

Full Length Research Paper

Testing vertical distance and growth medium for vertically farming bush beans (*Phaseolus vulgaris* L.) and tomatoes (*Solanum lycopersicum* L.) in urban agriculture

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Vertical farming implies growing crops in superimposed growth beds. This study assessed the effects of vertical distance between growth beds and growth medium on beans and tomatoes. Three levels of vertical spacing and three levels of growth medium were studied in a split plot design and three replicates. The vertical distance was tested in main plots while the growth medium was tested in subplots. The main plot was a wood-made vertical structure with the ground growth bed and the top bed vertically separated by either 80, 120 or 160 cm. The subplot was a bottom-holed plastic bucket containing a thorough growth mix of loam soil and 0, 40, or 60% added manure (volume/volume). Three buckets were used per growth medium and growth bed, making 6 observations for each factorial combination. Tomato was cropped after bush bean harvest. Maximum bean grain yields were projected for 130 cm vertically spaced beds and for 30% added manure growth medium. Maximum tomato fruit yields should be expected for growth medium containing more than 60% manure and for spacing distance above 160 cm. Vertical farming appeared highly productive with 0.86 kg m⁻² of total dry bean grain yield and 14.1 kg m⁻² of total tomato fruits from the two beds.

Key words: Vertical farming, vertical spacing distance, growth beds, growth medium, tomatoes, bush beans.

INTRODUCTION

Urban agriculture is a new concept of agriculture that implies producing food in urban and peri-urban areas

where the land has already been transformed into human settlements (Tornaghi, 2014). The practice balances a bit

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the reduction of the arable land while minimizing the distance from food production areas to consumers (Al-Kodmany, 2018; Molin and Martin, 2018; Birachi et al., 2011). Urban agriculture simply relates to the production of plants- and animal-related food within urban dwellings through home gardening or specifically designated zones for vegetable production (Tornaghi, 2014; Zezza and Tasciotti, 2010).

Within urban agriculture, vertical farming is the practice of vertically expanding the productive space above the ground surface (Vyas, 2018; Despommier, 2009) with the view to producing more food or medicine. Vertical farming can also be practiced on simple wood or metallic poles (pole farming) or constructed growth beds and sacks (Vyas, 2018; Peprah et al., 2014). As urban population grows and arable land declines, vertical farming can locally provide an interesting approach for sustainably growing fresh produces for the family and the community (Kalantari et al., 2017; Banerjee and Adenaeuer, 2014). However, the profitability of the technology is still debated although recent research findings validate its viability (Eaves and Eaves, 2018; Shao et al., 2016).

With the development of vertical farming technology, the range of crops that can be grown also expands (Cornia, 2014). Bush beans is the most commonly consumed legume while tomato is the most commonly consumed vegetable in many urban and rural areas of the African Great Lakes Region (Larochelle et al., 2014; Sonko et al., 2005). For instance, the annual consumption of beans is around 29 and 11 kg per capita in Rwanda and Uganda, respectively (SPIA, 2014). Tomatoes represent up to 28.4% of total volume of sales of horticultural produces in Rwanda (Clay et al., 2014). Bush beans are a major source of proteins while both bush beans and tomatoes supply vitamins and minerals such as iron and zinc (Takusewanya et al., 2017; Bizimana et al., 2013).

Home gardening of vegetables in small land plots or in containers has been promoted in the African Great Lakes Region notably for tomatoes, onions, and cabbages. In countries like Rwanda, home gardening is known as “kitchen gardening” and it is mainly promoted in rural areas as part of a national strategy to improve human nutrition. However, home gardening of beans is quite inexistent although the crop easily grows and the market of greens and grains is huge. Moreover, given the land scarcity and long distances from the production areas, backyards of urban residences could contribute fresh beans to urban consumers. However, very little is known about the productivity of both bush beans and tomatoes in a sunlight-dependent vertical farming technology. In addition, the appropriate growth medium based on locally available growth medium has not yet been documented for such a system. Therefore, this study aimed at testing the productivity of bush beans and tomatoes in a two-level vertical farming structure using growth medium made of mixes of locally available loam

soil and cow manure.

