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The effect of plant density and vermicompost rate on snap bean yield in substrate culture

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ABSTRACT

The Egyptian state moves forward to increase the cultivation area of greenhouse under the water and available agricultural soil shortages and climate change impacts to increase the horticultural production. The use of substrate culture as a soilless culture technique especially when using the available local materials such as gravel could play a role in improving the snap bean yield under Egyptian conditions. The current investigation was carried out at Central Laboratory for Agricultural Climate (CLAC), Giza, Egypt under the unheated double span plastic house during the two successive autumn seasons of 2016/2017 and 2017/2018. The study aimed at sustainably produce the snap bean in container system of gravel culture investigating the effect of plant density on the vegetative growth and pod yield through different plant distances 20, 30 and 40 cm in between snap bean plants combined with 1 and 2 rows for container beside determining the effect of vermicompost in different proportions 20 and 30 % as substrate amendment mixed with gravel in open container system. Snap bean (*Phaseolus vulgaris* L.) cv. Alhamma was cultivated in both two seasons in a split-split plot design with three replicates.

The obtained results indicated that the using of vermicompost as a substrate amendment mixed with gravel and lower density of plants / m^2 had a significant positive effect on vegetative growth characteristics and yield components of snap bean. Increasing the in-row plant distance from 20 to 40 cm and vermicompost rate from 20 to 30 % while decreasing the No. of rows/container from 2 to 1 led to increasing the vegetative growth characteristics (plant fresh weight (g), Dry weight (g), No. of shoot/plant and total chlorophyll content (Spad) and yield parameters (No. of pods/plant and total pod/plant) of snap bean while oppositely decreasing the total yield per square meter. 1 row/container gave the higher yield per plant in contrast with the treatment of 2 rows/container recorded the higher yield per square meter. The same trend obtained in the nutrients contents of N, P and K (%).The interaction treatment 1 row/container, Vermi. 30 % and 40 cm in-row plant distance recorded the highest vegetative growth characteristics and total yield per plant. Otherwise, the highest total yield per m^2 achieved by the interaction treatment 2 rows/container, Vermi. 30 % and in-row plant distance 30 cm (plant density 6.6 plant / m^2).

The study supported the sustainable production of snap bean under greenhouse condition in gravel substrate culture. The promotion of substrate culture and vermicomposting technique under the soil and water shortages and climate change condition can help food security to increase the vegetables production and mitigating greenhouse gases (GHG's) emission.

Keywords: Substrate culture, plant density, plant distance, vermicompost, gravel, snap bean yield, food security.

Introduction

The human population accelerated dramatically last 50 years while climate change impacts become more serious on global and regional levels. The need to increase the food production to satisfy the rising food security demand under high urbanization and natural resources shortage (soil, water, nutrients, and etc..) drive to use more modern agriculture methods such as soilless culture and vermicomposting technique. The Egyptian state moves forward to increase the cultivation area of greenhouse under the water and available agricultural soil shortages and climate change impacts to increase the horticultural production. The use of substrate culture as a soilless culture technique

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especially by using available local materials such as gravel may play a role in improving the snap bean yield under Egyptian conditions.

Snap bean is one of the most important legume vegetable not just for export or national consumption levels but also for the food security level regarding to its high nutritious value. Snap bean cultivated under open field, low tunnel and greenhouse conditions while the production of snap bean under greenhouse presented the main export yield.

Substrate culture is a promising agriculture method to increase and maximize the food production under the shortage of water, cultivated soil and nutrients while avoid the climate change impacts and reduce the pesticides use. The use of local substrate (sand, gravel, expended clay and etc..) instead of imported substrates could create the financial promotion for the substrate culture regarding to the high cost of imported substrate (peat moss, perlite, rock wool and etc..). A majority of horticultural crops are produced in commercially available substrates. In general, growers want substrates that are consistent, reproducible, available, easy to handle and mix, cost effective, and have the appropriate physical and chemical properties for the crop they are growing (Klock-Moore, 2000). Enhance the local substrate to illustrated the appropriate physical and chemical properties could be done by using vermicompost as a substrate amendment (AboSedera *et al.,* 2015, Abul-Soud *et al.,*2014, 2015 a, b, Abul-Soud *et al.,* 2017) as well as different compost. Butt (2007) reported that substrate culture take a place in more than 50000 hectares for producing different vegetable crops.
Vermicompost is a rich organic fertilizers with a high macro and micro nutrients contents beside different encouragement hormones, enzymes and growth regulators for the plants and soil. Vermicompost produced through vermicomposting processing of the different organic residues (animal manure, fruit and vegetable wastes, crop canopy (stalks and straw) and urban wastes. Vermicomposting is double process which epegic earthworms play a major role in decomposing the agriculture residues to worm manure (vermicompost) and microbes play a secondary process (humification) in decrease C: N ratio and enhanced the decomposition (worm cast) while mitigate CO_2 emission through sequestration of the organic carbon into more stabilized dark, earth-smelling soil conditioner and nutrient-rich compost (Abul-Soud *et al.*, 2009, 2014 and 2015 a,b,c). Vermicompost is used as an organic fertilizer or as a substrate amendment in both of soil or soilless culture.

Plant density (No. of plants per unit area) as a procedure in good agriculture practices affect not just the vegetative growth but also the total and quality of snap bean yield (Mojaddam, 2014). Moreover, the plant density had a financial factor regarding to the cost of seeds beside the yield (quality and quantity). Optimizing the plant density depending on the plant growth behavior, agriculture system and environmental conditions led to present the highest yield as a results of decreasing the competition among the plants on the water and essential nutrients, less overlapping and shading of leaves, better light penetration to the basal leaves (Motsenbocker, 1996, Papadopoulos & Pararajasingham, 1997, Charlo *et al.,* 2007, Shirtliffe and Johnston 2002, Santos *et al.,* 2010 and Khairy, 2013).

