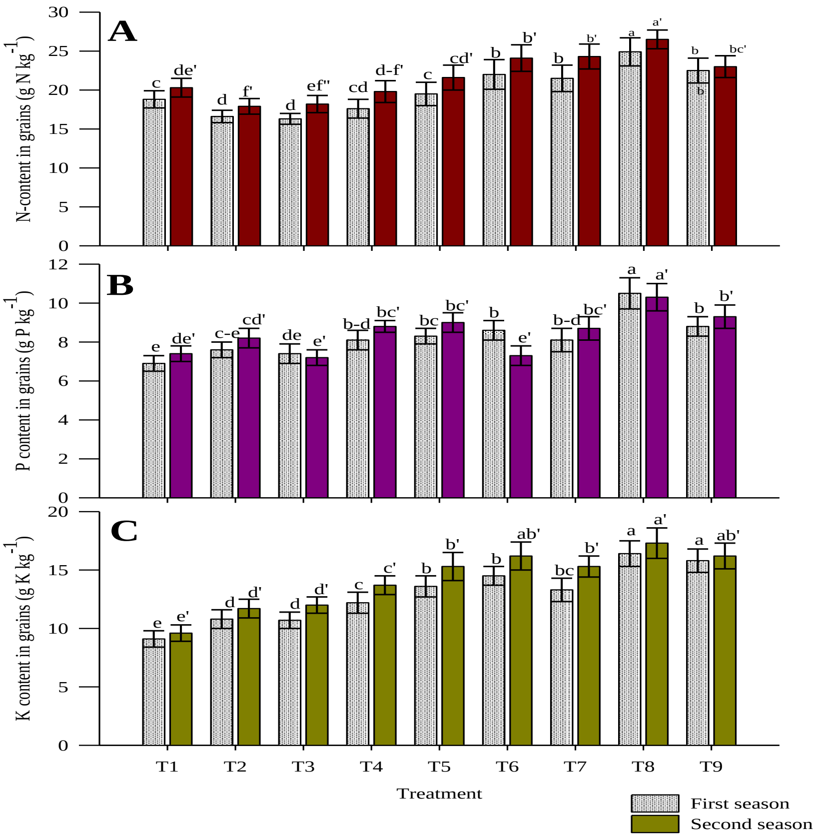

Fig. 4. Concentrations of NPK in wheat grains (means± standard deviations) as affected by the integral management of P and K synthetic, organic and bio-inputs. No statistical difference among treatments sharing same Dunkin's letters. See footnote Fig. 2.

Application of the investigated bioagents in absence of organic additives as in the case of T_2 or in presence of biogas as its half (T_3) or full dose (T_4) decreased significantly nutrient contents within seeds versus the reference dose. Probably, these inoculants took part in organic matter degradation as mentioned above and competed on soil nutrients with the grown plants.

In case of P and K contents in wheat grains, application of relative low biodegradable organic additives and/or bioagents that release slowly nutrients might account for the significant reductions in P and K contents within grains. Overall, the third hypothesis indicating that organic additives and biofertilizers raised significantly NPK contents within wheat plants, particularly in grains becomes acceptable if integrated with the application inorganic of organic fertilizers.

3.4. Effect of organic and bio fertilizers on soil pH, residual organic matter and soil bulk density

All organic applications raised significantly soil organic matter, and this consequently decreased soil bulk density (Fig 5). On the other hand the least contents of residual soil organic matter were noted with the application of both T_2 and T_9 treatments with no significant variations between these treatments. Also, these two treatments recorded the highest increases in values of soil bulk density. These results signify the importance of organic applications on raising soil organic matter forming aggregates.