MATERIALS AND METHODS

Experimental site

The study was conducted on the main Campus of the University of Kibungo, at Karenghe (Kibungo town), southeastern Rwanda, at 1646 m above sea level, -2.149672° South, and 30.546533° East. The region is under tropical conditions with averages of 20°C of annual temperature and 1200 mm of rain precipitation. The climate follows a bimodal pattern with heavy rain precipitations extending from March to May and from October to December, alternating with two dry seasons.

Factorial treatments

Treatments composed of two factors: Vertical spacing and growth medium. Vertical spacing characterized the distance separating two growth beds or growth platforms, one on the ground level and the second at a variable distance above the ground. Three distances/levels of vertical spacing were studied: 80 cm (VS080), 120 cm (VS120), and 160 cm (VS160) between the two growth beds. Growth medium represented the second factor with three levels: a 0% dairy cow manure + 100% loam soil (GM00), a mix of 40% dairy cow manure + 60% loam soil (GM40), and a mix of 60% dairy cow manure + 40% loam soil (GM60). These mixes were made volume by volume. Therefore, 9 factorial combinations of the two treatments were generated for the study.

Experimental design

White plastic buckets (12-L), 25 cm mouth width, 27 cm depth, and 17 cm bottom width, were individually filled with thoroughly mixed growth medium to 2 cm below the top. Three buckets were used for each level of growth medium and for each growth bed (ground and top beds) by vertical spacing level. Each bucket was bottom-perforated to drain excess water.

A wood-made structure was built such that top growth beds are located at either 80, 120, or 160 cm distances above ground (Figure 1). Each individual structure was 1 m × 1 m framed so as to contain only nine (9) buckets by growth bed or 18 plants over the two superposed beds. An iron sheet beneath each top platform diverted the drainage water out of the ground bed.

A split plot design and three replicates were used for this study. The vertical spacing factor was randomly distributed in the main plots (wood structures) while the growth medium was randomly tested in the subplots (on the growth beds).

Agronomy

Bush beans

Two grains of RWA2245 bush bean variety were seeded in each bottom-holed bucket on 14 July, 2014 and watered throughout the dry season to maturity. A compound fertilizer (200 g of 17-17-17) was mixed with each growth substratum level before planting. This was equivalent to banding 400 kg 17-17-17 ha⁻¹ in the soil having 1.4 kg dm⁻³ specific gravity.

Tomatoes

After bush beans, containers were emptied and the growth medium



Figure 1. Wood-made experimental structures with growth beds and sprouting beans emerging from containers.

re-worked by level to make it suitable for receiving tomato seeds. Additional 200 g of 17-17-17 were incorporated. Four grains of Better Boy tomato variety were seeded by container on December 16th 2014 and later thinned to the best two plantlets. Watering was done throughout the January - February dry season to the rainy season.

Recommended plant spacing was controlled by adjusting the distance between containers. In addition, weeding was done manually by picking and removing undesired plant species from containers. A mosquito net wrapped the site up to protect sprouting plants, particularly bush beans, against birds and insects. Dithan M-45 fungicide was applied a few times on tomatoes during the rainy season in late February 2015.

Data collection

Bush beans growth was monitored 14, 21, 28, and 35 days after planting by measuring each plant length. Plant diameter was measured at 2 cm above ground 45 days after planting. Flower counts and maturity pods were monitored 45 and 60 days after planting, respectively. Bean grain yield and biomass were monitored at harvest time. The grains and biomass were dried under atmospheric conditions until constant weight.

Tomato growth was monitored 40 and 55 days after planting by measuring the length of the plants. Collar shoot diameter was monitored 55 days after planting and fruits set monitored 60 and 75 days after planting. Harvesting of mature fruits was done three times, at 90, 97, and 104 days after planting. All the parameters were collected from every container. Few containers had missing data because of various damages due to birds and insects for beans and diseases for tomatoes.

