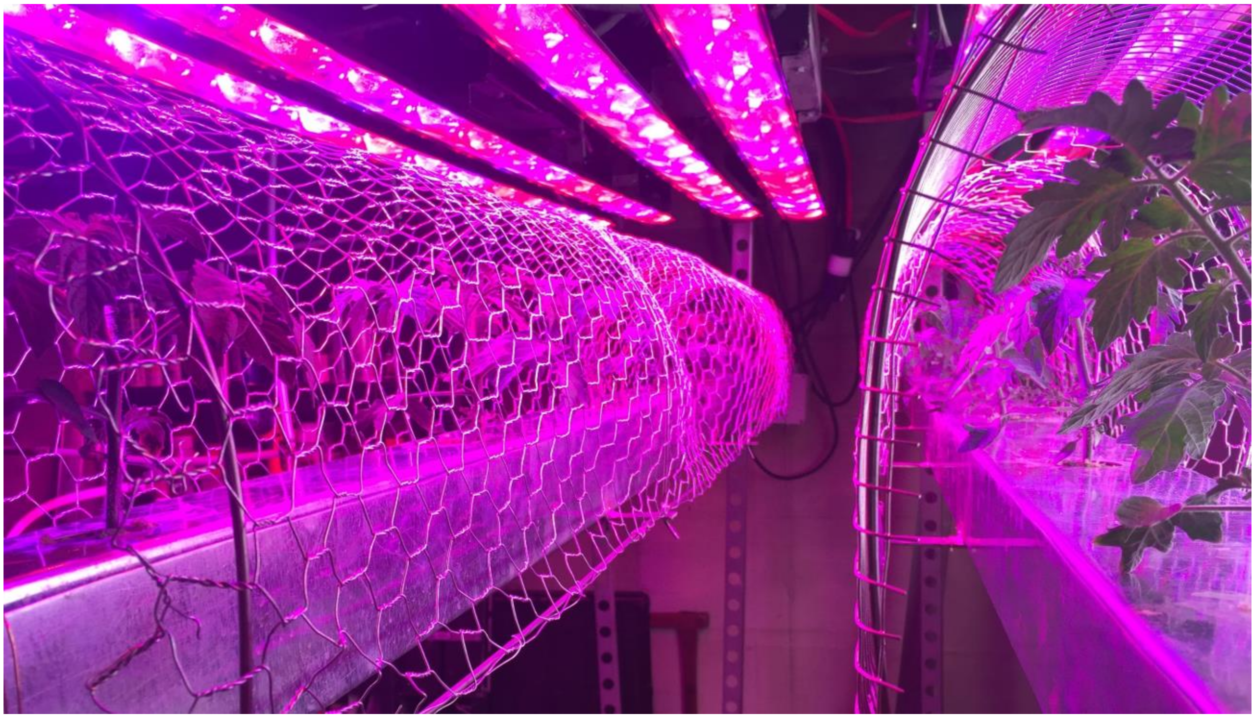
Optimized Medical Marijuana Growth: Automation and Height Control

Nathaniel Lambert, Joseph Perreault, Aleksander Stokke, Martín Villaverde
Bioresource Engineering, McGill University, Montreal, QC



Executive Summary

Urban agriculture is currently gaining attention at a global scale as a sustainable approach to food security. However, current growing systems such as the Cubic Farming module proposed by Urban Barns located in Mirabel, Quebec, are unsuited for plants of larger biomass such as tomatoes and peppers. Furthermore, growing demand for the indoor production of medical marijuana (Cannabis sativa) as but increased the interest towards such growing systems. The following research paper proposes a novel trainer and redesigned growth tray to be fully integrated within the Cubic Farming module. During a trial phase, the redesigned tray with novel trainer successfully limited apical growth while promoting lateral branching through the use of a metallic mesh barrier.

1. Introduction and Project Description

The current global population growth, especially in urban centers, coupled with growing demands for food production has spurred an unprecedented interest in urban agriculture. Unprecedented research and funds are being allocated to developing benchmark systems capable of producing high quality, local produce. Currently, fossil fuel resources are allocated to the processing and shipping of produce around the world by sea and air, with the average produce found in supermarkets having travelled hundreds if not thousands of kilometres.

Instead of producing food and shipping it vast distances, cultivation in an urban setting provides a viable alternative to conventional model of food production, while making efficient use of resources and space. Moreover, the highly controlled nature of urban agriculture environments allows for more efficient use of energy and other resources, while limiting the contamination potential of pests and other biological contaminants. By virtue of being produced in the same region that the goods will be consumed, urban agriculture saves a tremendous amount of money on fossil fuels, while decreasing emissions and ensuing environmental impacts. The environmental and economical potential of these growth systems has triggered research regarding the feasibility of such systems, to optimise and standardize their use. The medical marijuana market, despite being subject to social stigmas, is a viable and vibrant industry with powerful economic potential. The controlled nature and proximity to urban centers make urban agriculture and medical marijuana cultivation a lucrative, and viable match.

The Cubic Farming design trademarked by Urban Barns is a tray based system used to grow produce on an industrial scale in urban settings. The design makes efficient use of space and resources by rotating trays through a mechanised grid in a controlled environment. There are dimensional restrictions inherent to the Cubic Farming™ design that limit the range of viable cultivars to small, leafy, greens with smaller biomasses. Our goal is to design a modified tray specialised to cultivate plants with larger biomasses, namely medical marijuana strains, which have unrivaled profit margins. Moreover, the specialized and controlled nature of the environments in which urban agriculture is performed has the potential to create a quality of medical marijuana that is unprecedented; with the potential to improve the quality of life of individuals suffering from chronic pain and a plethora of other illnesses.

