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Bean Yield and Soil Parameters as Response to Application of Biogas Residues and Ammonium Nitrate under Different Water Requirements

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ANAEROBIC digestion is a useful way to treat organic waste matter, resulting in biogas and residue. Two field experiments were carried out for a sandy loam soil under drip irrigation system using faba bean (*Vicia faba* L.) during 2014/2015 and 2015/2016 seasons at Ismailia Governorate to evaluate the effect of biogas residue (BR) and inorganic fertilizer as ammonium nitrate (AN) individually or in combination with different rates of each other fertilizers and irrigation levels on faba bean production, nutrients uptake and soil fertility after two season of cultivation. The experiment includes two factors; 1st one was N-application with 6 treatments as follows: (1) 100% of N rate as BR, (2) 100% as AN, (3) 75% BR+25% AN, (4) 50% BR + 50 % AN, (5) 25% BR + 75% AN and (6) non-treated (control). The second factor was irrigation levels as follows: 100% from water requirement (WR) and 75% of WR. Main effects of fertilization showed that, the highest plant dry weight, 100- seed weight, seed yield were obtained with 100% of BR followed by 25% AN + 75% BR and lowest plant dry weight was found with unfertilized treatment in both seasons. Similar trend occurred with available N, P and K remaining in soil at harvest. Significant positive correlation was found between soil available N, P and K contents and seed N, P and K. Application of biogas residues is of great benefit to plant and increases soil fertility.

Keywords: Biogas residues, Water requirement, Faba bean, Yield, Macronutrients availability, Soil fertility.

Faba bean (*Vicia faba* L.) is the most important legumes crop in Egypt. It has become one of its strategic crops. It is important for soil fertility, human nutrition, animal feeding and industry purposes (Sharaan *et al.,* 2004). Soil fertility in Egypt is negatively affected by crop intensification and imbalance use of chemical fertilizers with little or no addition of organic fertilizers. Organic fertilizers including animal manure can provide crops with considerable portions of plant needs of N and P (MØller *et al.,* 2007 and Bauer *et al.,* 2009).

The biogas produces digested organic matter which is used as compost providing plant nutrients such as N, P and K beside other nutrients (Möller & Müller, 2012 and Bachmann *et al.,* 2011). Biogas residues include solid as well as liquid materials. The organic materials used in Egypt as raw materials for biogas plant are mainly cattle and poultry manure mixed with crop residues. Digestion process of biogas produces materials containing high contents of N. The produced material also contains other macro- and micronutrients important for plant growth. Raw undigested cattle slurry materials have lower pH value, higher NH_4^+-N as well as C:N ratio compared with digested cattle slurry (Gutser *et al.,* 1987, Asmus *et al.,* 1988 and Möller *et al.,* 2008). It was reported that N uptake by plant from the biogas slurry exceeded that from the unfermented slurry by about 10 to 20%. It is reported that, a higher yield and N uptake after the application of the digested than undigested materials can be occurred (De Boer, 2008).

Irrigation plays an important role in water utilization and consequently on crop yield and quality. Plant height, biological stover and seed yield of bean plants were decreased with decreasing irrigation water rate (Abou-Baker *et al.,* 2012). Abdel-Mawgoud (2006) tested the impact of three irrigation levels (80, 100 and 120 % of class A-pan) on the growth and yield of green bean. Vegetative growth parameters as well as yield components responded positively with increasing the irrigation level. Plant height, number of leaves and fresh and dry weights were increased with increasing irrigation rate.

Therefore, the objective of the present study was to evaluate the integrated effect of biogas residues and inorganic fertilizer individually or in combination as well as irrigation levels on faba bean production, nutrient uptake and soil fertility after two seasons of cultivation.

Materials and Methods

Soil and growth conditions

Two field experiments were conducted at a private farm (30 º 22` 02.48 ˝ N and 31 º 53` 01.19 ˝ E) in Ismailia Governorate , Egypt during winter seasons 2014/2015 and 2015/2016 to study the response of faba bean (*Vicia faba* L. cv. Giza 716) to application of nitrogen fertilizer from two sources, *i.e*., ammonium nitrate, (AN) and biogas residue, (BR) at different rates, *i.e.*, 0, 25, 50, 75 and 100 kg N fed^{-1} under two irrigation levels, *i.e*. 75 and 100% of water requirements (WR) on faba bean productivity and macronutrients content. Also, some soil properties after harvest were taken into consideration. A representative soil sample of the field was taken from 0 – 30 cm layer, air dried, crushed and sieved through a 2 mm sieve and analyzed for determining some physical and chemical properties of studied soil whose results are presented in Table 1 according to Page *et al.* (1982) and Klute (1986).