Statistical analyses

The effects of treatments on monitored parameters were analyzed using the analysis of variance (ANOVA) with multiple observations in three different but complementary tests:

i) Tests on the effects of treatments considering the data from the

two growth beds as continuous sets of observations; consequently, six observations were tested for each factorial combination; ii) Tests on the effects of treatments using the sums of values of parameters from the two growth beds; consequently, three observations were tested by factorial combination; iii) Comparison of the performance of the two growth beds by running separate T-tests with paired observations for specific parameters such as flowers and pods counts or tomato fruits, bean grain yield and biomass.

Adjustments for missing data were made based on Steel and Torrie (1980). All of the statistical analyses were performed using NCSS Computer Package, 2004 version (Hintze, 2004). Bartlett's Chi Square tests were run on all the data, and when the homogeneity of variances was not valid, ANOVA was performed on log-transformed data. Duncan multiple range test was performed for multiple means comparison. A 5% probability level was set for the significance of tests.

RESULTS

Effects of vertical spacing on yields and yield components of bush beans and tomatoes

The vertical spacing effects on the yields and yield components of the bush beans and tomatoes are presented in Table 1. These results are mean values of continuous sets of 6 observations monitored from the two growth beds. Repeated measures ANOVA with multiple observations detected no significant differences between vertical spacing distances with regard to the growth rates for each crop. In addition, no differences were detected with regard to the bush beans stem diameter, flowers counts, pod counts, and total aerial biomass. The same was true for the basal diameter of tomato shoots. However, significant differences ($P \leq 0.05$) between the

Table 1. Effects of vertical spacing distance of growth beds on yield and yield components of bush beans and tomatoes

Crop type	Monitored parameter	Vertical spacing distance		
		VS80	VS120	VS160
Bush beans	Plant growth rate (cm)	23.0 ^a	20.7 ^a	22.9 ^a
	Stem diameter (mm)	5.8 ^a	6.0 ^a	6.2 ^a
	Flowers counts /plant	13.0 ^a	12.0 ^a	11.9 ^a
	Maturity pods /plant	8.9 ^a	8.8 ^a	8.1 ^a
	Aerial biomass (g /m ²)	680 ^a	750 ^a	750 ^a
	Grain yields (g /m ²)	370 ^a	480 ^b	440 ^{ab}
Tomatoes	Growth rate (cm)	30.3 ^a	32.0 ^a	32.6 ^a
	Stem diameter (mm)	3.70 ^a	3.94 ^a	4.10 ^a
	Fruit counts by plant	6.0 ^a	6.8 ^a	8.2 ^b
	Fruit yields (g /plant)	274.0 ^a	418.8 ^b	468.0 ^c

Numbers sufficed with different letters in same rows are significantly different.

Table 2. Effects of the growth medium on yields and yield components of bush beans and tomatoes.

Crop type	Monitored parameter	Growth medium type		
		GM00	GM40	GM60
Bush beans	Plant growth rate (cm)	21.4 ^a	21.1 ^a	24.2 ^b
	Stem diameter (mm)	5.8 ^a	6.2 ^a	6.1 ^a
	Flowers counts /plant	11.4 ^a	12.9 ^b	11.6 ^a
	Maturity pods /plant	8.6 ^a	9.0 ^a	8.1 ^a
	Aerial biomass (g /m ²)	650 ^a	800 ^b	720 ^a
	Grain yields (g /m ²)	410 ^a	480 ^a	400 ^a
Tomatoes	Growth rate (cm)	29.9 ^a	32.2 ^{ab}	32.9 ^b
	Stem diameter (mm)	3.67 ^a	3.93 ^{ab}	4.13 ^b
	Fruit counts by plant	5.7 ^a	7.4 ^b	7.8 ^b
	Fruit yields (g /plant)	272.1 ^a	413.5 ^b	475.0 ^c

Numbers sufficed with different letters in same rows are significantly different.

three levels of vertical spacing existed for the bush bean grain yields and tomato fruit counts and yields. In that respect, VS120 yielded higher quantity of grains (480 g/m²) than any other spacing distance, whether significantly or in actual value.