The study approach aimed to optimize the plant density of snap bean in gravel culture under greenhouse condition for increasing the quality and yield of snap bean while investigating the effect of vermicompost rate mixed with gravel as a substrate amendment on physical and chemical properties of gravel and its reflections on the growth, yield and nutrient contents of snap bean plants.

Material and Methods

The current experiment was carried out during the two autumn seasons of 2016/2017 and 2017/2018 in the experimental station of Central Laboratory for Agricultural Climate (CLAC), Agriculture Research Center (ARC), Egypt under unheated double span plastic house (18 x 60 x 4.5m).

Plant material:

Snap bean (*Phaseolus vulgaris* L.) *cv.* Alhamma seeds were sown in foam trays on the first of September in both cultivated seasons. At the stage of 3 – 4 leaves, snap bean seedlings were transplanted into the container system of gravel substrate. The No. of row / container and in-row plant distance varied regarding to the different treatments.

The vermicompost material:

Epigiec earthwoms, *Lumbriscus Rubellus* (Red Worm), *Eisenia Fetida* (Tiger Worm), *Perionyx Excavatus* (Indian Blue) and *Eudrilus Eugeniae* (African Night Crawler) were used in vermicomposting bedding system to convert different organic wastes (animal manure (rabbit + horse manure) + agriculture residues) into vermicompost under this study according to Abul-Soud *et al.*, (2009). The composition of the vermicompost material estimated dry matter (SWERI- chemical analysis service) presented in Table (1).

Table 1: The chemical analysis of macro nutrients (%) and micro nutrients (ppm) of the vermicompost.

Material	C/N ratio	Macro elements (%)				
		N	**P**	**K**	**Ca**	**Mg**
Vermicompost	12.1	1.94	1.27	1.51	1.09	0.86
		Micro elements (ppm)				
		Fe	**Mn**	**Zn**	**Cu**	**B**
		4469	502	98	47	88

System materials

Open system of 36 containers (0.6 m width, 8 m length and 0.25 height) of gravel culture were used under the study. The container performed of bricks on cement base. Black polyethylene (1 mm) was used to cover the inner sides and base of the bricks to create container system that filled by 1.2 m^3 gravel and vermicompost (regarding to the different mix rate). The drainage system is open to avoid the effect of vermicompost leached on the chemical nutrient solution composition.
Nutrient solution pumped via submersible pump (0.5 Horse power = 360 watt). Two water tanks (1 m^3) were used to fertigate the different containers of gravel .The nutrient solution used in the experiment was adapted from Cooper, (1979). The chemical composition of nutrient solution illustrated in Table (2).

Snap bean plants were irrigated by using drip system (one drippers each pant with 2 l/hr capacity). The fertigation was programmed to work 12 times / day via using digital timer. The duration of irrigation time depended on calculated water requirements and upon the season climate data (presented by Central Laboratory for Agricultural Climate (CLAC), Agricultural Research Center (ARC), Egypt.

The EC of nutrient solution was adjusted by using EC meter to the required level (1 up to 2 ds m^{-1}) according to the plant growth stage.

Table 2: The chemical composition of the used nutrient solution.

Nutrient solution	**Macro nutrients (ppm)**					**Micro nutrients (ppm)**					
	N	**P**	**K**	**Ca**	**Mg**	**Fe**	**Mn**	**Zn**	**Cu**	**B**	**Mo**
Chemical	220	45	300	180	60	3.0	1	0.25	0.15	0.25	0.012

The study treatments:

Three different factors were investigated under the current study. Two combined factors concerned on the plant density of snap bean plants combined with different rate of vermicompost as a substrate amendment mixed with gravel as follows:
1 – No. of rows per container: 1 and 2 rows / container
2 – In-row plant distance: 20, 30 and 40 cm
(Both factors created different plant densities as followed:

- 1 row / container x in row plant distance 20 cm = 5 plants / m
- 1 row / container x in row plant distance 30 cm = 3.3 plants / m
- 1 row / container x in row plant distance 40 cm = 2.5 plants / m

- 2 row / container x in row plant distance 20 cm = 10 plants / m
- 2 row / container x in row plant distance 30 cm = 6.6 plants / m
- 2 row / container x in row plant distance 40 cm = 5 plants / m

3 – Vermicompost rate: 20 and 30 % (*v/v*) mixed with the gravel substrate.

The selection of the two rate of vermicompost (20 and 30 %) and neglect the other rates due to AboSedera *et al.* (2015), Abul-Soud *et al.* (2014) and Abul-Soud *et al.* (2015) results. The vermicompost applied in both cultivation seasons. The physical and chemical properties of different vermicompost rate mixtures with gravel presented in Table (3).

Table 3: The average physical and chemical properties of different vermicompost rates mixes with gravel in both cultivation seasons.

	Physical				Chemical		
Substrate	**B.D Kg/l**	**T.P.S %**	**W.H.C %**	**A.P %**	**E.C dsm^{-1}**	**pH**	**O.M%**
Gravel 100%	0.60	38.2	9.6	28.6	0.1	7.2	0.0
G + Ver.20 %	0.62	33.7	18.2	15.5	0.9	7.3	7.1
G + Ver.30 %	0.65	31.9	22.4	9.6	1.3	7.4	10.4
Vermicompost	0.72	183.4	118.0	65.4	7.2	7.8	36.9

Substrate physical properties (Bulk density (B.D), total pore space (T.P.S), water holding capacity % (W.H.C) and air porosity % (A.P)) were measured regarding to Wilson (1983) and Raul (1996). The pH of the different mixtures were determined referring to Inbar *et al.,* (1993). Electrical conductivity (dsm^{-1}) of different mixtures were estimated by with a conductance meter that had been standardized with 0.01 and 0.1M KCl.

The experimental design was a spilt split design with 3 replicates. The No. of rows were assigned as main plots, vermicompost rates as subplots and in-row plant distance as sub-subplots.