TABLE 1. Physical and chemical characterization of the investigated soil

Parameter	Value	Parameter	Value
Particle Size distribution (%)		**S**oluble cations and anions	
Coarse sand	33.6	Ca^{++}	13.6
Fine sand	39.9	Mg^{++}	7.5
Silt	18.0	K^{+}	7.9
Clay	8.5	Na^{+}	45.1
Textural class	Sandy loam	CO_3^{--}	-
pH (1 : 2.5 soil : water)	8.1	HCO_3-	3.2
EC (Soil paste extraction)	7.5	Cl^{-}	65.5
		SO_4^{--}	6.3
Available macronutrients (mg kg^{-1}			
N	35.5		
P	7.2		
K	111.6		

Used fertilizers

Biogas residue was collected from biogas digester and provided from Moshtohor Research of Agriculture Centre. Cattle residue was used as raw material for fermentation substrates in biogas process. The main hydraulic retention time of the material in the fermenter ranged from about 40-60 day. All organic fertilizers were stored in closed vessels at a temperature of 2 °C. Before the start of the experiment, total N, NH_4^+-N and NO_3^--N were determined in fresh sub samples of the residue using the Kjeldahl technique (Bremner and Mulvaney ,1982). Total P and K were analyzed according to Chapman & Pratt (1961) and Page *et al.* (1982), respectively. The value of pH was determined by pH meter after 1:10 dilution with distilled water. Table 2 shows properties of the BR used in the study.

TABLE 2. Physical and chemical properties of biogas fertilizer obtained from anaerobic digestion of cattle manure

Properties	Value	Properties	Value
Moisture content (g kg^{-1}**)**	**219**	**Macronutrients (g kg^{-1})**	
pH (1:10)	**6.90**	Total N	**18.5**
EC (dSm^{-1}) of 1:5 extract	**1.75**	Total P	**8.80**
Bulk density (Mg m^{-3}**)**	**0.35**	Total K	**9.20**
Organic matter (g kg^{-1}**)**	**643**		
C:N ratio	**20.2**	NH_4 (mg kg^{-1})	**55.0**
Ash (g kg^{-1}**)**	**357**	NO_3 (mg kg^{-1})	**18.0**
Odor	-	Weed seeds	-

Experimental methods

Seeds of faba bean (*Vicia faba* L. cv. Giza 716) were supplied from Food Legumes Department, Field Crop Research Institute, Agriculture Research Center, Giza, Egypt. It's sown in November 20^{th} and 25^{th} in two seasons 2014/2015 and 2015/2016, respectively. The experiment treatments included actor A: N-fertilization, 6 treatments, *i.e.*, (1) no-fertilization, (2) 100% of N as biogas residue (100% BR), (3) 100% N as mineral form of ammonium nitrate, AN (100% AN), (4) (75% BR+25% AN), (5) (50% BR+50% AN) and (6) (25% BR+75% AN). Factor B includes 2 treatments, *i.e.*, irrigation levels: (1) 75% of water requirement (WR) and (2) 100% WR. Phosphorus fertilizer was added to all plots before sowing at a rate of 100 kg fed^{-1} as superphosphate (68 g P kg^{-1}). Potassium sulphate (400 g K kg^{-1}) was applied as soil application at rate of 75 kg fed^{-1} in two equal splits 21 and 45 days after sowing (DAS). Nitrogen fertilizer was added in the form of ammonium nitrate (330 g N kg^{-1}) in three equal splits, 21, 38 and 42, DAS. All agricultural practices for growing faba bean were done as recommended by the Ministry of Agriculture.

Water requirement was calculated by average 10 years of meteorological parameters using CROPWAT computer model (FAO, 1992), based on calculation using Penman Monteith equation and the Kc values illustrated in FAO-56 (Allen *et al*., 1998) according to the formula; $ETc = Kc \times ET_0$, whereas: ETc = crop evapotranspiration in mm, ET_0 = potential evapotranspiration in mm/day and Kc = crop coefficient.