For tomatoes, VS160 significantly generated higher fruit counts (8.2 fruits/plant) and fruit yields (468g/plant) than lower spacing distances.

Effects of growth medium on yields and yield components of bush beans and tomatoes

The results on the growth medium effects were given in Table 2 for both bush beans and tomatoes. With regard to bush beans, significant differences between the three types of growth substratum were found in relation to the plant growth ($P < 0.05$).

Very significant differences also existed with regard to

flower counts per plant ($P < 0.001$) and total biomass ($P < 0.001$) per m² of land cropped to bush beans. However, no statistical differences were found between GM00, GM40, and GM60 with regard to basal shoot diameter, maturity pod counts by bush bean plant, and grain yields. GM40 resulted in higher number of flowers and aerial biomass weight than the two other levels. In addition, with regard to bean grain yields, although statistically insignificant, GM40 yielded 70 and 80 g higher than GM00 and GM60, respectively. Such yield differences were not negligible since they were significant at 6.8% probability level.

For tomatoes, significant differences between GM00, GM40, and GM60 were found for plant growth ($P \leq 0.05$), stem diameter ($P \leq 0.05$), fruit counts ($P \leq 0.01$), and fruit yields ($P \leq 0.01$). Again, GM40 resulted in equal or higher tomato stem diameter and fruit counts than GM60. This latter, however achieved significantly higher tomato fruit yields with 475 g/plant than the former with 413.5 g/plant.

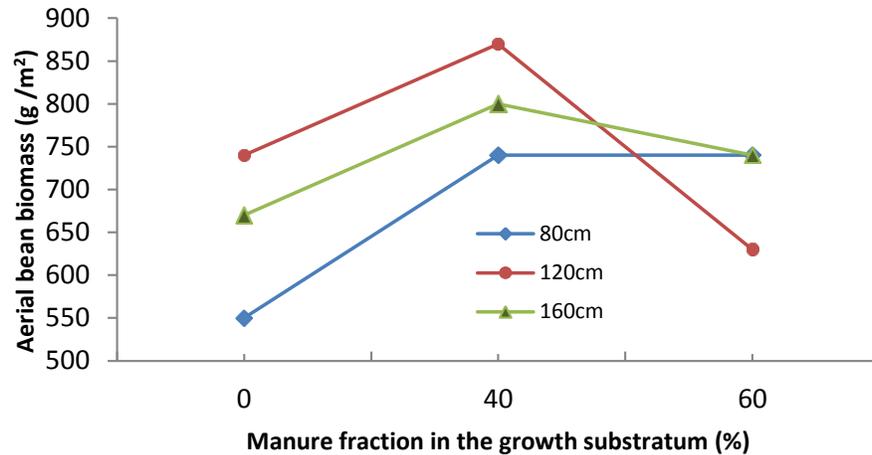


Figure 2. Interaction effects of added-manure growth medium and vertical spacing distance on the aerial biomass of bush beans.

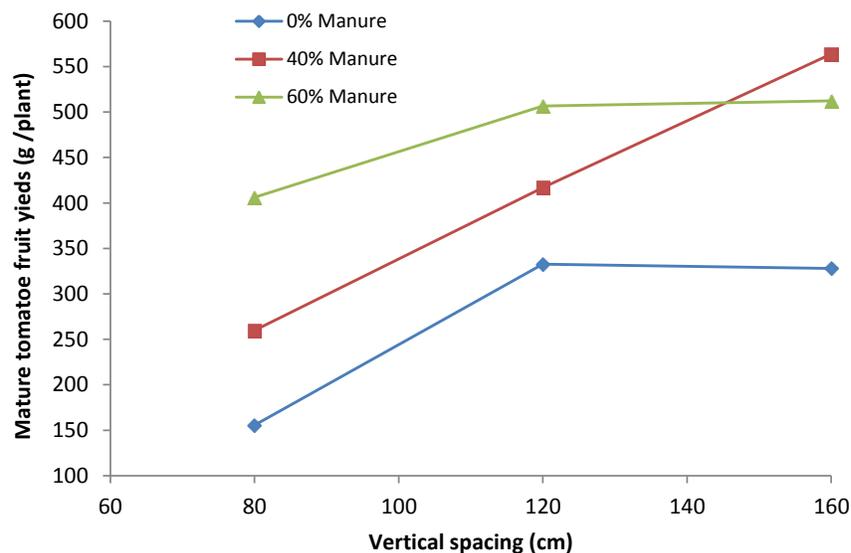


Figure 3. Interaction effects of vertical spacing and growth medium on tomatoe fruit yields.