Measurements

Vegetative characteristics:

Samples of three snap bean plants of each experimental plot were marked and removed to determine growth parameters at 120 days from the sowing as follows Plant height (cm), Total plant fresh and dry weight (g) (Total dry weight was determined after oven-drying the samples at 70 ºC for 24 hours) and total chlorophyll content (Spad) of the true mature leaf (the leaves No. 4 – 6 from the top) was measured using Minolta chlorophyll meter Spad-501.

Yield measurements:

Total yield per plant and per m^2 (g) as well as physical and quality properties of pod performed in weight (g), dry matter (%), fiber content (%) and No. of pod /plant were measured and estimated.

Chemical analysis (N, P and K):

Three snap bean plants samples of each plot were dried at 70^o C in an air forced oven for 24 h. Dried plats were digested in H_2SO_4 according to the method mentioned by Allen (1974). Total nitrogen was determined by Kjeldahl method according to FAO (1980). Phosphorus content was determined using spectrophotometer according to Watanabe and Olsen (1965). Potassium content was determined photo-metrically using Flame photometer as described by Chapman and Pratt (1961).

The statistical analysis

The obtained data were statistically analyzed using the analysis of variance method according to Snedecor and Cocharn (1980). Duncan's multiple range tests at the 5% level of probability was used to compare means of treatments.

Results

The effect of plant density (No. of row / container and plant distance) and vermicompost rate on vegetative characteristics of snap bean plants:

Table (4) illustrated the effect of different No. of row / container, vermicompost rate (%) and in-row plant distance (cm) on vegetative growth characteristics of snap bean. The highest values of fresh weight (g), dry weight (g) and No. of shoot / plant were recorded by 1 row / container while 2 rows / container gave the highest total chlorophyll content (Spad).

Table 4: Effect of different No. of rows /container, vermicompost rate (%) and in-row plant distance (cm) on vegetative characteristics of snap bean plants.

Treatment			First season				Second season			
			Fresh weight	Dry weight	No. of shoot	Chlorophyll (Spad)	Fresh weight	Dry weight	No. of shoot	Chlorophyll (Spad)
No. of row / container										
1 row			572.3 A	110.4 A	3.83 A	46.63 B	611.1 A	125.4 A	4.11 A	50.05 B
2 row			497.9 B	103.1 B	3.44 B	48.18 A	533.9 B	117.9 B	3.61 B	51.38 A
Vermicompost rate (%)										
20% V			447.7 B	89.2 B	3.33 B	47.11 A	476.9 B	100.9 B	3.61 B	50.27 A
30% V			622.6 A	124.3 A	3.94 A	47.70 A	668.1 A	142.3 A	4.11 A	51.17 A
In-row plant distance (cm)										
20 cm			444.9 C	89.4 C	2.92 C	47.95 A	473.2 C	100.7 C	3.17 C	51.38 A
30 cm			519.1 B	107.1B	3.75 B	47.67 A	557.1 B	123.6 B	3.92 B	51.08 A
40 cm			641.3 A	123.8 A	4.25 A	46.59 B	687.2 A	140.6 A	4.50 A	49.70 B
No. of row / container X Vermicompost rate										
1 row	20% V		469.7 c	90.5 c	3.67 b	45.96 c	499.4 c	101.7 c	4.00 a	49.20 b
	30% V		674.8 a	130.4 a	4.00 a	47.30 b	722.7 a	149.1 a	4.22 a	50.91 a
2 row	20% V		425.6 c	87.9 c	3.00 c	48.25 a	454.3 d	100.1 c	3.22 b	51.34 a
	30% V		570.3 b	118.3 b	3.89 a	48.10 ab	613.5 b	135.6 b	4.00 a	51.43 a
No. of row / container X In-row plant distance										
1 row	20 cm		466.1 cd	88.5 c	3.00 d	47.05 b	498.3 d	98.5 c	3.17 c	50.75 ab
	30 cm		536.0 bc	107.1 b	4.00 b	46.80 b	571.3 c	124.5 b	4.33 ab	50.25 b
	40 cm		714.7 a	135.6 a	4.50 a	46.04 b	763.6 a	153.2 a	4.83 a	49.16 b
2 row	20 cm		423.7 d	90.3 c	2.83 d	48.85 a	448.1 d	102.9 c	3.17 c	52.01 a
	30 cm		502.2 c	107.0 b	3.50 c	48.54 a	542.8 cd	122.7 b	3.50 c	51.91 a
	40 cm		568.0 b	112.1 b	4.00 b	47.14 b	610.8 b	127.9 b	4.17 b	50.24 b
Vermicompost rate X In-row plant distance										
20% V	20 cm		393.4 d	76.8 d	2.50 d	49.28 a	411.6 e	84.3 e	2.83 c	52.77 a
	30 cm		442.7 d	91.3 c	3.50 c	46.27 c	467.6 d	104.0 d	3.67 b	49.18 bc
	40 cm		506.9 c	99.5 c	4.00 b	45.77 c	551.4 c	114.4 cd	4.33 a	48.86 c
30% V	20 cm		496.4 cd	102.0 c	3.33 c	46.61 bc	534.8 c	117.1 c	3.50 b	49.99 bc
	30 cm		595.5 b	122.8 b	4.00 b	49.07 a	646.5 b	143.1 b	4.17 ab	52.98 a
	40 cm		775.7 a	148.2 a	4.50 a	47.42 b	823.0 a	166.7 a	4.67 a	50.54 b
No. of row / container X Vermicompost rate X In-row plant distance										
1 row	20% V	20 cm	418.5 de	73.7 d	3.00 d	47.14 c	434.9 de	77.4 e	3.33 c	50.78 c
		30 cm	453.4 de	88.9 d	4.00 b	44.61 d	468.1 d	101.5 d	4.33 b	47.54 d
		40 cm	537.4 cd	108.8 c	4.00 b	46.13 cd	595.3 c	126.1 c	4.33 b	49.28 cd
	30% V	20 cm	513.7 cd	103.3 cd	3.00 d	46.95 cd	561.8 cd	119.6 cd	3.00 cd	50.72 c
		30 cm	618.7 bc	125.4 bc	4.00 b	48.99 b	674.6 bc	147.4 b	4.33 b	52.97 bc
		40 cm	892.0 a	162.3 a	5.00 a	45.96 cd	931.8 a	180.3 a	5.33 a	49.04 cd
2 row	20% V	20 cm	368.2 e	79.9 d	2.00 e	51.43 a	388.4 e	91.1 de	2.33 d	54.76 a
		30 cm	432.0 de	93.8 cd	3.00 d	47.93 bc	467.1 d	106.6 d	3.00 cd	50.82 c
		40 cm	476.5 d	90.1 d	4.00 b	45.40 d	507.4 d	102.7 d	4.33 b	48.45 d
	30% V	20 cm	479.2 d	100.6 cd	3.67 c	46.26 cd	507.8 d	114.7 cd	4.00 bc	49.26 cd
		30 cm	572.3 c	120.2 bc	4.00 b	49.16 b	618.5 c	138.8 bc	4.00 bc	53.00 b
		40 cm	659.5 b	134.1 b	4.00 b	48.88 b	714.2 b	153.1 b	4.00bc	52.04 bc