At harvest, ten plants were taken randomly from each plot and tagged for yield assessment. Straw weight, seed weight (g plant-1) and 100 seed weigh were measured. In addition, the middle three rows of each plot were harvested, then seed yield (ton/ha) was estimated. Representative ten plants were taken and macronutrients content of seeds was determined in aliquots of digested solutions resulting from the digestion of seeds samples by a mixture of H2SO4 and HClO4 acids after drying in an oven at 65º C as described by Chapman & and Pratt (1961) and Jackson (1973).

Soil characteristics

After harvest, representative soil samples of the field were taken (0 – 30 cm) from each plot. Samples were analyzed for soil salinity (EC; in soil paste extract), soil acidity (pH; in 1: 2.5, *i.e.*, soil: water suspension), available N, P and K according to Page *et al.* (1982).

Statistical analysis

Results were statistically analyzed using MSTATC software. The ANOVA test was used to determine significantly ($p \leq 0.01$ or $p \leq 0.05$) treatment effect and least significant difference (LSD) at 0.05 probability level was applied (Gomez and Gomez, 1984).

Results and Discussion

Growth parameters

Plant parameters and traits of faba bean which were recorded after harvest show significant variation among treatments (Table 3). All trails increased by applying N in its various forms. The main effect shows that the highest values among the treatments which received N regarding seed weight, seed yield and 100-seed weight were given by 100% BR. The main effect for the N-treatments (average of 2 seasons) shows that 100% BR gave increases of 120.5 for plant dry weight, 220% for seed weight plant^{-1} and 223% for seed yield. The high WR level surpassed the 75% WR level. The main effect of irrigation levels (average of two seasons) showed that the 100% WR surpassed the 75% WR by 12.2% for plant dry weight, 59.5 % for seed weight plant^{-1} and 59.4 % for seed yield. It is reported that, biogas residue leads to increase dry weight of shoots and roots and yield of Indian spinach (Hossain *et al.*, 2014). It is also found that, the application of cattle manure to various crops increased the growth parameters (Islam, 2006). It is also found that, organic manures have the ability to supply all nutrients required for crop growth and development (Parry *et al.*, 2005). Garg *et al.* (2005) reported that soil fertilization with biogas slurry generated from cattle manure improved the yield of wheat over non-modified controls.

Results of the current study indicated that application of BR solely or combined with the mineral source increased all growth parameter compared to 100% mineral source treatment. The effect of biogas residue in increasing crop yield was reported by Montemurro *et al.* (2008) who found that biogas residue increased yield of fodder crops.

With respect to the effect of irrigation levels on vegetative characters, results showed the most effective treatment was irrigation levels 100%. It gave the highest values of plant dry weight; seed weight per plant, 100 seed weight and seed yield. Similar results were recorded by Al-Suhaibani (2009) who reported that plants under higher water supply recorded higher number of leaves per plant and higher leaf area per plant. On the other hand, plants grown under water deficit conditions had less growth parameter. Similar results indicating negative effects caused by water stress on growth of faba beans were reported by Abdel-Mottaleb *et al.* (2000) and Ahmed *et al.* (2008). It is showed that, the reduction in water rate to 80% ETc reduced bean seed by 35.4 % compared with 100% Etc (Rasheed *et al.*, 2010). Hegab *et al.* (2014) found that high irrigation levels increased seed yield of faba bean.

Nitrogen, P and K uptake by bean seeds

Nitrogen uptake by seeds of non-fertilized was averaged 5.63 kg fed^{-1} as a mean for the two growing seasons (Table 4). The highest N uptake occurred with BR under 100% WR giving a considerable increase averaged nearly nine folds. The 100% WR gave higher N uptake than the 75% WR. With an average of 33.7% over the two seasons, the patterns of P and K uptake were rather similar to that of N uptake. It is found that N uptake by ryegrass from biogas residue was comparable to that from inorganic N fertilizers (Gunnarasson *et al.*, 2010). Rubaek *et al.* (1996) also found that digested slurry increased N uptake compared with the undigested slurry and attributed this to the higher ammonia volatilization from latter source. It is also reported that, the residual effect of N increased with a decreasing short term N release from organic manure further soil microorganisms may have increased in the slurry treatment immobilizing N in their bodies (Gutser *et al.*, 2005). Kocar (2008) compared the fertilizer value of anaerobically digested cattle slurry with those of commercial organic and chemical fertilizers. Higher yields of safflower were obtained with biogas residue than with the commercial fertilizers.

TABLE 3. Effect of different levels of biogas residues and AN under two levels of water requirements on faba bean growth parameters and seed yield.