Also, significant interaction effects ($P < 0.05$) between the growth rate monitoring time and the growth medium were observed for bush beans. The plant grew longer under GM60, reaching 45.1 cm after 35 days while the plant length under GM00 and GM40 were 6.8 cm and 5.9 lower at the same period, respectively.

Interaction effects of vertical spacing and growth medium on yields and yield components of bush beans and tomatoes

Significant interaction effects ($P \leq 0.05$) between the two factors were only observed for the aerial bush bean biomass and tomato fruit yields. Maximum bush beans

biomass (846 g/m^2) was produced when GM40 was combined with VS120 (Figure 2).

For tomatoes (Figure 3), combining GM40 and VS160 or GM60 and VS160 statistically produced equal fruit yields of 564 g/plant and 522 g/plant for the first and second combinations, respectively. However, tomato plants did not achieve their maximum potential under these interactions, thus pointing to different combinations that might be more suitable for full production potential of tomato plants.

Yield comparisons from the two growth beds

The analysis results using T-tests with paired

Table 3. Comparisons of yields and yield components of Bush Beans and Tomatoes from the ground and top growth beds.

Monitored parameter	Bush bean		Tomatoes	
	Ground bed	Top bed	Ground bed	Top bed
Plant height (cm)	23.7 ^a	20.7 ^b	33.0 ^a	30.4 ^b
Basal stem diameter (mm)	5.5 ^a	6.5 ^b	3.40 ^a	4.42 ^b
Flowers' counts by plant	9.0 ^a	14.9 ^b	N/A	N/A
Pods /Fruits' counts by plant	6.9 ^a	10.2 ^b	3.2 ^a	10.8 ^b
Aerial biomass (g/m ²)	610 ^a	840 ^b	N/A	N/A
Bean grains (g/m ²)	310 ^a	550 ^b	-	-
Tomato fruits (g/plant)	-	-	207.0 ^a	568.3 ^b

Numbers sufficed with different letters in same rows by crop species are significantly different. N/A means "not available".



Figure 4. Delayed maturity of bush beans on ground bed as compared to maturity of beans on top growth bed.

observations for all the parameters are presented in Table 3. All the mean values were very significantly ($P \leq 0.001$) higher on the top growth bed than on the ground bed for the two plant species and for all monitored parameters, except the plant growth. Bush bean biomass and grain yields were 27.4 and 43.6% lower on ground bed than on top bed, respectively, while a drastic 73.6% tomato fruit yield reduction was noted on the ground bed as compared to the yield on the top bed.

Otherwise, bush bean plants grew longer on the ground bed than on the top bed. This was also true for tomatoes. Moreover, not only the numbers of bush bean flowers and pods were higher on top bed, but also the maturity of pods and ripening of tomatoes were faster. A visual example is given for beans in Figure 4.

Effects of treatments on total yields and yield components of bush beans and tomatoes

