8.3: Research Track

IMPROVING THE PRODUCTION OF URBAN FARMS

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Abstract

Urban farms present an opportunity for cities and municipalities to feed their residents while at the same time reducing emissions and environmental impacts from farming, transporting produce, and processing produce for commercial usage. However, one major setback for urban farms, primarily when operating on a rooftop, is the lack of space for farming. According to NPR (2016), "nearly 60% of all urban farms are less than 5 acres". Thus, while the benefit of growing food closer to home is apparent, most cities and municipalities opt not to invest in creating and operating urban farms due to the initial cost and capacity limits. This study attempts to increase the production of urban farms, whether on rooftops or on the ground, using the same amount of space or less compared to traditional ground-level farming. The methods of farming were analyzed over a few months. The results show that various forms of farming, such as vertical and terrace farming, can help increase production, food variety, and land efficiency and reduce water consumption. These results highlight that by implementing these methods, urban farms can be more profitable and thus more likely to be incorporated into city and zoning planning.

Key Words: green roof, urban farms, waste, stormwater, community

Introduction

A rooftop farm on Staten Island in New York City was recently opened in April 2022. An article on the website Living Architecture Monitor described the rooftop farm as an approximately 32,000-square-foot roof planted with perennial wildflowers and organic vegetables, which helped to absorb the approximate yearly 3.5 million gallons of rain instead of onto an impermeable roof (NYC.org, 2022).The roof, located at Lois and Richard Nicotra's Corporate Commons Three on South Avenue, includes 23,375 square feet of green roof and 9,500 square feet of vegetated walkway designed by Brooklyn Grange, a business that builds rooftop farms (Liotta 2022). The produce harvested from the farm will be donated to the Commons Cafe and Pienza Brick Oven Pizza, while the remainder will be donated to a local food pantry.

To visualize how many people benefit from this rooftop farm, 4,000 square feet of land is needed to feed one person on a vegetarian diet for a year (Trevor 2014). Potentially, the rooftop farm can feed approximately six people for an entire year on this diet. With a construction cost of $670,000, the rooftop is about $21.00 per square foot. In comparison, the average farm real estate in New York state is approximately $0.08 per square (Cornell Extension 2021). While the benefits of constructing this green roof are clear, its lack of space and the expensive initial cost means it can only do so much to feed the population and reduce emissions.

Research Question: How can yield from urban farm be increased with different spacing considerations?

Methodology

Different methods were analyzed to increase production and increase the economic value of urban farms. Of the various methods, three were selected for further analysis.

Tier Farming

This method implies a simple notion of a right triangle: The hypotenuse side of a triangle will always be longer than either side of a right triangle. This notion clearly shows the benefit of growing crops at an angle (Figure 1). Plants with a 15 cm (6 in.) spacing requirement could potentially be increased by 45% by planting plants at a slope of 1H:1V. Likewise, plants with 7.5 cm (3 in.), 20 cm (8 in.), and 30 cm (12 in.) were increased by 43%, 47%, and 50% respectively when sloped at a slope of 1H:1V.