Treatment (A)	Plant dry weight (g)						Seed weight g/plant					
	Water requirement (B)											
	100%	75%	Mean	100%	75%	Mean	100%	75%	Mean	100%	75%	Mean
	First season			Second season			First season			Second season		
Control	35.17 g	25.34 h	30.26 D	23.07 e	26.37 e	24.72 E	18.74 i	10.80 j	14.77 E	19.24 j	12.19 k	15.71 E
100% BR	73.47 a	54.73 f	63.25 A	62.9 a	53.1 d	58.00 BC	61.15 a	33.49 h	47.32 A	58.57 a	41.7 b	50.17 A
100% AN	60.43 d	52.8 f	56.62 C	53.03 d	51.33 d	52.18 D	52.54 b	27.32 h	39.93 C	52.17 c	36.9 g	44.57 BC
25% AN+ 75% BR	69.07 b	53.03 f	61.05 B	62.4 a	60.6 ab	61.50 A	57.70 c	32.33 f	45.01 B	56.70 c	40.2 g	48.46 B
50% AN+ 50% BR	65.67 c	54.2 f	59.93 B	57.53 bc	60.6 a	59.07 AB	55.42 d	330.19 g	42.80 D	54.60 d	39.1 h	46.88 C
75%AN+25% BR	63.17 c	57.67 e	60.42 B	54.73 cd	56.97 c	55.85 C	52.07 d	29.27 g	40.67 D	53.62 e	37.8 i	45.71 D
Mean	61.16A	49.63 B		52.28 A	51.49 A		49.60 A	27.23 B		49.15 A	34.6 B	

Treatment (A)	100 seed weight (g)						Seed yield (ton ha^{-1})					
	Water requirement (B)											
	100%	75%	Mean	100%	75%	Mean	100%	75%	Mean	100%	75%	Mean
	First season			Second season			First season			Second season		
Control	24.6 h	21.6 g	23.1 E	24.37 j	23.43 k	2.88 D	1.50 g	0.86 h	1.18 E	1.54 j	0.98 k	1.26 F
100% BR	82.33 d	66.97 a	74.65 A	83.53 a	22.65 f	9.31 A	4.89 a	2.68 e	3.79 A	4.68 a	3.34 f	4.01 A
100% AN	78.73 e	54.63 c	66.68 C	79.63 e	20.87 i	8.01 BC	4.20 d	2.18 f	3.19 D	4.17 i	2.95 i	3.56 E
25% AN+ 75% BR	74.27 f	64.63 a	69.45 B	78.3 b	21.59 g	8.94 B	4.61 b	2.59 f	3.60 B	4.53 b	3.22 g	3.88 B
50% AN+ 50% BR	73.87 f	60.37 b	67.12 C	75.73 c	21.44 h	8.52 C	4.40 c	2.42 e	3.43 C	4.37 c	3.13 h	3.75 C
75%AN+25% BR	71.77 f	58.53 c	65.15 D	73.83 d	21.32 i	8.12 C	4.17 c	2.34 f	3.26 D	4.29 d	3.02 i	3.66 E
Mean	67.59 A	54.46 B		67.59A	21.88 B		3.79 A	2.18 B		3.93 A	2.77 B	

*BR, biogas residues and AN, ammonium nitrate

*Different lower case letters indicate statistically significant differences between treatments ($p \leq 0.05$). Capital letters indicate statistically significant differences between water treatments or amendment treatments $p \leq 0.05$

TABLE 4. Effects of different levels of biogas residues and inorganic fertilizers with two levels of water requirements on Faba bean nitrogen, phosphorus and potassium seed uptakes.

Treatment (A)	N uptake (ton ha^{-1})						P uptake (ton ha^{-1})					
	Water requirement (B)											
	100%	75%	Mean	100%	75%	Mean	100%	75%	Mean	100%	75%	Mean
	First season			Second season			First season			Second season		
Control	3.99 h	7.6 g	5.79 F	6.92 h	4.02 i	5.47 E	0.92 i	0.49 j	0.70 D	0.96 f	0.51 g	0.74 D
100% BR	26.95 a	23.1 c	25.03 A	44.9 a	29.57 d	37.23 A	5.38 a	1.47 h	3.43 A	5.11 a	3.55 c	4.33 A
100%AN	20.73 d	16.29 f	18.51 E	32.68 d	22.15 g	27.41 D	3.68 d	1.76 g	2.72 C	3.65 c	2.37 e	3.01 C
25%AN+ 75%BR	24.65 b	22.56 c	23.61 B	41.35 b	25.09 f	33.22 B	4.5 b	2.42 e	3.46 A	5.06 a	3.55 c	4.30 A
50%AN+ 50%BR	22.71 c	20.34 d	21.52 C	36.28 c	24.9 f	30.59 C	4.21 c	2.11 f	3.16 B	4.22 b	2.74 d	3.48 B
75%AN+25% BR	20.53 d	18.44 e	19.49 D	36.46 c	24.27 f	30.36 C	3.92 d	2.14 f	3.03 C	3.86 c	2.43 de	3.14 C
	19.93A	18.06B		33.1A	21.67B		3.77A	1.73B		3.81A	2.52B	