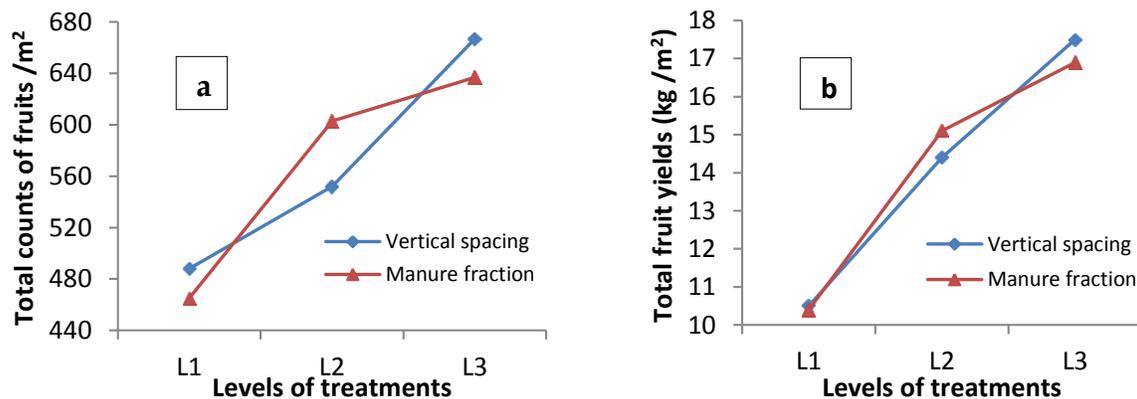
The interest of multi-level growth beds lie in their multiplicative potential of yields on the same land area unit. In this respect, in Table 4 are presented the results on sums of flower counts, pod counts, biomass yields, and grain yields of bush beans. The vertical spacing factor only significantly impacted on total bush bean grain yields ($P \leq 0.05$) with VS120 and VS160 equally yielding, and yielding higher than VS80.

For the growth medium factor, significant differences only noticed for the bush bean flower counts ($P \leq 0.01$) and grain yields ($P \leq 0.05$) indicated that GM40 yielded higher than any other growth medium level.

Table 4. Multiplicative effects of a two-level growth beds on yields and yield components of bush beans as influenced by the treatments

Factorial treatments	Vertical spacing (cm)			Growth medium manure content (%)		
Measured parameter	80	120	160	0	40	60
Flower counts /m ²	534 ^a	451 ^a	484 ^a	472 ^a	525 ^b	484 ^a
Pod counts/m ²	342 ^a	318 ^a	331 ^a	328 ^a	342 ^a	320 ^a
Biomass (kg/m ²)	1.35 ^a	1.49 ^a	1.49 ^a	1.30 ^a	1.60 ^a	1.43 ^a
Grain yields (kg/m ²)	0.74 ^a	0.95 ^b	0.88 ^b	0.81 ^a	0.96 ^b	0.80 ^a

Numbers sufficed with different letters in same row are significantly different.



Figures 5. Total fruit counts (a) and fruit yields (b) of tomatoes as influenced by the two factors (L₁, L₂, and L₃ respectively stand for 80 cm, 120 cm, and 160 cm for vertical spacing or 0, 40, and 60% for manure content in the growth medium).

Regarding tomatoes, the vertical spacing factor did not significantly affect the sums of counts and yields of tomato fruits. However, the actual values of total fruit counts linearly stretched out from 488 counts m⁻² for VS80, through 552 counts m⁻² for VS120 to 667 fruit counts for VS160 per land square meter (Figure 5a). In the same order, the actual values of total fruit yields varied from 10.5 kg m⁻², through 14.4 kg m⁻² out to 17.5 kg m⁻² of land area (Figure 5b) for VS80, VS120, and VS160, respectively.

On the contrary, very significant differences were found between the three added-manure levels of the growth medium for each of total fruit counts and fruit yields. These differences were reflected in significantly linear effects visualizable in Figure 5a for fruit counts ($P \leq 0.01$) and Figure 5b for fruit yields ($P \leq 0.001$). GM40 and GM60 produced equal numbers of fruits, which were 29.5 and 36.9% higher than GM00, respectively. With regard to fruit yields, all the three levels of the growth medium were different from one another, yielding 10.4², 14.4, and 17.5 kg m⁻² for GM00, GM40, and GM60, respectively.

The regression equations developed from statistically significant key results as related to bush beans and tomato fruit yields revealed that maximum values of each

factor generating maximum yields were computed and the results presented.