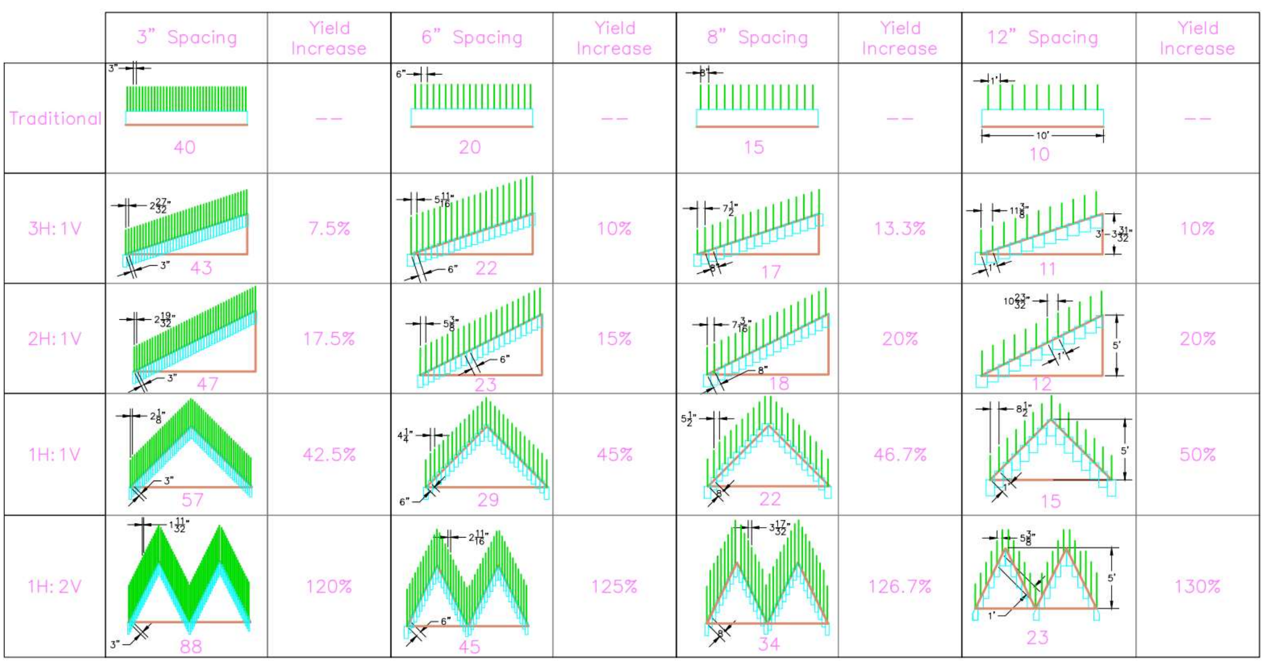

Figure 1: Yield increase chart for tier farming based on slope and spacing requirements.

Terrace Farming

Like tier farming, terrace farming uses the slope to allow plants to grow in otherwise unsuitable conditions. Popular in Eastern Asia, terrace farming uses a series of flat platforms to allow crops, such as rice, to grow in any terrain. This method also conserves both soil and water by nearly 50% (Deng et al., 2022). This is possible due to the water from one platform being transmitted to the next platform below, saving countless nutrients to be used by other plants.

Vertical Farming

Vertical farming was considered due to the reduced horizontal spacing requirement for plants and the potential for water collection. According to Ling and Atland (2021), by stacking rows on top of each other, "10 to 20 times the yield can be obtained per acre in vertical farming compared to open-field crops".

Experimental Design

An experiment was conducted outdoors in a residential backyard in the city of Warner Robins, Georgia. The climate is described as humid subtropical. Four plots were erected in 61 cm by 91 cm (2 ft. by 3 ft.) plots and are characterized based on the method used: traditional, tier, terrace, and vertical. Each plot had the same type of soil. Two plant species, corn and tomatoes, were analyzed in all methods while peppers and okra plants were analyzed in tier, terrace, and vertical plots. The corn and tomato plants were analyzed to show change in yield production in all methods, while the peppers and okra plants were inserted to demonstrate the increased change in diversity.

The traditional method used only fill soil and 10 cm by 10 cm (4 in. by 4 in.) wood beams. This plot was able to support only ten corn plants in two rows and one row of two tomato plants spaced 15 cm (6 in.) and 61 cm (2 ft.) apart, respectively. The tier method used 2.5 cm by 5 cm (1 in. by 2 in.) wooden poles and erected at a slope of 1H:2V (Figure 2). Plastic pots were used for corn, tomatoes, and peppers. This plot can support five pepper plants, seventeen corn plants, and four tomato plants.

Six of the corn plants were grown in plastic drinking bottles that would otherwise be recycled or thrown away. The plastic pots and drinking bottles were screwed into the wooden poles (Figure 3). Two tomato plants were on the ground, while the other tomato plants were placed on brick piles about a foot tall. Initially, the 2.5 cm by 5 cm (1 in. by 2 in.) wooden poles were erected to support the tomato plants but proved unsuitable, especially during storm events and heavy winds.