Treatment (A)	K uptake (ton ha^{-1})					
	Water requirement (B)					
	100%	75%	Mean	100%	75%	Mean
	First season		Mean	Second season		Mean
Control	3.01 f	1.08 g	2.05 D	3.00 g	1.59 h	2.15 E
100% BR	20.83 a	10.05 d	15.44 A	21.78 a	10.96 e	15.81 A
100%AN	14.37 c	6.83 e	10.6 C	15.23 d	9.36 f	11.28 D
25%AN+ 75%BR	18.7 b	9.9 d	14.3 AB	17.96 b	9.67 f	14.1 B
50%AN+ 50%BR	17.44 b	8.61 de	13.03 B	17.00 c	11.66 e	13.55 B
75%AN+25% BR	14.48 c	7.07 e	10.77 C	16.44 c	9.98 f	11.75 C
Mean	14.8A	7.25B		14.8A	8.87B	

* BR, biogas residues and AN, ammonium nitrate.

* Different lower case letters indicate statistically significant differences between treatments ($p \leq 0.05$). Capital letters indicate statistically significant differences between water treatments or amendment treatments $p \leq 0.05$.

Soil nutrients accumulation after harvest

At the end of the experiment after harvest, available N, P and K contents in soil were greater in fertilized treatments (organic or mineral N) particularly when added 100% of water requirement (Table 5). Significant effect observed between all treatments in available N, P and K contents in soil. Hence, the increases in biogas residues proportion, the increases were in available N, P and K content. Most of the N remaining in the soil at end of crop season was reported by Morvan *et al.* (1997) to accumulate in soil. Dick (1992) noted a positive relationship between soil organic matter content and soil microbial biomass and concluded that practices that increase soil biological activity in the soil. Organic and inorganic input of N, when combined with appropriate management increases the amount of residue returning to the soil and thus increases the soil biological activity (Fouda, 2011). Sørensen and Jensen (1996) attribute the higher N mineralization in manure-treated soils compared to the mineral fertilizer treated ones to the mineralization processes occurred to organic N in manure.

Relationship between soil *N, P and K content after harvest and seed N, P and K uptake*

Correlation analysis between soil available N, P and K and seed N, P and K contents was concerning the treatments which received N (Fig. 1). Results show that in nearly all cases, there were significant positive correlation between soil contents of NPK and their uptake by seeds.

Conclusion

Biogas residues are considered one of the great sources for nutrients in agriculture. Amending soils with biogas plant residues enhanced the vegetative growth of faba bean. Fertilization with biogas residues alone resulted in more available mineral N, P and K in soil after harvest compared with addition of mineral fertilizer solely. After two seasons, a positive correlation between soil available N, P and K content and their uptake by plant seeds from biogas residues indicated that the accumulation of N_{org} from biogas residues leads to an increase of N release from the soil N pool. The authors propose that the input of chemical fertilizers should decrease with the use of anaerobically digested residues, whereas soil texture is improved.

TABLE 5. Effects of different levels of biogas residues and inorganic fertilizer with two levels of water requirements on soil nitrogen, phosphorus and potassium after harvest .