* Similar letters indicate non-significant at 0.05 levels.
** Capital letters indicate the significant difference of each factor (P<0.05)
*** Small letters indicate the significant difference of interaction (P<0.05)

The obtained data indicated that increasing the vermicompost rate mixed with gravel substrate as amendment from 20 to 30 % had a positive impact on the vegetative growth of snap bean plants.

The effect of vermicompost rate 30 % had the highest fresh weight, dry weight and No. of shoot / plant while there is no significant difference between 30 and 20 % in the respect of total chlorophyll content.

Increasing the in-row plant distance between the snap bean plants from 20 up to 40 cm led to an increase in the vegetative characteristics but decreased the total chlorophyll content. The in-row plant distance of 40 cm offered the highest fresh weight, dry weight and No. of shoots / plant compared to the other treatments but the highest total chlorophyll content gave by in-row plant distance of 20 cm followed by 30 cm as showed in Table (4).

Regarding to the interaction between No. of rows / container combined with vermicompost rate, the highest records of fresh weight, dry weight and No. of shoots / plant were presented by 1 row / container combined with Vermi. 30 % while 2 rows / container combined with Vermi. 30 % had the highest total chlorophyll content.

The interaction effect between No. of rows / container combined with in-row plant distance on snap bean plants showed that 1 row / container combined with in-row plant distance40 cm recorded the highest vegetative growth characteristics but the highest total chlorophyll content was obtained by 2 rows / container combined with in-row plant distance of 20 cm.

Vermicompost rate of 30 % combined with in-row plant distance 40 cm gave the highest results of fresh weight, dry weight and No. of shoot / plant. The highest total chlorophyll content recorded by vermicompost rate 30 % combined with in-row plant distance30 cm according to the interaction between vermicompost rate and plant distance.

Table (4) illustrated the interaction among No. of row / container, vermicompost rate (%) and in-row plant distance (cm) on vegetative characteristics of snap bean plants, The interaction treatment 1 row / container, Vermi. 30 % and in-row plant distance40 cm had the highest fresh weight, dry weight and No. of shoot / plant. On the other hand, the highest total chlorophyll content illustrated by interaction treatment 2 row / container, Vermi. 20 % and in-row plant distance 20 cm.

The effect of plant density (No. of row / container and plant distance) and vermicompost rate on yield parameters of snap bean plants:

Effect of different Plant No. of rows/container, vermicompost rate (%) and in-row plant distance (cm) on parameters and quality of snap bean yield presented in Table 5).

The effect of No. of rows / container on yield parameters of snap bean showed that 1 row / container gave the highest average No. of pods / plant and dry weight percent compared to 2 rows / container that recorded the highest average weight of pod (g). There was no significant effect between 1 or 2 rows / container on the fiber content (%) of snap bean pods.

Similar results were obtained regarding to the effect of vermicompost rate mixed with gravel substrate as amendment on yield parameters of snap bean plants. Increasing the vermicompost rate from 20 to 30 % led to increase significantly the average No. of pods / plant, average weight of pod and fiber (%) while reduce dry weight percent. of pod.

The in-row plant distance effect varied regarding to the different yield parameters of snap bean. Increasing the in-row plant distance from 20 up to 40 com led to increase the average No. of pods / plant, dry weight percent while decrease the average pod weight and fiber content as Table (5) illustrated.

The interaction between No. of row / container and vermicompost rate, The treatment of 1 row / container combined with vermi 30 % recorded the highest results of average No. of pods / plant, dry weight percent and fiber content while the highest average pod weight was presented by 2 rows / container combined with Vermi. 30 %.

However, the interaction effect between No. of rows / container and in-row plant distance as presented in Table (5) showed that 1 row / container combined with in-row plant distance40 cm had the highest record of average No. of pods / plant while the highest average pod weight gave by 2 rows / container combined with in-row plant distance30 cm. 1 row / container combined with in-row plant distance30 cm recorded the highest dry weight percent while the highest value of fiber (%) presented by 1 row / container combined with in-row plant distance 20 cm.

Table 5: Effect of different No. of rows/container, vermicompost rate (%) and in-row plant distance (cm) on parameters and quality of snap bean yield.