After careful consideration of the different design alternatives, our selected design was ultimately inspired by the screen of green method for training medical marijuana. The decision was based on a variety of factors such as labour intensity, scalability, adaptability to other benchmark systems, feasibility, and ease of use. The screen of green method was selected in our design II report as the most viable solution, in lieu of a helical trainer and other low-stress training method extensively detailed. The design alternative chosen allows for optimal integration into the Cubic Farming™ Machine template, while having the most automation potential.

In this context, the Cubic Farming™ system is an ideal template for the growth of highly profitable crops due the fact that it allows for the manipulation of more factors than conventional agriculture, and to a high degree of precision. The controlled environment it provides reduces the risks of pests and biological contaminants, making it ideal for the growth of medical marijuana, a heavily regulated cultivar held to the highest standards of quality and assurance, akin to pharmaceuticals.

The inherently taboo nature of the product as a controlled substance that is illegal in a number of countries across the world makes it an exceptionally difficult crop to grow and test, despite McGill having one of the only research licenses to grow marijuana in the country. Therein, for the purpose of testing our prototype trays, analogs had to be evaluated and selected. Several crops with similar biomasses and foliage densities were considered, including cucumbers, peppers, tomatoes, and hops. In the pursuit of a cultivar exhibiting a plant physiology and growth pattern analogous to that of marijuana, tomatoes were chosen as the most viable alternative. Moreover, tomatoes exhibit a rather fast growth cycle that allowed us to grow the tomatoes from seed to maturity quickly, rendering the iterative prototyping and testing process more feasible than other plants which would take longer to reach maturity. Obviously, discrepancies exist between the growth of medical marijuana and tomatoes, including the plant physiology, responses to stress, and root systems. Therein, further research using actual marijuana strains would be ideal in order to make any necessary adjustments to the tray.

A key design consideration that had to be decided rather early on in the process was whether to modify the existing tray design, or to build an entirely new one. However, considering the old tray was designed for smaller plants with much smaller biomasses and root systems, we had concerns that the marijuana plant, with its much larger root system, would compound the already present problem of uneven water distribution. Ensuring that water and nutrient availability is not compromised is essential. Ultimately, the decision was made to build a new tray from scratch, considering this would give us the greatest amount of freedom to optimize specific dimensional properties, including the space allocated to rooting depth versus vegetative growth.

Overall, the integration of both hard and soft solutions is crucial in delivering a design that will meet the criteria and accomplish the design goal, namely the cultivation of world grade medical marijuana. The design of a cultivar specific growth tray is not solely a hardware consideration, but also one that needs to consider the specific variety of crop plan. In our case, the selection of appropriate strains suited for cultivation in a constricted space is crucial. The strain selection criteria, which involves physiological properties, size, foliage density, growth cycle length, and flowering properties are outlined in the strain selection portion of the report. The use of an appropriate strain in conjunction with the designed hardware is vital in accomplishing the design objective.

Although the following report focuses on the growth of medical marijuana in the context of the Urban Barns Cubic Farming™ system, we designed the tray keeping in mind the eventual integration of the design into other urban agriculture benchmark systems.

2. Design Criteria

During the first half of the design cycle a number of criteria were defined in conjunction with our client and mentors to guide the design of our cultivar specific growth trays for medical marijuana. The criteria were stated as follows:

Integration into Urban Barns' Cubic Farming™ system.

There are physical and dimensional restrictions that need to be clearly outlined and respected for successful integration. In terms of length, the tray will span a length of roughly 83 inches. The available width and height, which set the boundaries that must encompass the tray and the plant, are eight by ten inches, respectively.

Promote directional growth.

More specifically, vertical growth needs to be limited to the allowed dimensions, while growth in the lateral direction, along the length of the tray, needs to be promoted. There is a maximum height allowed of 10 inches. There are also 3 inches of space on either side of the tray horizontally.

Automation Potential.

Automation potential will be a primary design focus in the planting, growing, and harvesting phases. Although our design will not itself be automated, the costs of labour currently constitute the greatest cost of operations, and automation potential is therefore a viable space in which innovations can be made to increase profitability. Consequently, minimizing the amount of labour required in all phases of operation will be a key design and strain selection criteria.

Medical Marijuana as Primary Design Cultivar.

The design will be based on medical marijuana as the primary design cultivar. Research will be done on existing plant properties, as well as on variations between different stains. Being a highly regulated medicinal product, quality assurance is of utmost importance. Ultimately, the design proposed must not negatively impact the concentrations of medically relevant cannabinoids.

3. Literature Review

Appropriate Medium Selection

The ability of soil to provide support for the root system, water supply and essential nutrients is dependent on the soil quality and structure. While optimal growth conditions in regular soils usually consists of 25% water space, 25% air space, 45% mineral matter and 5% organic matter (Resh, 2013), these elements must be supplemented in hydroponic systems. The choice of growth substrate is thus an essential consideration for growth operations that lack soil. In this context, several different substrates are commonly used for hydroponics, which include gravel, coconut fibre, perlite and rockwool among others. While the nutrient solution will be responsible for providing the water and nutrients for growth, how the plant interacts with these components will be dependent on the specific medium chosen.

The choice of medium will be determinant in water retention due to its dependence on the particle size, shape and porosity of the medium (Resh, 2013). An ideal medium will thus be capable of good water retention as well as good drainage. Another important criterion to consider is the durability of the medium. A durable medium will retain its hardness and thus structure and root aeration.

Furthermore, the choice of medium should exempt substrates that contain harmful materials. The use of coconut fibre as a growth medium is conditioned to first being retreated to remove high concentrations of sodium chloride when sourced from coconut trees near the ocean (Resh, 2013). Similarly, gravel from calcareous origin should be avoided due to the high content of calcium carbonate (Resh, 2013). The presence of harmful or foreign materials that could be released to the nutrient solution and affect pH, and ultimately growth, should thus be avoided.