For bush bean grain yield (Table 4):

$$Y_{VS} = -9e^{-5}X^2 + 0.0228X - 0.52$$

with $R^2 = 1$; Y_{VS} variable is the grain yield while X variable is the vertical spacing distance of growth beds; a calculated distance of 127 cm provides for the maximum grain yield.

$$Y_{GM} = -0.0002X^2 + 0.0116X + 0.81$$

with $R^2 = 1$; Y_{GM} variable is the grain yield while X variable is the added manure fraction in the growth medium; a calculated 29% rate of manure in the growth medium provides for the maximum grain yield.

For tomato fruit yields (Figure 5b).

$$Y_{VS} = 0.087X + 3.6333$$

with $R^2 = 0.9957$; Y_{VS} is the tomato fruit yield while X is the vertical spacing factor. No maximum yield could be achieved within the studied interval of the vertical spacing

factor.

$$Y_{GM} = 0.1096X + 10.479$$

with $R^2 = 0.9962$, no maximum yield can be achieved within the studied interval of the growth medium factor. However, a maximum number of fruit counts could be projected for a growth medium containing 80% added manure.

DISCUSSION

Vertical spacing factor

Under natural conditions of vertical farming, the vertical spacing effect is directly linked to how much of sunlight energy reaches the lower growth beds. In fact, the plant growth and productivity is highly determined by the radiation absorption, the photosynthetic efficiency and the respiration efficiency (Bugbee, 1995). In this study, any significant effect of the vertical spacing factor must have impacted on these three components for each crop growing on the lower bed. The impact of sunlight efficiency was effective with regard to bush beans grain yields as well as tomatoes fruit counts and yields (Table 1). Bush bean grains and tomato fruit counts and yields were lowest under VS80 while VS160 yielded highest tomato fruits counts and yields. The impact of sunlight efficiency was much more obvious when the two growth beds were compared with regard to the yields and yield components (Table 3). Significantly highest values were systematically monitored on top beds for all of the measured parameters except the plant growth rate. Such differences resulted from the difference in daily light integral received by plants growing on the two superimposed beds (Morgan, 2013; Dorais, 2003). The higher growth of plants on the ground beds implies the insufficiency of sunlight and their elongation is an attempt to expose to as much energy as possible. Overall, the yield reductions of 43.6% for bean grains and 73.6% of tomato fruits were tangible evidence of reduced radiations on ground beds in comparison to top beds. Also, when yields from the two beds were summed up for each parameter and total values were analyzed with regard to the vertical spacing factor (Table 4), VS120 and VS160 significantly yielded 28.4 and 18.9% bean grains higher than VS080, respectively. The bush bean maximum grain yield could be achieved with a projected vertical spacing of 127 cm (\cong 130 cm) distance between the two beds.

For tomatoes, the maximum levels of fruit counts and fruit yields could not be achieved within set boundaries of vertical spacing (Figure 5). The optimum spacing distance for optimum fruit counts and yields fall beyond the interval of this study. This implies that a higher spacing distance was needed to achieve maximum

production potential of tomatoes in such a vertical farming system. In fact, previous findings indicated that tomato was a more light-demanding plant than bush beans (Morgan, 2013; Papadopoulos, 1991). However, both bush beans and tomatoes exerted an exceptionally high productivity with yield averages of 0.86 kg/m² of dry bean grains and 14.1 kg/m² of tomato fruits for the potential of these crops in the region. Of course, this high productivity allows for increased food availability (Drost and Wytsalucy, 2014) while fostering the protection of the environment by reducing the need for more agricultural land (Edgerton, 2009). In addition, this vertical farming technology allowed for a sequenced period of crop maturity with plants on the top bed maturing earlier than plants on the ground bed (Figure 4), thus making fresh food available for a longer period of time. The increase of both of plant productivity and food availability is what the major interest of vertical farming technology is all about.