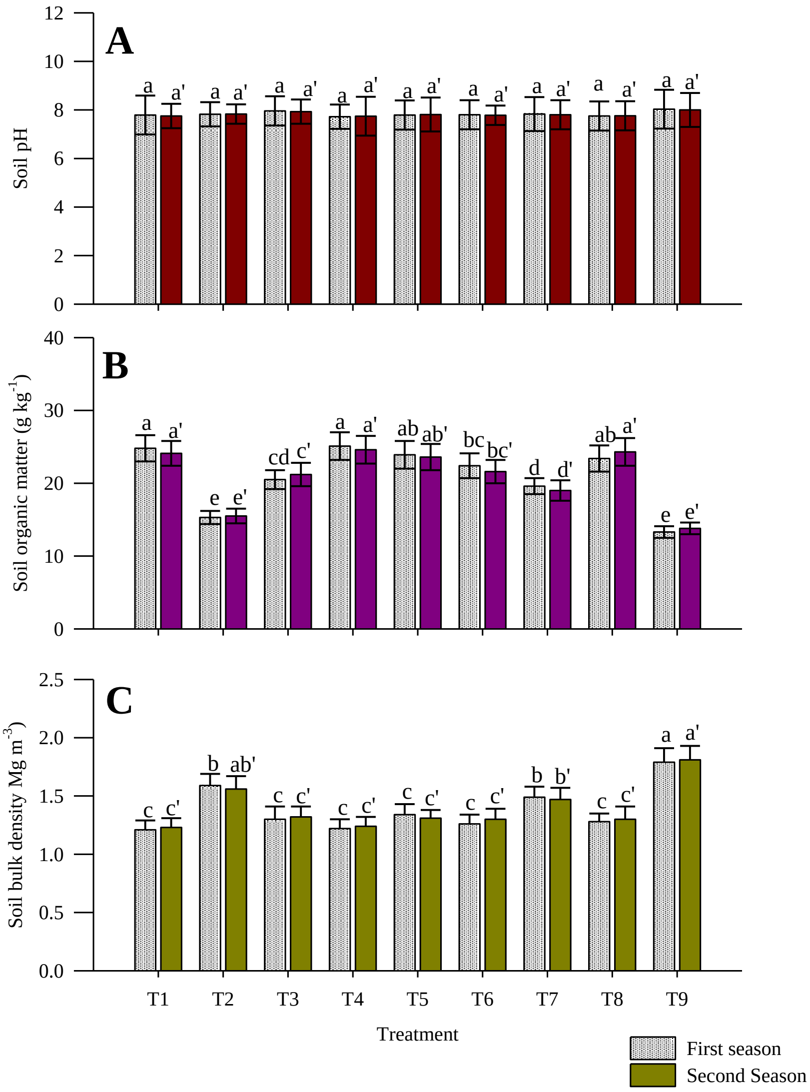

Fig. 5. Soil pH, residual organic matter and bulk density (means ± standard deviations) as affected by the integral management of P and K synthetic, organic and bio-inputs. No statistical difference among treatments sharing same Dunkin's letters. See footnote Fig. 2.

Two scenarios might explain these findings: (1) organic fractions were trapped within soil aggregates (Kleber *et al*., 2021); hence decreased soil bulk density. The other assumption indicates that these organics underwent degradation in soil forming microbial resistant biproducts (Abdelhafez *et al*., 2018) which were trapped among soil particles forming aggregates (Mohamed et al., 2021). Both scenarios seemed to be applicable at the same time in soil as the first one explains the increases that took place in soil organic matter owing to application of each of humic acid or potassium humate which are characterized by their high molecular mass (Abd El-Aziz *et al*., 2020; Farid *et al*., 2021a and b) thus exhibited higher resistance against degradation while in case of fulvic acid, its low organic molecular mass facilitates its mobility in soil (Ukalska-Jaruga *et al*., 2021) and become more easily biodegradable versus either humic or potassium humate treatments (Fourti *et al*., 2010).

Application of 50% biogas plus 50% chemical fertilizers and biofertilizers (T_8) recorded comparable values of soil organic matter content and soil bulk density with the treatment that received double the biogas dose (T_1). May be, organic matter and mineral additives stimulated microbial activities and, at the same time, enhanced plant growth. This beneficial relationship within the rhizosphere could increase microbial byproducts which may take part in building up of soil organic matter and formation of aggregates (Abdelhafez *et al*., 2018); hence lessen soil bulk density.

In case of application of 50% biogas+ 50% K as rock phosphate and feldspars+ biofertilizers, the results of organic matter content and soil bulk density were a bit confusing.

Although, the investigated bioagents increased the rate of organic matter degradation; yet their corresponding bulk density values were still high. Probably, the rate of degradation of organic additives or their byproducts were relatively high; hence these residues did not account for either increasing soil organic matter content or even decreased soil bulk density. These results signify the importance of the symbiotic relation between soil biota and organic additives on organic matter build up within soil aggregates as stated above.

Concerning soil pH, no significant variations were found among treatments. This result might be related to the high buffering capacity of the clay content in soil (Dvořáčková *et al*., 2022) that resisted changes in soil pH. Also, released organic acids during degradation of organic additives might increase soil buffering capacity (Xue *et al*., 2022). Generally, organic and bio additives raised soil organic matter, and this consequently increased soil aggregation while did not affect soil pH. These results support partially the fourth hypothesis.

3.5. Correlation coefficients between wheat growth parameters and grain yield with relation to the NPK contents in grains and the corresponding available contents in soil

Concentrations of NH_4-N and NO_3-N in soil were correlated significantly and positively with the activity of N_2-ase enzyme (Table 3). This simply refers to the positive relationship between organic applications and the activities of soil N_2 fixers. Also, there was a significant correlation between NH_4-N and NO_3-N. Probably, the released ammonium ions underwent partial oxidation in soil forming nitrate ions.

Overall, grain and straw yield were correlated significantly and positively with the available indices of N, P and K in soil. Likewise, the nutritional status of these nutrients in grains was correlated positively with the available indices of these nutrients in soil.