Treatment			First season				Second season			
			No. of pods/ pl.	**Av. Pod weight**	**Dry wt. (%)**	**Fiber (%)**	**No. of pods/ pl.**	**Av. Pod weight**	**Dry wt. (%)**	**Fiber (%)**
			No. of row / container							
1 row			156.6 A	5.38 B	14.75 A	9.63 A	169.2 A	5.28 B	14.62 A	10.16 A
2 row			131.7 B	5.93 A	13.92 B	9.51 A	135.3 B	5.89 A	13.78 B	10.08 A
			Vermicompost rate (%)							
20% V			129.5 B	5.54 B	14.67 A	9.43 B	134.0 B	5.40 B	14.51 A	9.94 B
30% V			158.9 A	5.78 A	14.00 B	9.71 A	170.6 A	5.78 A	13.89 B	10.30 A
			In-row plant distance (cm)							
20 cm			100.3 C	5.89 A	13.88 B	9.70 A	106.7 C	5.81 A	13.92 A	10.29 A
30 cm			125.6 B	5.53 B	14.50 A	9.67 A	130.0 B	5.46 B	14.29 A	10.23 A
40 cm			206.6 A	5.56 B	14.63 A	9.35 B	220.2 A	5.48 B	14.39 A	9.86 B
			No. of row / container X Vermicompost rate							
1 row	**20% V**		138.3 b	5.38 c	14.83 a	9.47 b	146.0 b	5.30 bc	14.80 a	9.92 b
	30% V		175.0 a	5.38 c	14.67 ab	9.79 a	192.5 a	5.25 c	14.44 a	10.41 a
2 row	**20% V**		120.7 c	5.70 b	14.50 ab	9.40 b	122.1 c	5.49 b	14.21 a	9.97 b
	30% V		142.8 b	6.17 a	13.33 b	9.62 ab	148.6 b	6.30 a	13.34 b	10.20 ab
			No. of row / container X In-row plant distance							
1 row	**20 cm**		120.9 c	5.88 a	14.00 bc	10.01 a	130.1 c	5.70 b	13.95 b	10.64 a
	30 cm		119.0 c	4.98 b	15.50 a	9.51 b	129.4 c	4.88 d	15.22 a	10.03 b
	40 cm		230.0 a	5.30 b	14.75 ab	9.38 b	248.1 a	5.26 c	14.70 ab	9.82 b
2 row	**20 cm**		79.6 d	5.90 a	13.75 bc	9.38 b	83.2 d	5.93 ab	13.88 b	9.93 b
	30 cm		132.3 c	6.08 a	13.50 c	9.83 ab	130.5 c	6.05 a	13.37 b	10.43 ab
	40 cm		183.3 b	5.83 a	14.50 b	9.32 b	192.3 b	5.70 b	14.08 b	9.89 b
			Vermicompost rate X In-row plant distance							
20% V	**20 cm**		92.5 e	5.45 b	14.75 a	9.30 c	99.1 d	5.29 b	14.70 a	9.84 b
	30 cm		105.5 de	5.53 b	14.75 a	9.63 bc	104.0 d	5.38 b	14.52 a	10.13 b
	40 cm		190.4 b	5.65 b	14.50 a	9.37 bc	199.0 b	5.51 b	14.30 a	9.86 b
30% V	**20 cm**		108.0 d	6.33 a	13.00b	10.09 a	114.3 d	6.33 a	13.13 b	10.73 a
	30 cm		145.8 c	5.53 b	14.25 a	9.71 b	156.0 c	5.55 b	14.07 ab	10.33 ab
	40 cm		222.9 a	5.48 b	14.75 a	9.33 c	241.4 a	5.45 b	14.48 a	9.86 b
			No. of row / container X Vermicompost rate X In-row plant distance							
1 row	**20% V**	**20 cm**	123.5 de	5.70 bc	14.50 ab	9.83 ab	132.7 d	5.52 cd	14.57 ab	10.34 ab
		30 cm	106.6 e	5.00 c	15.50 a	9.39 bc	109.9 de	4.98 e	15.40 a	9.80 bc
		40 cm	184.9 bc	5.45 bc	14.50 ab	9.20 bc	195.3 b	5.40 d	14.43 ab	9.61 bc
	30% V	**20 cm**	118.3 de	6.05 ab	13.50 b	10.19 a	127.6 d	5.87 c	13.33 b	10.94 a
		30 cm	131.4 d	4.95 c	15.50 a	9.62 b	148.9 cd	4.77 e	15.03 ab	10.25 b
		40 cm	275.1 a	5.15 c	15.00 a	9.56 bc	300.9 a	5.11 de	14.97 ab	10.04 b
2 row	**20% V**	**20 cm**	61.6 f	5.20 c	15.00 a	8.78 c	65.5 f	5.06 de	14.83 ab	9.35 c
		30 cm	104.4 e	6.05 ab	14.00 ab	9.86 ab	98.1 e	5.77 cd	13.63 b	10.45 ab
		40 cm	196.0 b	5.85 b	14.50 ab	9.55 bc	202.7 b	5.63 cd	14.17 ab	10.11 b
	30% V	**20 cm**	97.7 e	6.60 a	12.50 b	9.98 ab	101.0 e	6.79 a	12.93 b	10.52 ab
		30 cm	160.2 c	6.10 ab	13.00 b	9.79 ab	163.0 c	6.32 b	13.10 b	10.40 ab
		40 cm	170.6 c	5.80 b	14.50 ab	9.09 c	181.9 bc	5.78 c	14.00 ab	9.67

* Similar letters indicate non-significant at 0.05 levels.
** Capital letters indicate the significant difference of each factor ($P<0.05$)
*** Small letters indicate the significant difference of interaction ($P<0.05$)

On the other hand, the interaction between vermicompost rate and in-row plant distance showed that Vermi 30 % combined with in-row plant distance40 cm illustrated the highest average No. of pods / plant and dry weight (%) while vermi 30 % combined with in-row plant distance20 cm had the highest value of average pod weight.

According to the interaction effects among No. of rows / container, vermicompost rate (%) and in-row plant distance (cm) on yield parameters of snap bean plant as presented in Table (4), 1 row / container combined with Vermi. 30 % combined with in-row plant distance40 cm recorded the highest average No. of pods / plant while the highest average pod weight presented by 2 rows / container combined with Vermi. 30 % combined with in-row plant distance 20 cm in both seasons. 1 row / container combined with Vermi. 30 % combined with in-row plant distance20 cm had the highest fiber (%) result as Table (5) presented.