Growth medium factor

The manure fraction in the growth medium plays a physical role through improved water holding capacity, aggregate stability, and drainage potential (Nalivata et al., 2017). It also plays a chemical role as a plant nutrient source (Sankaranarayanan and Karemangingo, 2012). In this study, the impact of the growth medium was dependent on monitored parameters and the plant species (Tables 2 and 4). In general, the impact was almost none on bush beans for most of the parameters although GM40 statistically or actually produced the highest values for flower counts, maturity pods, aerial biomass, and grain yields. Moreover, total yields of bush beans were statistically higher under GM40 than under any other level (Table 4). The GM40 treatment might have offered the best growing conditions to bean plants in terms of drainage conditions and adequate nutrient supply through mineralization. Bush beans thrive better in well drained soils (Worku, 2015) such as sandy loams and sandy clay loams (Liebenberg, 2002). The maximum yields of bean grains could be achieved with a projected growth medium containing 30% manure (the calculated rate was 29%).

As regards tomatoes, GM60 resulted in the highest impact, statistically or in actual values for all the parameters (Table 2). The same is true when the factor's levels were compared with regard to total counts of tomato fruits (Figure 5a) and total fruit yields (Figure 5b) from the two beds. Tomato plants prefer growth media containing high rates of organic materials as supported by several studies (Atif et al., 2016; Lin et al., 2015; Nabi et al., 2002). The actual GM60 did not allow for achieving the maximum productivity of tomatoes. It is however close to the 3:1 ratio of organic materials and soil mix recommended by Lin et al. (2015) and the 2:1 best growth medium mixes reported by Atif et al. (2016) and

Gama et al. (2015) for growing tomatoes in containers. In the present study, a projected growth medium containing 80% manure could have achieved maximum tomato fruit counts only.

Interaction effects of vertical spacing and growth medium

On bush beans, the maximum grain yield is achieved when GM40 is combined with any level of the vertical spacing factor. In particular, GM40 and VS120 interacted to significantly produce highest yields than any other factorial combinations (Figure 2). On tomatoes, the fruit yield from GM40 constantly increased under increasing VS factor and no maximum yield could be obtained within the range of the study for the VS factor (Figure 3). Therefore, based on the above discussion on the main effects of the two factors, vertically farming bush beans and tomatoes in built structures shall require specific growth media and specific vertical spacing distances of the growth beds.

Conclusion

This study aimed at determining the productivity of bush beans and tomatoes in a constructed two-level vertical farming structure. Two factors comprising vertical spacing distance of growth beds and growth medium were tested in a split plot design and three replicates. Three levels of vertical distance, namely VS80, VS120, and VS160 were tested in the main plots while three levels of growth medium, namely GM00, GM40, and GM60 were tested in subplots. Monitored parameters included plant growth rate, stem diameter, flower counts, bean pods and tomato fruit counts, bean above-ground biomass, bean grain yields, and tomato fruit yields.

Key findings indicated that both bush beans and tomato yields were reduced on ground beds when compared to top bed yields. When the data from the two beds were considered as same sets of observations, the productivity response of the two crops were variable: Bush beans significantly yielded highest grains (480 g/m²) under VS120 while tomatoes significantly yielded highest fruits (468 g/plant) under VS160. Also, bush beans grew better in GM40 while tomatoes did not achieve their potential even in GM60. When the sums of data collected from the two beds were considered, VS120 and GM40 generated the highest bean grain yields in the amounts 0.95 and 0.96 g/m², respectively. For tomatoes, the higher the level of each factor, the higher the fruit counts and fruit yields in actual values or statistically. The actual values of total fruit yields varied from 10.5 kg m⁻², through 14.4 kg m⁻² out to 17.5 kg m⁻² of land area unit. The high productivity of the vertical farming technology is clearly demonstrated by the above yields of the two crops (as

weight/land area unit).

Yield projections based on the regression equations of yields on each factor indicated that bush bean maximum total yield would be achieved in a 30%-added manure growth medium while tomato plants might require up to 80%-added manure growth medium. For vertical spacing, projections for maximum bean yields could be achieved with 130 cm distance between the two superimposed growth beds. Tomatoes would possibly achieve their maximum production potential for a vertical spacing distance higher than the upper boundary of the present study for the factor.

Overall, vertical farming technology represents an opportunity for urban cities to significantly contribute to national food security. However, how the high productivity of the technology would compensate for the investment effort required to get it established is still lacking for the region.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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