Among the different growth mediums available for soilless cultures, the two most commonly used mediums are coconut fibre and rockwool. Coconut fibre, also known as coco coir, is obtained from ground-up coconut palm husks after drying. The material is not screen to remove fibers thus adding both porosity and aeration (Resh, 2013). It is a biodegradable material but can take up to twenty years to degrade (Resh, 2013). A study by Shinohara and others has shown that the water holding capacity of organic substrates such as coco coir increases with use, while this is beneficial it does imply degradation of the substrate. It further showed high levels of potassium leaching and Ca absorption in new organic substrates due to the initial inorganic element composition and cation exchange capacity.

However, growth of crops in controlled environments has been developed to maximize yield and quality, while preserving water and land, and reducing labour (Inden et al. 2004). The yield production of rock wool is greater than other inert materials and thus preferable (Inden et al. 2004).

While composition of rockwool can be different depending on the manufacturer, it typically consists of 45% silica dioxide, 15% aluminium oxide, 15% calcium oxide, 10% iron oxide and 5% of other oxides (Resh, 2013). Its preference as a growth medium is given by the fact that it is slightly alkaline with a pH of 7 to 8 while inert and biologically non-degradable (Schwarz, 1995). Furthermore, it has a water-holding capability of around 80% and about 95% pore spaces (Resh, 2013. Beyond the water-holding capacity, excess nutrient solution drains easily from the rock wool, making watering to excess an essential consideration to insure appropriate concentrations of rapidly absorbed nutrients such as nitrate and potassium, and nutrients that are easily depleted such as sodium and sulphate (Schwarz, 1995). According to a study by Smith (1987), rockwool has a runoff of 15-20% under normal conditions or up to 30-30% in conditions where it is necessary to restore the nutrient balance in the substrate.

The choice of rockwool as an ideal medium is thus primarily due to its water holding capacity, when drained to field capacity rockwool contains about 80% solution, 15% air pore space and 5% rockwool fibers. (Morard et al. 2000; Carazo et al. 2005) It therefore provides the plants with a constant supply of nutrient solution while maintaining appropriate aeration.

Material Selection

The growth of medical grade crops requires an appropriate analysis of the materials to be used to ensure that they comply with health and safety standards. The design of the tray will thus depend on a material in addition to being malleable to allow for bending during the construction process, must not pose a risk of contamination by hazardous trace elements.

The literature available regarding trace elements in hydroponics is limited and thus our analysis will be based on the impact of material selection in household plumbing. The corrosion of the material is the main issue in this aspect, and is affected by the composition of the water flowing through the material, as well as the contact time between the water and the material. The accumulation of metals can be further affected by the pH, alkalinity and dissolved oxygen in the water (Viraraghavan et al. 2007).

The use of stainless steel is preferable due to a superior corrosive resistance as well as fabrication properties (Baddoo, 2011). It is not only corrosion-resistant and long-lasting, but offers advantages in terms of durability, strength, ductility and formability (Baddoo, 2011).

Irrigation and Space Restriction

The available literature on the ideal type of spacing to be used for the trainer system to restrict growth was limited. The decision process on what size of mesh to use was ultimately driven by prototyping and testing. It was based on a size that would be small enough to restrict vegetative growth through the mesh, while allowing the fruit to grow out of the mesh for ease of harvest. As it will be later discussed, smaller mesh openings were ultimately prefered due to capability to effectively restrict vertical growth and promote lateral branching.

The irrigation of the trays was performed in an analogous manner to the way it is performed in the Cubic Farming machine and most hydroponic cultivation systems. This consist of a ebb and flow (flood and drain) method. As detailed in the testing section of this paper, a high volume, low frequency watering system was preferred over the high frequency, low volume system implemented in the Urban Barns design due to the high absorbing capabilities of the larger rockwool growth mediums used in the novel design.

4. The Soft Side: Strain Selection

As maintained since the beginning of this design process, delivering a comprehensive solution enabling the cultivation efficient cultivation of medical marijuana in the Cubic Farming™ system is wholly dependent on the integration of both hard and soft solutions. The “hard” aspect of the solution refers to the designed and constructed hardware, namely the growth tray and trainer, which are both detailed in other sections of this report. On the other hand, the “soft” aspect of the solution lies in the selection of an appropriate strain. Similarly, to other well known cultivars like tomatoes that have been selectively bred for specific characteristics, cannabis strains come in all shapes and sizes, with varying strains displaying different lifecycle lengths, growth patterns, chemical compositions, biomass concentrations, and physiological properties. The two primary psychoactive and medically relevant chemicals present in Cannabis plants are tetrahydrocannabinol (THC) and cannabidiol (CBD). Although they are present throughout the plant in very small quantities, the concentration of these two compounds is by far the highest in the flowering buds of the plant, which are the The THC compounds have generally more psychoactive effects, and are therefore valued by recreational users. CBD compounds, on the other hand, are not known to be psychoactive, but are more medically relevant due to their painkilling and analgesic properties (Cohen, 2009).