The quality parameter (1000-grain weight) also increased with increasing NPK contents in grains. Plant height was correlated positively and significantly with only P and K available contents in soil. A point to note is that K is a mobile nutrient within plants that is not metabolized to an organic form; thus it plays vital physiological processes in its soluble forms such as osmoregulation (Wang *et al*., 2021); thus there is no wonder to find out that the grain yield was not affected significantly by K in grains. Also, plant height was not affected by K-grains.

Table 3. Wheat growth parameters and yield in relation to the available contents of NPK in soil and corresponding contents in grains.

	N_2-ase enzyme	Available NH_4-H	Available NO_3-H	Available-PO_4^{3-}	Available-K^+	Grain yield	Straw yield	1000-grain weight	Plant height	N-grain	P-grain	K-grain
N_2-ase enzyme												
Available NH_4-H	0.267											
Available NO_3-H	0.366**	0.918**										
Available- PO_4^{3-}	0.444**	0.100	0.437**									
Available- K^+	0.317*	0.215	0.415**	0.767**								
Grain yield	-0.332*	0.015	<0.001	-0.047	0.138							
Straw yield	0.446**	0.753**	0.774**	0.284*	0.332*	0.071						
1000- grain weight	0.235	0.552**	0.762**	0.719**	0.640**	0.069	0.579**					
Plant height	0.273*	0.204	0.246	0.388**	0.629**	-0.001	0.464**	0.356**				
N-content in grains	0.155	0.372**	0.575**	0.764**	0.804**	0.205	0.295*	0.767**	0.324*			
P-content in grains	0.223	0.369**	0.626**	0.740**	0.649**	0.256	0.489**	0.776**	0.390**	0.728**		
K-content in grains	0.254	0.164	0.435**	0.775**	0.720**	0.276*	0.299*	0.584**	0.251	0.858**	0.793**	

* Significant at the 0.05 level ** Significant at the 0.01 level

3.6. Financial revenues of the used treatments

The highest revenue was recorded for the treatment that received "50% of P and K as biogas + 50% mineral fertilizers+ bioagents" (T_8) in both seasons of study (Fig 6). Revenues of each of T_1, T_7 and T_9 seemed also to be high and somehow comparable in the two seasons of study, yet still below the corresponding ones of T_8. On the other hand, the least net profit was estimated for T_6 treatment that received 24 kg HA ha^{-1}+100% of P and K as rock phosphate and feldspars+ bioagents.

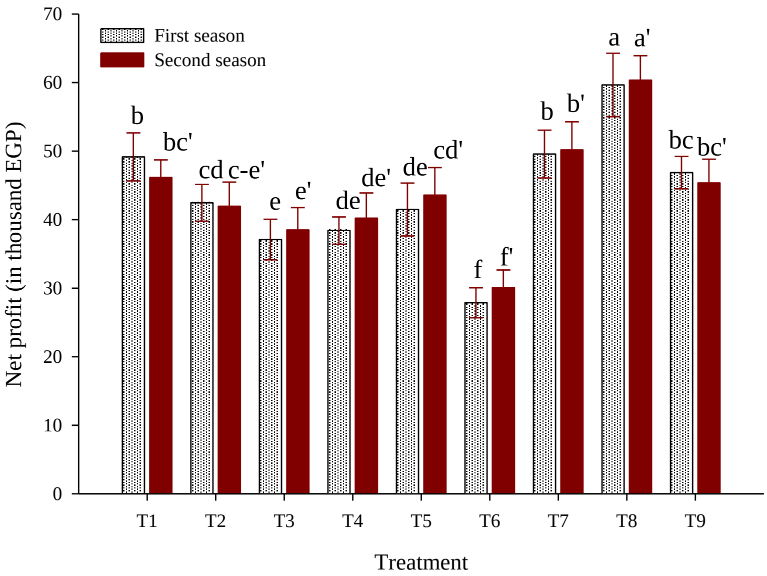

Fig. 6. Net profit in thousand EGP (means ± standard deviations) as affected by the integral management of P and K synthetic, organic and bio-inputs. No statistical difference among treatments sharing same Dunkin's letters. See footnote Fig. 1.

4. Conclusions

The treatment "50% of P and K as biogas + 50% of P and K as mineral fertilizers+ bioagents" recorded the highest available increases in NPK contents in soil, exceeding even the reference treatment that received the full dose of P and K as chemical fertilizers. Such increases lead to significant increases in NPK uptake by plants, to raise their contents in grains. This might consequently enhance wheat growth and productivity. Moreover, soil characteristics were improved considerably owing to this combined application i.e. residual organic matter content increased significantly while soil bulk density decreased considerably. Accordingly, this treatment is guaranteed to increase and sustain soil productivity within arid regions

5. Conflicts of interest

There are no conflicts to declare.

6. Formatting of funding sources

List funding sources in a standard way to facilitate compliance to funder's requirements

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