Table (6) presented the effect of different No. of rows /container, vermicompost rate (%) and in-row plant distance (cm) on total yield per plant (g/plant) and per m^2 (g/m^2) of snap bean plant. Increasing the No. of rows / container led to increase the total yield per plant but decrease the total yield per m^2.

Table 6: Effect of different No. of rows/container, vermicompost rate (%) and in-row plant distance (cm) on total yield per plant (g/plant) and per m^2 (g/m^2) of snap bean plants.

Treatment			First season		Second season	
			Total yield (g/ plant)	Total yield (g /m^2)	Total yield (g/ plant)	Total yield (g /m^2)
No. of row / container						
1 row			837.5 A	3060.8 B	888.4 A	3234.6 B
2 row			779.0 B	5557.4 A	800.1 B	5702.2 A
Vermicompost rate (%)						
20% V			722.4 B	3750.0 B	728.2 B	3745.7 B
30% V			894.1 A	4868.1 A	960.4 A	5191.1 A
In-row plant distance (cm)						
20 cm			594.5 C	4448.5 A	623.2 C	4680.4 A
30 cm			695.0 B	4015.0 B	712.4 B	4071.6 B
40 cm			1135.3 A	4463.8 A	1197.1 A	4653.1 A
No. of row / container X Vermicompost rate						
1 row	20% V		747.4 b	2795.9 d	777.6 b	2905.1 d
	30% V		927.6 a	3325.7 c	999.2 a	3564.0 c
2 row	20% V		697.5 b	4704.2 b	678.7 c	4586.3 b
	30% V		860.5 a	6410.6 a	921.5 a	6818.1 a
No. of row / container X In-row plant distance						
1 row	20 cm		709.7 d	3784.9 c	737.7 c	3934.6 b
	30 cm		589.9 e	2162.9 e	628.9 d	2306.0 c
	40 cm		1213.0 a	3234.5 d	1298.7 a	3463.1 b
2 row	20 cm		479.3 f	5112.2 b	508.7 e	5426.2 a
	30 cm		800.1 c	5867.1 a	796.0 c	5837.3 a
	40 cm		1057.7 b	5693.0 a	1095.6 b	5843.1 a
Vermicompost rate X In-row plant distance						
20% V	20 cm		510.7 e	3568.5 c	530.8 e	3714.4 c
	30 cm		580.7 e	3286.4 c	556.7 e	3078.8 d
	40 cm		1076.0 b	4395.2 b	1097.1 b	4443.9 b
30% V	20 cm		678.3 d	5328.6 a	715.7 d	5646.4 a
	30 cm		809.3 c	4743.6 b	868.2 c	5064.5 ab
	40 cm		1194.7 a	4532.3 b	1297.2 a	4862.3 b
No. of row / container X Vermicompost rate X In-row plant distance						
1 row	20% V	20 cm	704.4 d	3757.0 e	730.1 c	3894.0 c
		30 cm	530.1 e	1943.8 g	547.3 d	2006.7 e
		40 cm	1007.5 c	2686.7 f	1055.4 b	2814.5 d
	30% V	20 cm	714.9 d	3812.7 e	745.4 c	3975.2 c
		30 cm	649.6 d	2381.9 fg	710.5 c	2605.2 de
		40 cm	1418.4 a	3782.3e	1541.9 a	4111.7 c
2 row	20% V	20 cm	316.9 f	3379.9 e	331.4 e	3534.9 cd
		30 cm	631.2 de	4628.9 d	566.0 d	4150.9 c
		40 cm	1144.4 b	6103.7 b	1138.7 b	6073.2 b
	30% V	20 cm	641.7 d	6844.4 a	686.0 cd	7317.5 a
		30 cm	968.9 c	7105.2 a	1026.0 b	7523.7 a
		40 cm	970.9 c	5282.2 c	1052.4 b	5613.0 b

* Similar letters indicate non-significant at 0.05 levels.
** Capital letters indicate the significant difference of each factor ($P<0.05$)
*** Small letters indicate the significant difference of interaction ($P<0.05$)

It was so obvious that the positive effect of vermicompost rate mixed with gravel substrate on snap bean yield, increasing the vermicompost rate from 20 to 30 % led to significant increase on both of total yield per plant and per m^2.

Also, increasing the in-row plant distance from 20 to 40 cm led to increase the total yield per plant while had surprise results regarding to the total yield per m^2. The in-row plant distance 20 and 40 cm recorded the highest total yield / m with no significant difference while in-row plant distance 30 cm gave the lowest record.

Referring to the interaction effect between No. of rows / container and vermicompost rate on snap bean yield, the obtained results indicated that 1 row / container combined with Vermi. 30 % had the highest total yield per plant while 2 row / container combined with Vermi 30 % gave the highest total yield per m^2.

The interaction effect between No. of rows / container and in-row plant distance on snap bean plants showed that 1 row / container combined with in-row plant distance 40 cm recorded the highest total yield per plant while the highest total yield per m^2 gave by 2 rows / container combined with in-row plant distance of 30 cm followed by 40 cm.

Vermicompost rate 30 % combined with in-row plant distance 40 cm proved the highest result of total yield / snap bean plant while the highest total yield of snap bean per m^2 recorded by vermicompost rate 30 % combined with in-row plant distance20 cm.

According to the interaction among No. of rows / container, vermicompost rate (%) and in-row plant distance (cm) on total yield of snap bean as presented in Table (6), The interaction treatment 1 row / container, Vermi. 30 % and in-row plant distance 40 cm had the highest total yield per snap bean plant while the lowest value gave by 2 row / container, Vermi. 30 % and in-row plant distance 20 cm. Otherwise, the highest total yield per m illustrated by interaction treatment 2 rows / container, Vermi. 30 % and in-row plant distance 30 cm followed by interaction treatment 2 row / container, Vermi. 30 % and in-row plant distance 20 cm with no significant difference. Moreover, the lowest total yield per m^2 presented by 1 row / container, Vermi. 20 % and in-row plant distance 40 cm.