The two species of the Cannabis genus that are most commonly grown for both medicinal and recreational purposes are Cannabis indica and Cannabis sativa. Pure sativa varieties are relatively tall, with narrow bladed leaves, long branches, and relatively low density foliage and budding flowers (Andersen, 1980). These sativa varieties tend to take longer times to reach maturity, and their high THC to CBD ratio make sativa strains popular among recreational users. Indica varieties, on the other hand, are shorter, bushier, and stout in nature. Their leaf blades are broader, and the plant exhibits much denser foliage and buds than sativa varieties (Andersen, 1980). The indica varieties contain relatively higher concentrations of CBD, the medically relevant chemical known for analgesic and painkilling properties, and are therefore more widely used in the treatment of physical ailments, and in palliative care (Hillig et al, 2004). A third species in the Cannabis genus, ruderalis, has negligible concentrations of relevant chemical compounds, has little biomass, is very short, and is therefore not commonly grown for recreational, medical, or industrial use (Clarke, 1981). Sativa and indica strains transition from vegetative growth phases to flowering phases based on photoperiods (light cycles), an evolutionary adaption made by many plants by which the transition from vegetative growth to flowering coincides with nature's seasonal lighting fluctuations. The long days of summer trigger powerful vegetative growth, in which the plants spend their energy adding branches, leaves, and root systems. Then, as summer turns to fall and the days become shorter, the shorter light exposure trigger a physiological response in the plant to start flowering. When exposed to the shorter light cycles, the plants stop growing and instead focus their energy into producing flowering buds. Being an auto-flowering variety, the ruderalis strains differ from the photoperiod dependent sativa and indica strains (Green, 2010).

We outlined a number of criteria in the selection of an appropriate strain to maximize the efficiency and productivity with which medical marijuana could be cultivated in the Cubic Farming™ system. Considering the medical nature of the product, an indica dominant strain should be employed, considering the indica variety has higher concentrations of medically relevant cannabinoids (Cohen, 2009). Considering the end goal of growing medical marijuana in the Cubic Farming™ system is economic output, the selected strain would ideally have a very short grow cycle, so that the number of growing cycles performed in a given time period would be as high as possible. Moreover, considering the dimensional restrictions inherent to both the designed tray and the Cubic Farming™ system, a short and stout strain with high density buds and biomass would be ideal in order to generate the highest possible biomass and yields per unit volume. Also, considering ease of operation, the strain selected would ideally have autoflowering properties, so that the occurrence of growth and flowering phases are dependent on time, not lighting cycles.

Considering the outlined criteria, our proposed strain selection is the Red Dwarf strain, which was developed by the Buddha Seed Company. The Red Dwarf is a relatively rare strain of cannabis that is an autoflowering variety. The autoflowering trait is the result of selective crossbreeding between the medically relevant indica varieties, and ruderalis varieties. The Red Dwarf strain is also an ideal strain selection for the Cubic Farming™ system due to its incredibly short growing cycle that is nearly unrivaled by other strains; the red dwarf takes only six weeks to grow from seed to maturity. Moreover, the product of selective breeding between indica and ruderalis varieties, the Red Dwarf strain is short and small in stature, standing roughly two feet tall, and exhibits high density biomass and flowering buds. Considering the tray designed is roughly eight feet long, we believe that four plants could conservatively fit in one tray, allowing us to make optimal use of space.

5. Prototyping

In order to achieve full integration within the Urban Barns Cubic Farming™ system, it was determined that the redesigned trays should preserve most of the existing features observed in the trays currently used by the company. Therefore variables such as length, material, and overall shape and look should be retained. After an analysis of the Cubic Farming™ system, vertical and horizontal space constraints were measured and served as our maximum allowance for space use.

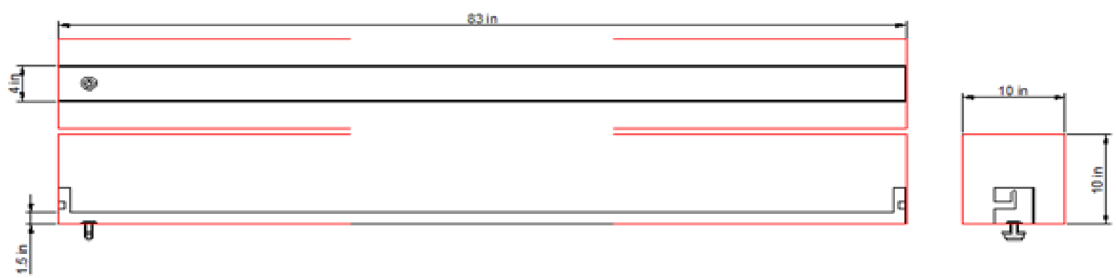


Figure 1: Original tray with space constraints

Due to the high cost of stainless steel (approx. $150 per 4'X8'), the material currently used by Urban Barns for their growth trays, it was established that for prototyping purposes, a cheaper alternative, namely galvanized steel (approx. $60 per 4'X8'), would be suitable.