The terrace method had six plastic garden boxes supported by the 2.5 cm by 5 cm (1 in. by 2 in.) wooden poles (Figure 4). Each of the garden boxes has three 0.5 cm (3/16 in.) holes at the bottom side for drainage. The plot was able to support ten corn plants, two tomato plants, three pepper plants, and three okra plants. The vertical method consists of two metal shelves standing three feet tall. One of the shelves, located in the north portion, had five corn plants on the top and the bottom two shelves had two tomato plants on each shelf. The other shelf had twelve pepper plants and two okra plants.

Figure 2: Tier method plot (right) and traditional method plot (left). **Figure 3**: Plastic containers attached to the wooden post.

The purpose of the experiment was to prove that each method could increase production and to visualize the economic visibility of each method. Though the setup could reflect both rooftop and on-ground urban farming, the experiment was set up to resemble on-ground conditions due to unavoidable factors such as shading.

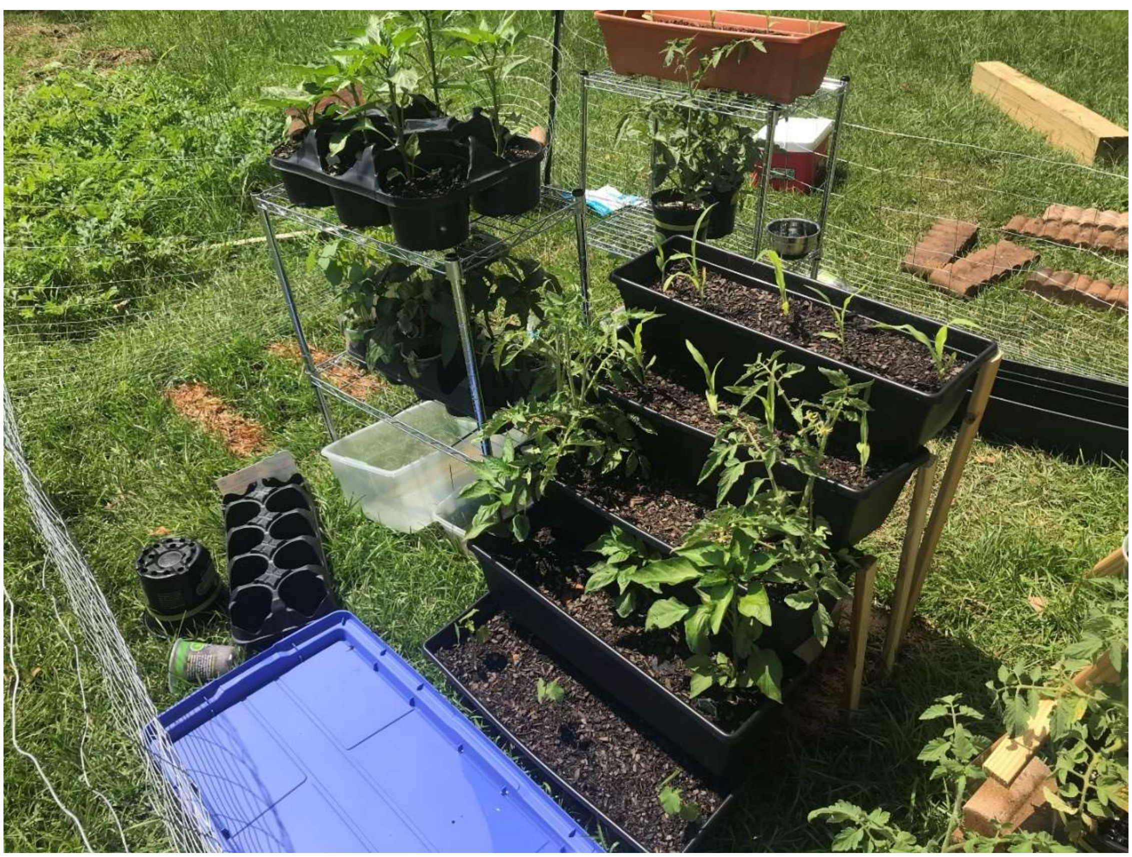

Figure 4: Terrace method plot(right) and vertical method plot(left).