3.3 The effect of plant density (No. of row / container and plant distance) and vermicompost rate on N, P and K contents of snap bean plants:

The lowest snap bean plant density through applied 1 row / container and in-row plant distance 40 cm compared to the other treatments led to an increment in the nutrients contents of N, P and K (%) of snap bean plant. Increasing the vermicompost rate that mixed with gravel substrate as amendment from 20 to 30 % led to increase the nutrient contents N, P and K (%) of snap bean plant as Table (7) presented.

Regarding to the interaction effect of No. of rows / container and vermicompost rate, the highest records of N, P and K (%) of snap bean plant were obtained by 1 row / container combined with Vermi. 30 % while 2 row / container combined with Vermi. 20 % gave the lowest N, P and K (%) of snap bean plant.

Moreover, the low plant density had the highest nutrient contents of snap bean plants regarding to low nutrients competition among the plants that presented in 1 row / container combined with in-row plant distance 40 cm which recorded the highest N, P and K (%) of snap bean plant while 2 rows / container combined with in-row plant distance 20 cm had the lowest contents of N, P and K (%).
The revealed results of interaction effect between vermicompost rate mixed with gravel substrate and in-row plant distance indicated that Vermi. 30 % combined with in-row plant distance 40 cm had the highest contents of N, P and K (%) of snap bean plant while the lowest recorded by Vermi. 20 % combined with in-row plant distance 20 cm.

Table (7) illustrated the effect of different No. of row/container, vermicompost rate (%) and in-row plant distance (cm) on nutrients contents N, P and K (%) of snap bean plant. The interaction effects among No. of row / container, vermicompost rate (%) and in-row plant distance (cm) on N, P and K contents of snap bean plants presented that 1 row / container, Vermi. 30 % and in-row plant distance 40 cm gave the highest values of N, P and K (%) of snap bean plant followed by 1 row / container, Vermi. 30 % and in-row plant distance 30 cm while the lowest results N, P and K (%) presented by Vermi. 20 % combined with in-row plant distance 20 cm.

Table 7: Effect of different No. of rows/container, vermicompost rate (%) and in-row plant distance (cm) on nutrients contents N, P and K (%) of snap bean plant.

Treatment			First season			Second season		
			N	P	K	N	P	K
			No. of row / container					
1 row			3.23 A	0.54 A	2.48 A	3.07 A	0.56 A	2.37 A
2 row			2.49 B	0.43 B	2.12 B	2.37 B	0.45 B	2.08 B
			Vermicompost rate (%)					
20% V			2.55 B	0.43 B	2.32 A	2.42 B	0.45 B	2.21 A
30% V			3.17 A	0.54 A	2.27 A	3.03 A	0.56 A	2.24 A
			In-row plant distance (cm)					
20 cm			2.69 C	0.45 B	2.08 C	2.55 C	0.47 B	2.01 C
30 cm			2.88 B	0.46 B	2.31 B	2.74 B	0.49 B	2.24 B
40 cm			3.00 A	0.54 A	2.50 A	2.88 A	0.55 A	2.42 A
			No. of row / container X Vermicompost rate					
1 row	**20% V**		2.85 b	0.50 b	2.53a	2.69 b	0.51 b	2.35 a
	30% V		3.60 a	0.58 a	2.43 a	3.46 a	0.61 a	2.39 a
2 row	**20% V**		2.24 d	0.37 c	2.12 b	2.14 c	0.39 c	2.07 b
	30% V		2.73 c	0.49 b	2.11 b	2.60 b	0.51 b	2.08 b
			No. of row / container X In-row plant distance					
1 row	**20 cm**		3.04 c	0.52 b	2.34 b	2.89 b	0.54 ab	2.27 b
	30 cm		3.28 b	0.52 b	2.52 ab	3.10 a	0.55 ab	2.37 ab
	40 cm		3.36 a	0.58 a	2.59 a	3.23 a	0.59 a	2.47 a
2 row	**20 cm**		2.35 f	0.38 c	1.83 d	2.20 d	0.40 c	1.75 d
	30 cm		2.48 e	0.41 c	2.10 c	2.38 c	0.43 c	2.10 c
	40 cm		2.63 d	0.50 b	2.42 b	2.54 c	0.52 b	2.38 ab
			Vermicompost rate X In-row plant distance					
20% V	**20 cm**		2.51 e	0.41 c	2.09 c	2.37 d	0.42 c	2.03 c
	30 cm		2.52 e	0.42 c	2.36 b	2.42 d	0.43 c	2.26 b
	40 cm		2.62 d	0.48 b	2.53 a	2.47 d	0.49 b	2.34 b
30% V	**20 cm**		2.88 c	0.50 b	2.08 c	2.72 c	0.52 b	1.99 c
	30 cm		3.25 b	0.51 b	2.26 b	3.07 b	0.55 b	2.21 b
	40 cm		3.38 a	0.59 a	2.48 ab	3.30 a	0.61 a	2.51 a
			No. of row / container X Vermicompost rate X In-row plant distance					
1 row	**20% V**	**20 cm**	2.82 d	0.50 bc	2.35 b	2.66 c	0.51 bc	2.29 b
		30 cm	2.82 d	0.48 c	2.61 a	2.66 c	0.49 bc	2.37 ab
		40 cm	2.92 c	0.51 bc	2.63 a	2.76 c	0.52 bc	2.37 ab
	30% V	**20 cm**	3.25 b	0.55 b	2.33 b	3.13 b	0.56 b	2.26 bc
		30 cm	3.75 a	0.55 b	2.42 b	3.54 a	0.60 ab	2.36 ab
		40 cm	3.80 a	0.65 a	2.54 ab	3.70 a	0.66 a	2.56 a
2 row	**20% V**	**20 cm**	2.20 h	0.31 d	1.83 d	2.08 d	0.32 d	1.77 d
		30 cm	2.22 h	0.35 d	2.10 c	2.17 d	0.36 d	2.15 bc
		40 cm	2.31 g	0.45 c	2.42 b	2.18 d	0.47 c	2.30 b
	30% V	**20 cm**	2.50 f	0.46 c	1.82 d	2.32 d	0.48 c	1.72 d
		30 cm	2.74 e	0.47 c	2.10 c	2.59 c	0.49 bc	2.06 c
		40 cm	2.95 c	0.54 b	2.42 b	2.90 bc	0.56 b	2.46 ab

* Similar letters indicate non-significant at 0.05 levels.
** Capital letters indicate the significant difference of each factor (P<0.05)
*** Small letters indicate the significant difference of interaction (P<0.05)

Discussion

The use of local substrate as a gravel as an alternative of imported substrate (ex: peat moss, perlite, rockwool and etc...) under the current study in substrate culture to avoid the soil problems and water shortage is a promising method to increase the yield production and reduce the infrastructure cost.