Treatment (A)	Total N (ton ha^{-1})			Total P (ton ha^{-1})			Total K (ton ha^{-1})		
	Water requirement (B)								
	100%	75%	Mean	100%	75%	Mean	100%	75%	Mean
	Second season			Second season			Second season		
Control	37.13 e	31.43 f	34.28 E	4.93 f	4.60 f	34.28 F	4.93 i	4.60 i	127.92 F
100% BR	89.70 a	86.77 a	88.23 A	18.07 a	18.23 a	88.23 A	18.07 a	18.23 h	177.88 A
100% AN	34.23 ef	34.63 ef	34.43 D	6.20 e	6.67 e	34.43 E	6.20 h	6.67 h	81.12 E
25%AN+ 75% BR	87.43 a	74.47 b	80.95 B	17.57 a	15.97 b	80.95 B	17.57 b	15.97 c	154.89 B
50%AN+ 50% BR	75.00 b	63.33 c	69.17 C	16.70 b	14.50 c	69.17 C	16.70 d	14.50 e	135.62 C
75%AN+25% BR	63.33 c	59.03 d	61.18 D	14.07 c	10.50 d	61.18 E	14.07 f	10.50 g	107.38 D
Mean	64.47A	58.28B		12.92A	11.74B		286.99A	268.44B	

* BR, biogas residues and AN, ammonium nitrate.

* Different lower case letters indicate statistically significant differences between treatments ($p \leq 0.05$). Capital letters indicate statistically significant differences between water treatments or amendment treatments $p \leq 0.05$.

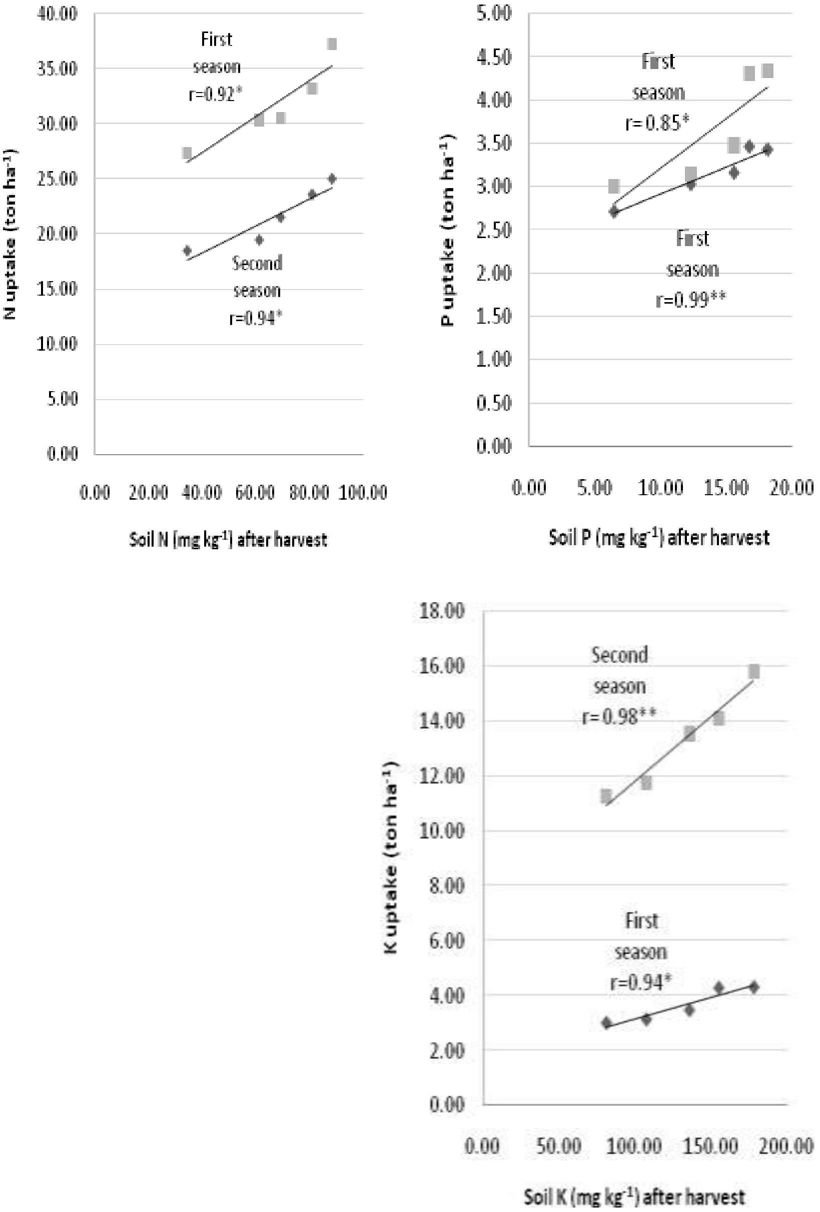

Fig. 1. Correlation between soil available nutrients and content of nutrients in seeds of faba bean (in treatments receiving N fertilizers)

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