Data Collection

Each method was analyzed based on yield production (Table 1). The yield per method was determined based on how many plants were incorporated within the 61 cm by 91 cm (2 ft. by 3 ft.) plot. For example, the traditional method had ten corn plants and two tomato plants planted with the designed 61 cm by 91 cm (2 ft. by 3 ft.) plot or two plants per square foot.

Seven trials were conducted to show how each plot could potentially collect excess water from watering and storm events (Table 2). This was done to incorporate the potential cost of watering for each method in the economic analysis. The tier and vertical methods had buckets underneath the plants to collect water, while the terrace had a dish pan at the foot of its base to collect excess water.

Table 1. Yield production by plant.

Traditional	Corn	Tomato	Pepper	Okra	Total	SF	Yield per SF
Number of plants	10	2	0	0	12	6	2.00
Number of plants sprouted	8	2			10	6	1.67
Tier							
Number of plants	17	4	5	0	26	6	4.33
Number of plants sprouted	15	4	5	0	24	6	4.00
Yield Increase percentage	87.5%	100%			140%		140%
Terrace							
Number of plants	10	2	3	3	18	3	6.00
Number of plants sprouted	10	2	3	3	18	3	6.00
Yield Increase percentage	25%	0%			80%		260%
Vertical							
Number of plants	5	4	12	2	23	6	3.83
Number of plants sprouted	5	4	12	2	23	6	3.83
Yield Increase percentage	-37.5%	100%			130%		130%

Table 2. Storm event data collection.

	Trial 5	**Trial 6**	**Trial 7**	**Average**
Rainfall control measurement (ml)	32.5	750	946	**576.17**
Traditional (ml)	0	0	0	**0.00**
Vertical (ml)	250	11250	5500	**5,666.67**
Terrace (ml)	60	3000	5000	**2,686.67**
Tier (ml)	385	19045	13450	**10,960.00**

Data analysis

During the trials, the amount of runoff collected from each method varied from 1% to 50% during watering. The terrace method had the least collection of water during watering and storm events (Figure 5). The vertical and tier methods were able to collect significant amounts of water runoff during watering and storm events. The tier method proved the most successful in water conservation, saving nearly 43% in water runoff during all watering sessions. During storm events, the tier method collected the most rainfall.