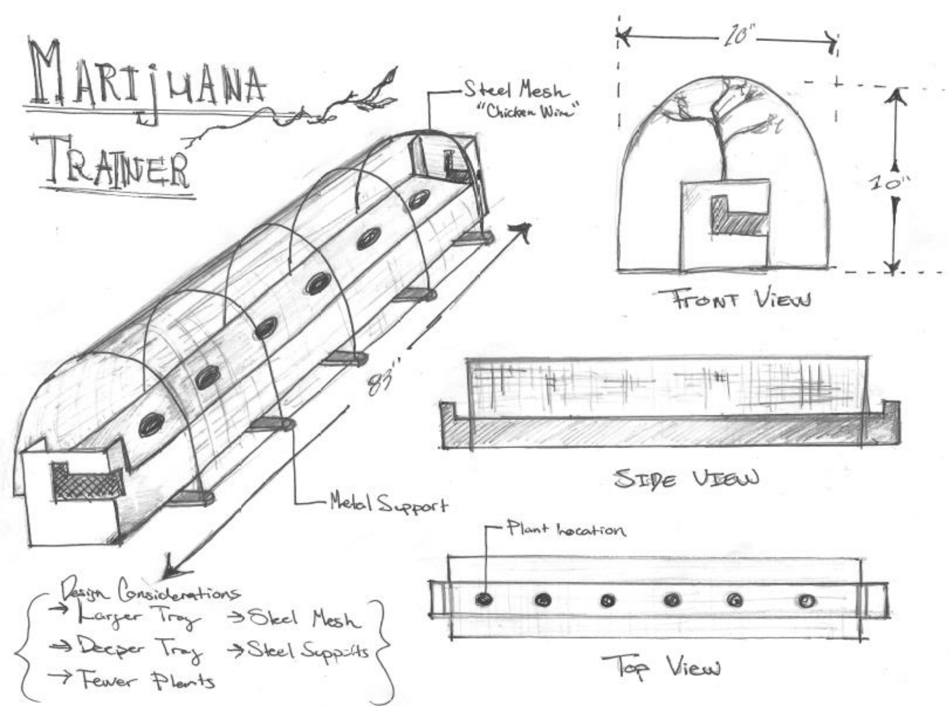


Figure 2: Original concept sketch

After initial concept drawings, autocad mockups were created along with drawings of the sheet metal cutouts and bends required to assemble the prototypes. Figures of these may be seen in the Design Blueprint section.

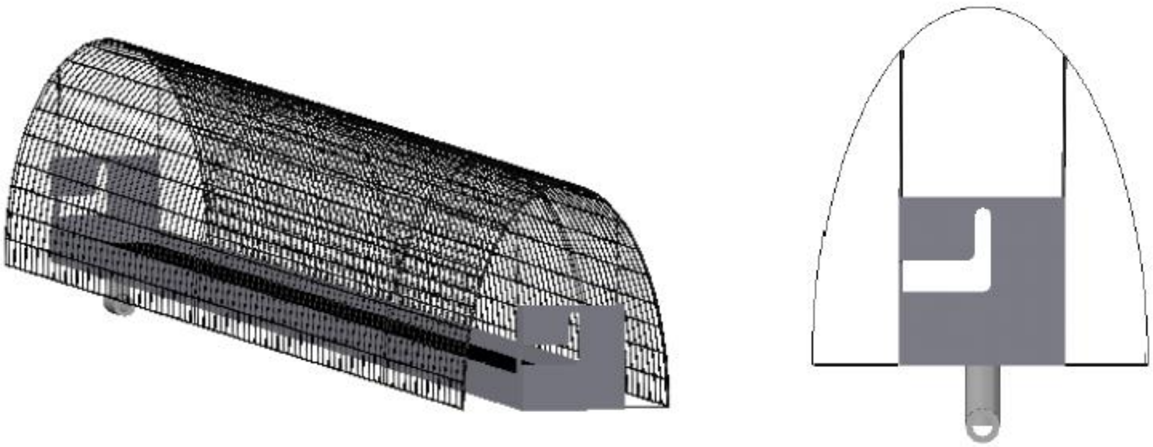


Figure 3: 3 Dimensional rendition of tray and trainer. Profile & End view.

The Building Process

Prototype 1 was completed in roughly 2 days within McGill's Macdonald workshop. Overall building time for later prototypes was reduced to approximately one whole day due to the integration of more efficient building techniques and through lessons learned.

The construction process began by drawing the outline of the tray on a 4'X8' piece of sheet metal (Figure 12), the outline was then cut using a hand held shear. Smaller and more precise cut-outs such as drain holes and tray mount holes were created using a sheet metal press with the appropriate die. The metal sheet was then folded using various sheet metal bending machines. Once folded, the ends were secured to the trays by spot welding. Any remaining gaps in the tray were filled in with caulking to make the tray water tight.

Trainer assembly began by cutting the required length of steel rod forming the frame of the trainer. These were joined together initially by soldering and later by spot welding which proved to be more efficient and elegant. Once the frame was assembled, metallic mesh or "chicken wire" was overlayed and secured to the frame with small gauge metallic wire.

For prototype 1 and 2, supports consisted of rectangular steel plates (Figure 6) soldered to the underside of the tray. The trainer could then be mounted and fixed by inserting rod segments of the steel frame within holes drilled in the steel brackets. Prototype 3's support system was created using sheet metal bent to approximately 45 degrees at its extremity allowing the training to be clipped in placed easily and rapidly (Figure 16). Listed below are the technical specifications of prototypes.

Table 1. Prototype materials

Prototype 1	
Tray/Attachment	Galvanized steel (20 gauge)
	1/8 in. steel plates (For attaching the trainer)
Cover	Galvanized Steel (20 gauge)
Trainer	1/8 in. cold-rolled steel rods
	1 in. hexagonal shaped mesh

Prototype 2	
Tray/Attachment	Galvanized steel (20 gauge)
	1/8 in. steel plates (For attaching the trainer)
Cover	Galvanized Steel (20 gauge)
Trainer	1/8 in. cold-rolled steel rods
	1/2 in. square shaped wire mesh

Prototype 3	
Tray/Attachment	Stainless Steel (22 Gauge)
	Stainless Steel Strips (22 Gauge)
Cover	Stainless Steel (22 Gauge)
Trainer	1/8 in. cold-rolled steel rods
	1/4 in. cold-rolled steel rods
	1/2 in. square shaped wire mesh

Rockwool	1.5 in. high cylinder (1 in. diameter)
	4in x 4in x 2.5in Cubes

6. Testing

Testing was performed within a controlled area designed to specifically mimic the the growing conditions at the Urban Barns facilities as well as within the testing laboratory at McGill's Macdonald campus. Through our collaboration with Professor Lefsrud, 3 high intensity 150W LED light fixtures (250V, 0.65A) were obtained. In addition, three 96W neon ballast (120V, 0.8A) were used to maximize the amount of emitted light. for the fast growth of our analogs, namely tomatoes, cucumbers and peppers. This amounted to a total light output of 740 Watts. Supports that mimicked the Urban Barns systems were assembled in place upon which our newly designed trays could rest upon and be adjusted to the desired height. Trays were placed relatively high upon the support to maximize the amount of light transmitted to the plant. A timer was installed to ensure a constant 16 hours of light exposure per day.