However, applied vermicompost rate as a substrate amendment to enhance the physical and chemical properties of gravel substrate had a positive impact on bulk density, water hold capacity and organic matter while decreasing total pore space and air space values. These impacts led to increase the yield production significantly and also increase the vegetative growth characteristics of snap bean. These results agreed to those of Subler *et al.,* (1998), Bachman and Metzger, (2007); Grigatti *et al*., 2007, Abul-Soud *et al*., (2014), (2015 a and b) and Abul-Soud (2015) who illustrated that the application of vermicompost in moderate amounts produces beneficial effects on plant growth due to the enhancing effect on the physical and chemical properties of substrate.

The increase of vermicompost rate from 20 to 30 % led to give the highest yield as an individual factor or combined with other factors as a normal results regarding to the high notorious impact as a rich nutrient organic fertilizers beside the positive enhancement on the physical and chemical properties. Also, the application of vermicompost led to increase the available macro and micro nutrients that led to increase the plant nutrient contents (mainly N, P and K) (Abul-Soud 2015 and Abul-Soud and mency 2015).

Previous investigation of Arancon *et al.,* (2002), Arancon *et al*., (2004) AboSedera *et al.,* (2015), Abul-Soud *et al*., (2014), (2015 a and b) Abul-Soud (2015) Abul-Soud *et al*., (2017) and Sayed *et al*., (2017) were investigated the positive impacts of applied vermicompost as a substrate amendment on different vegetable crops (strawberry, tomato, peas, sweet paper, snap bean, lettuce, strawberry, celery, salad cabbage and red cabbage). The vermicompost contained an essential nutrients for supporting the plant nutrient requirements beside the high organic matter and assist in improve the physical and chemical properties of substrates. Bachman and Metzger (2008), Abul-Soud (2015) and Abosedera *et al.,* 2015 mentioned that the addition of vermicompost in media mixes of 10% VC and 20% VC had positive effects on plant growth and yield of many vegetable crops. These results agreed with that recommended for vermicompost application for encouraging plant growth and quality through increasing the available forms of nutrients (nitrates, exchangeable P, K, Ca and Mg) for plant uptake of strawberry (Arancon *et al.,* 2004). Vermicompost contained a large amounts of humic substances which release nutrients relatively slowly in the soil that improve its physical and biological properties of soil and in turn rise to much better plant quality (Muscolo *et al.,* 1999). The use of different organic and inorganic substrates allows the plants to have better nutrient uptake, sufficient growth and development to optimize water and oxygen holding (Albaho *et al.,* 2009).

Moreover, referring to the plant density effect through No. of rows / container and in-row plant distance, a significant effect on vegetative growth characteristics, yield properties and N, P and K contents of snap bean plant were occurred. Decreasing the No. of rows / container from 2 to 1 and increasing the in-row plant distance from 20 to 40 cm which resulted in the lowest plant density (2.5 plant /m) led to increase the vegetative growth characteristics, yield properties and N, P and K contents of snap bean plant but decrease the total yield /m.

On the contrary, the moderate plant density that presented as 2 rows / container x in row plant distance 30 cm (6.6 plants / m) had the highest total yield of snap bean / m. these results could be explained as a result of offering better ventilation among the plants, more space for root growth and less competition on water, nutrients and light compared to 2 row / container x in row plant distance 20 cm (10 plants / m) while the increase of total yield per plant for the lowest density 1 row / container x in row plant distance 40 cm (2.5 plants / m) didn't superior on the increase of the plant density. These results matched the findings of Khairy (2013) who presented that lowering plant density led to reduce the competition between plants on water, nutrients and increases the uptake of macro nutrients by plants. The obtained results of plant density are in line with Motsenbocker (1996), Papadopoulos & Pararajasingham (1997), Charlo *et al.,* (2007), Santos *et al.,* (2010) who found that increasing the plant space resulted higher yield per plant but lowered productivity per unit area while the opposite is right. They concluded that the higher yields were due to less overlapping and shading of leaves, better light penetration to the basal leaves, less competition for light, water and nutrients, and higher and more efficient CO_2 fixation.

Conclusion

The current research provided an evidence on how to improve the physical and chemical properties of gravel as a local, available and non-expensive substrate material by using vermicompost as a substrate amendment under Egyptian condition. Also, the study gave a good indicator for increasing the food production by using substrate culture. Otherwise, the optimum plant density for optimum potential yield of snap bean depending on the production target (quality or quantity). The recommended results indicated that implementing plant density of 6.6 snap bean plants /m^2 through the interaction treatment 2 row / container, Vermi. 30 % and in-row plant distance 30 cm gave the highest total yield per snap bean plant under greenhouse and enhance the vegetative growth and N, P

and K contents of snap bean plants. More studies need to investigate the economic factor beside the use of close system of substrate culture to maximize the water and nutrient use efficiency.
The study supported the sustainable production of snap bean under greenhouse condition in gravel substrate culture. The promotion of substrate culture and vermicomposting technique under the soil and water shortages and climate change condition can help food security to increase the vegetable production and mitigating greenhouse gases (GHG's) emission.

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Competing Interests

Authors have declared that no competing interests exist.

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