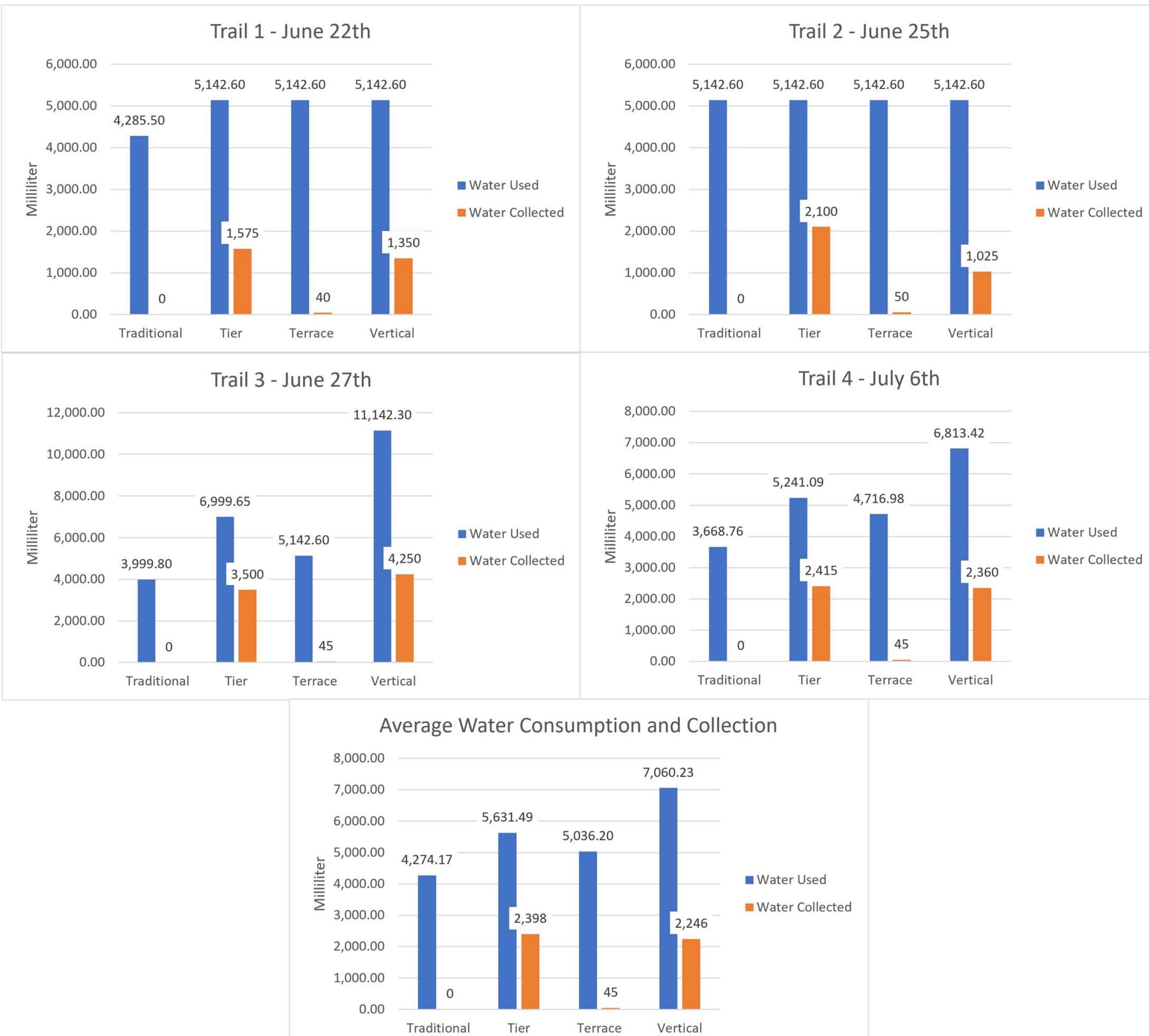

Figure 5: Watering consumption and collection data.

Economic Analysis

The materials bought and the number of plants grown were considered to demonstrate the economic feasibility of these methods. Each method has a list of materials in addition to the plants and seeds bought (Tables 3-6). After computing, the tier method was the only method to reap more economical value than the traditional method. Both the terrace and the vertical farming would lose profit if the materials used, and plants used were implemented.

Table 3. Traditional economic analysis.

	Price	Unit	Quantity		Total	Yield				
Soil	0	$/CF	3	CF	$0.00	15				
Tomatoes	0.10	$/Plant	2	EA	$0.20	10	lb/plant	$1.47	$/lb	$29.40
Corn	0.10	$/Plant	10	EA	$1.00	3	ears/ plant	$0.42	$/ear	$12.60
Water consumption	0.28	$/gallon/ day	1.13	GAL	$9.49					
				Total	**$10.69**		**Total Yield**			**$42.00**
				Area used	6	SF	Total yield per square foot			$7.00
				Total per square foot	$1.78	$/SF	**Profit per square foot**			**$5.22**

Table 4. Tier economic analysis.

	Price	Unit	Quantity		Total	Yield				
Soil	15.07	$/CF	0.25	CF	$3.77					
Brick	0.58	$/EA	24	EA	$13.92					
Wood post	0.36	$/LF	20	LF	$7.20					
Tomatoes	0.10	$/Plant	4	EA	$0.40	10	lb/plant	$1.47	$/lb	$58.80
Pepper	0.10	$/Plant	5	EA	$0.50	3	peppers/ plant	$0.74	$/pepper	$11.10
Corn	0.10	$/Plant	17	EA	$1.70	3	ears/pla nt	$0.42	$/ear	$21.42
Water consumption	0.28	$/gallon/ day	0.85	GAL	$7.18					
				Total	**$34.66**		**Total Yield**			**$91.32**
				Area used	6	SF	Total yield per square foot			$15.22
				Total per square foot	$5.78		**Profit per square foot**			**$9.44**

Table 5. Terrace economic analysis.