Seeds were purchased at a local supplier and were planted in rockwool cylinders used by both Urban Barns and the McGill research unit. Upon germination, these were transferred to larger rockwool cubes in the novel tray and monitored throughout the rest of their growth cycle.

Hoagland solution was used as a nutrient source throughout our testing phase. A concentrate of the solution was prepared at McGill university with the help of laboratory technicians. This solution was then diluted at our testing facility and administered to the plants. Plants were administered the nutrient solution twice daily via an ebb and flow method, which consists of flooding the growth tray and allowing it to drain naturally through a drain hole placed at the opposite end of the irrigation location. This method proved to be efficient in providing the nutrient solution to all the plants within the growth tray. In comparison, Urban Barns as well as the research laboratory at McGill University utilize a high frequency low-flow watering system. However, due to the increase in the size of the rockwool implemented in our design, the currently used watering system proved to be unsatisfactory due to the lack of nutrient water reaching the plant at the opposite end of the tray. This was found to be due to the high absorbing capacity of the larger rockwool cubes. Therefore, using the large volume ebb and flow method at fewer frequencies provided enough water to saturate all of the rockwool growth cubes throughout the tray, ensuring that each plant was provided the nutrients required for optimal growth.

Testing was also essential for the overall proof of concept, which was not fully achieved with the first prototype due to the larger openings of the initial mesh trainer. This was remediated by using metallic mesh with smaller openings, which effectively halted apical growth and promoted lateral growth.

7. Optimization

Prototype 1

Upon completion of the first prototype, we identified several areas which could be improved before beginning our second prototype. First, we observed that in order to obtain clean folds in our tray, we need to cut out thin segments of the sheet metal at the location of the fold so that the metal would not warp or twist. Second, we found that the holes drilled into the brackets could be enlarged to aid in the mounting and dismounting of the trainer. Furthermore, the brackets were rather found to be rather sharp which constituted a general safety hazard and therefore should be rounded off in the second prototype. Third, after completion, we observed that the extra depth added to the tray may have been overestimated and would therefore be adjusted downwards in the upcoming design. Fourth, the tray cover which serves as protection for the roots as well as for support was discovered to be unsatisfactory since it did not fit tightly within the tray, which could ultimately lead to unwanted algae growth. To remediate this problem, prototype 2's tray cover would need to be under bent and the tray, over bent, thus enabling a snug fit under pressure. Lastly, the first prototype made use of only four supporting brackets for the trainer which was found to be insufficient due to caving observed in the trainer mesh

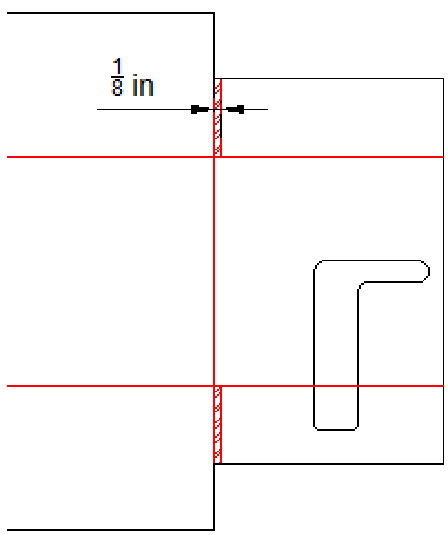


Figure 4: Tray end: showing portion of material removed to ease bending.

Prototype 2

Prototype 2 showcased newly rounded brackets with larger support holes as well as one additional support bracket for the trainer. In addition, a preliminary trial of a new welded metallic mesh with smaller openings provided a cleaner profile to the tray. However, even with the new brackets, it was evident that the trainer support system would require a redesign for the next prototype since it did not provided the ease of mounting and dismounting we sought after.

Picture 1: Initial trainer prototype

Prototype 3

Prototype 3 implemented the use of the new metallic mesh first tested in prototype 2. After testing in the lab, this new smaller mesh provided promising results in vertical plant restriction with no observable decrease in plant growth. After multiple failure with the original support system design, a new support system was conceptualized. The new support system consisted of rectangular sheet metal strips folded 45 degrees at both extremities, 8 inches apart. These brackets were spot welded under the tray compared to soldered in the previous designs which also streamlined the overall fabrication process. The folded support system not only was easier to fabricate but also offered the ease of mounting and dismounting we were looking for in the design, making it possible for the trainer to be installed by a single person.

8. Economic Analysis

In order to assess the economic viability and spatial efficiency of our design alternative to conventional growing techniques, the yields produced per unit area will be calculated and compared for both the Cubic Farming™ system and conventional growing methods. Considering the legal status of marijuana and the ensuing lack of peer-reviewed, academic studies, assumptions will have to be made in order to obtain yield estimates. Although these estimates are not the product of scientific literacy, they are informed by extensive online forums in which medical marijuana. Moreover, in order to limit the number of independent variables, an assumption will be made in the following calculations that both the conventional and proposed cultivation methods employ the same intensity and quality of light, as well as the same nutrient rich Hoagland solution. Also, because market prices are constantly in flux based on supply, demand, THC content, and a number of other factors, the yields obtained per unit area for each method will be compared directly in order to assess the viability of traditional cultivation compared to the Cubic Farming™ system.

By rotating growing trays through a mechanized grid, the Cubic Farming™ system developed by urban barns makes use of three dimensional space. All specifications for the machine, including the dimensions and tray capacity, were given to us by Dr. Lefsrud, who has worked extensively with Urban Barns as a consultant on the Cubic Farming™ project. The Urban Barns third generation machine is eight feet wide, twenty feet long, and roughly nine feet tall. Therein, the total footprint of the machine is 20 x 8 = 160 square feet. When fully loaded, the capacity of the machine is 105 trays. By conservative estimates, our current tray design and trainer, which are eight feet long, should be able to hold at least four plants. However, pending further testing and spacing optimization, more than four plants could potentially be grown in one tray. Assuming conservatively that four plants can be cultivated in each tray, the machine could 420 plants. As aforementioned, anecdotal evidence suggests that each plant of the selected red dwarf strain yield roughly 3 ounces of dried and trimmed product. Therein, 420 plants x 3 oz/plant would yield 1260 ounces of product per six week growing cycle. In terms of spatial efficiency, the 1260 ounces of product produced in the 160 square foot plot results in a production per square foot of 1260 oz / 160 square feet = 7.875 oz / square foot.

In contrast, conventional growing operations place potted plants on tables or directly on the floor, only utilizing space in two dimensions. The containers most widely employed for the selected strains are two gallon containers that are nine inches in diameter. Assuming the growing containers are arranged with optimal use of the twenty by eight foot space, an array consisting of 26 rows of 10 pots could be placed in the 160 square foot area, totaling 260 pots. Assuming each growing container houses one plant that produces three ounces, the 260 plants would yield 780 ounces per growing season. In terms of production per unit area, this would produce a yield per unit area of 780 ounces / 160 square feet = 4.875 oz / square foot.

By comparing the two yields per unit area obtained, it becomes evident that tray cultivation of medical marijuana in the Cubic Farming™ system results in more efficient use of space. Based on the yields estimated, the mechanized growing method is (7.875/4.871) – 1 = 61.5 percent more efficient on a yield per unit area basis. Moreover, the cultivation of the plants in the Cubic Farming™ system would likely make better use of resources like water and electricity, further improving the economic viability.

One of our mentors, Rob Michelle, who works as a lab technician at McGill University, works as a quality and assurance consultant for a medical marijuana company currently operating in

Ontario. Based on his insights of that operation, production costs are estimated to be roughly two dollars per gram of cannabis. This cost includes both the resources used during the cultivation, consisting primarily of energy and nutrient costs, as well as the costs of labor required to harvest and trim the buds. We learned that the current market prices are roughly 5 dollars per gram at retail, leaving a profit margin of roughly 3 dollars per gram. This implies that each ounce of cultivated product would fetch 28 x 3 = 84 dollars profit. Extrapolating that profit margin per ounce using the aforementioned 6 week growing cycle yield estimate of 1260 ounces, the Cubic Farming™ system could theoretically generate 1260 x 84 = 105,840 dollars every six weeks. However, it is noteworthy that the assumed costs are associated with conventional cultivation methods, which are less cost efficient on a resource basis than the Cubic Farming™ system exclude any taxes or fees, as these tend to fluctuate from region to region based on local fiscal policy. Also, considering the results of the latest federal election, in which the liberal party was elected, the economic landscape and viability of the marijuana market will likely change.

9. Conclusion

The newly designed tray system was able to successfully hinder vertical growth with the use of a mesh trainer. The plants in our testing responded well to the mesh, growing up to establish an initial contact, while continuing to grow laterally despite the physical barrier. Although testing using the intended growth cultivar (cannabis) was logistically and legally unfeasible, tomatoes used as an analogous crop effectively proved the concept of height restriction through the use of a metallic mesh. Therein, further testing using medical marijuana strains would be ideal, as this would allow us to observe how the actual design cultivar responds to the physiological stresses of the design environment, and would allow us to make necessary adjustments. Overall, lateral growth was visibly stimulated and improved in the tray, with the tomatoes exhibiting a higher propensity of lateral offshoots than control plants left to grow unrestricted. Moreover, the overall foliage density was higher in the design environment than the control plants, which makes sense considering the plants should theoretically be the same size while being restricted to a smaller volume. It was observed that six plants were effectively capable of filling the tray and trainer throughout its entirety with plant biomass. This represents a major improvement to the current tray and training methods employed at Urban Barns and at the McGill University research laboratory. As per the design goal, the final prototype is fully compatible to the Urban Barns Cubic Farming™ system.

10. Acknowledgements

The authors would like to thank Dr. Grant Clark for his continued support and guidance during the design process. For granting us the opportunity to work on this project and his mentorship, the authors are grateful to Dr. Mark Lefsrud. It would not have been possible to undertake this project had it not been for the resources provided by Dr. Lefsrud as well as the assistance of the whole research team in his Biomass Research Laboratory. A special thanks to Lucas McCartney and Ryan Knight for providing their time and expertise that were a key factor in bringing us up to date on the current state of indoor cultivation and the Urban Barns machine. A final acknowledgment is in order to another one of mentors, Rob Michelle, for a providing us with insight into the medical marijuana industry.

Appendix A: Design Blueprints

Prototype 1

Tray:

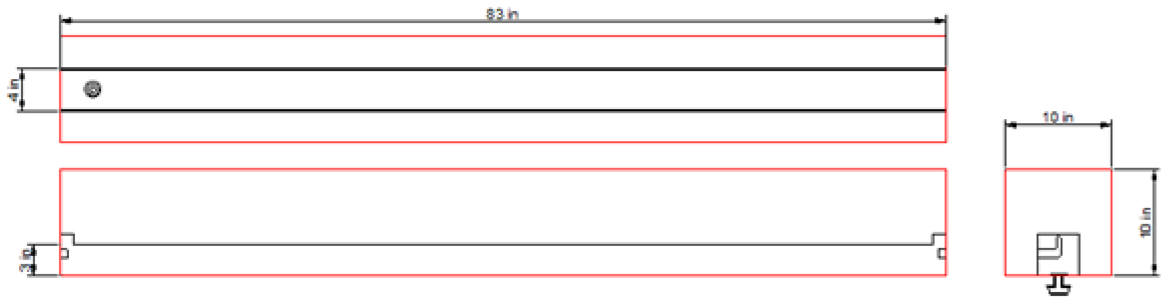


Figure 5: Tray dimensions with space constraints.