	Price	Unit	Quantity		Total	Yield				
Containers	11.68	$/EA	6	EA	$70.08					
Soil	15.07	$/CF	0.25	CF	$3.77					
Tomatoes	0.10	$/plant	2	EA	$0.20	10	lb/plant	$1.47	$/lb	$29.40
Pepper	0.10	$/plant	3	EA	$0.30	3	peppers/ plant	$0.74	$/ pepper	$6.66
Corn	0.10	$/plant	10	EA	$1.00	3	ears/pla nt	$0.42	$/ear	$12.60
Okra	0.10	$/plant	3	EA	$0.30	0.02	oz/plant	0.112	$/okra	$0.01
Water consumption	0.28	$/gallon/ day	1.33	GAL	$11.18					
				Total	**$86.82**				**Total Yield**	**$48.66**
				Area used	3	SF			Total yield per square foot	$16.22
				Total per square foot	$28.94				**Profit per square foot**	**-$12.72**

Table 6. Vertical economic analysis.

	Price	Unit	Quantity		Total	Yield				
Shelf	34.98	$/EA	2	EA	$69.96					
Soil	15.07	$/CF	0.25	CF	$3.77					
Tomatoes	0.10	$/plant	4	EA	$0.40	10	lb/plant	$1.47	$/lb	$58.80
Pepper	0.10	$/plant	10	EA	$1.00	3	peppers/ plant	$0.74	$/pepper	$22.20
Corn	0.10	$/plant	5	EA	$0.50	3	ears/pla nt	$0.42	$/ear	$6.30
Okra	0.10	$/plant	2	EA	$0.20	0.02	oz/plant	0.112	$/okra	$0.00
Water consumption	0.28	$/gallon/ day	1.27	GAL	$10.68					
Total					**$86.51**		**Total Yield**			**$87.30**
Area used					6	SF	Total yield per square foot			$14.55
Total per square foot					$14.42		**Profit per square foot**			**$0.13**

Results

The plants in the traditional method were able to sprout except for two corn plants. Three corn plants in the tier plot failed to germinate as well. It should be noted that the two failed germinated corn plants were located at the bottom of the beams. With the failed germination, the amount of corn grown on the tier method was increased by 88% in comparison to the traditional method. The tomato plants in the terraced plot were increased by 100% in comparison to the traditional method.

While the terrace plot did not yield more corn or tomato plants than the traditional, another two rows of plants were used, increasing the variety and amount of plants by 66%. In addition, the unused space could be used for other purposes, including composting and raising small animals. The vertical plot was able to yield four tomato plants, five corn plants, twelve pepper plants, and two okra plants. It was noted that the leaves on the tomato plants at the bottom were brown and weak in comparison to the tomato plants on the middle shelf. Otherwise, the corn, peppers, and okra grew without issue.

Concluding Thoughts

The experiment shows that urban farms have the potential to yield more plants. While the maximum height of these plots during the experiment was approximately 91 cm (3 ft.) tall, if the plots were increased to twice their size, then more plants would be grown and harvested. The increased production of plants would undoubtedly increase the economic value of urban farms and water conservation. It should be noted that labor cost was not incorporated into the economic analysis.

The tier method demonstrated how drastically urban farming can be improved by simply shifting the plants at an angle without degrading the plants. Partially, one more row of plants could be utilized to increase production. This simple design was only for small plants. Huge plants, such as tomatoes, showed how much more complex the sloped design would have to be to support a row of heavy and tall plants with deeper root systems. Thus, stronger supports and bigger pots would be considered to support taller and heavier plants.

The terrace farming demonstrated the increased variety of plants and increased production of other aspects of farming including composting and possibly raising small animals. The next step in urban farming production is to increase the size of the plots and integrate a variety of other crops, including carrots and lettuce, during the winter and spring seasons to see the limits of each crop. It should be noted that the design of the plots was only applicable to small areas where heavy machinery was neglected. On a large scale, especially concerning the harvest of cash crops such as cotton and pecans, these methods might be deemed uneconomical and thus unprofitable on an industrial scale.

If replicated next summer, the experiment would produce the familiar results if done in the same location. The results would vary based on container size, weather forecast, and how much water each plant consumed, and shading. If this experiment layout was conducted on a rooftop, the results would be different in terms of growth and water consumption due to lack of shade and water collection abilities.

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