Trainer Supports:

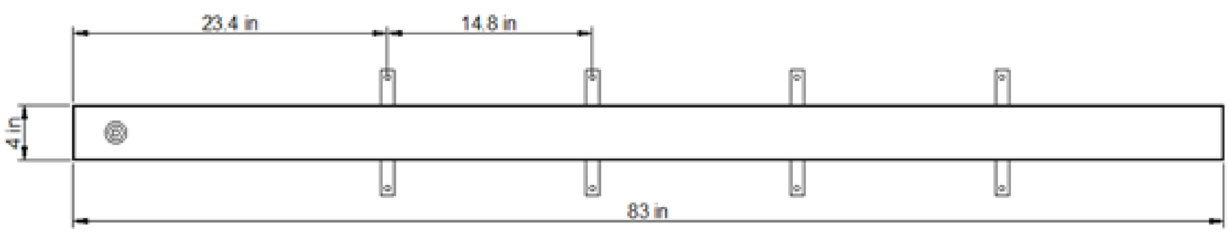


Figure 6: Tray with steel plate supports.

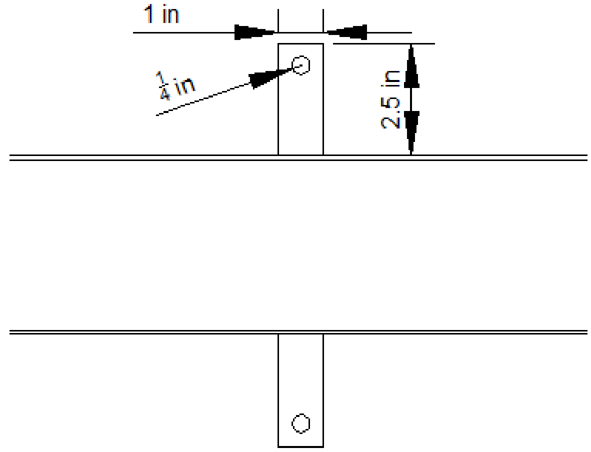


Figure 7: Support dimensions.

Trainer:

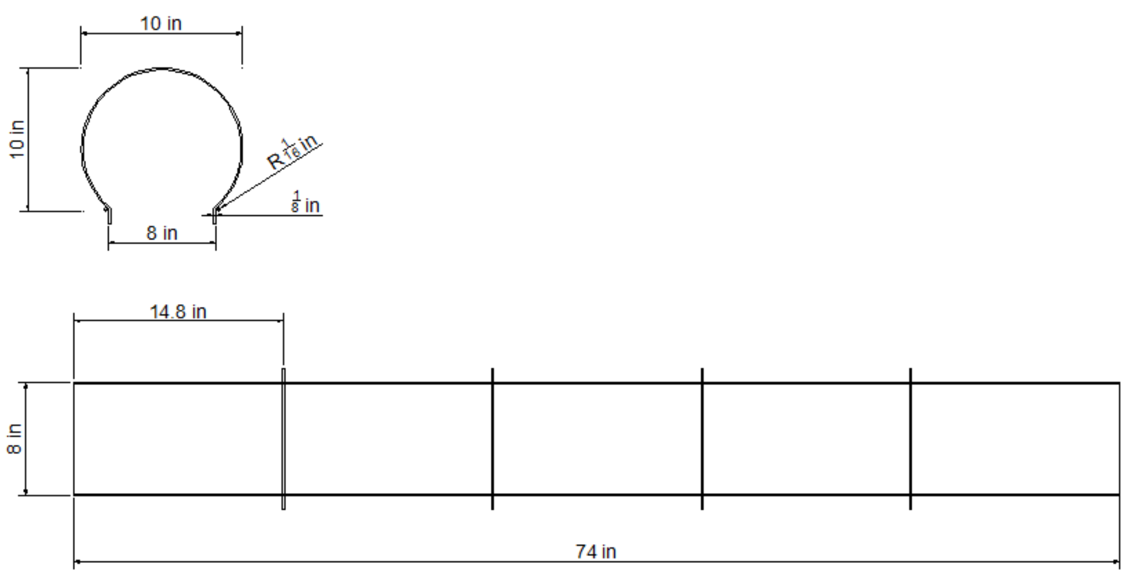


Figure 9: Trainer dimensions.

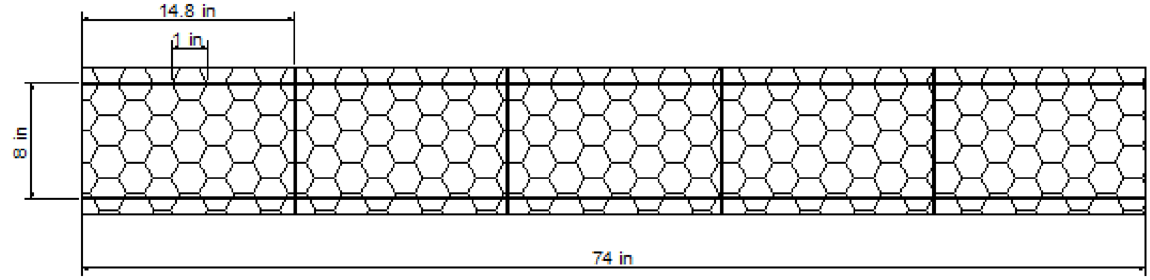


Figure 10: Trainer with 1 in. hexagonal mesh.

Prototype 2 & Final Design

Tray:

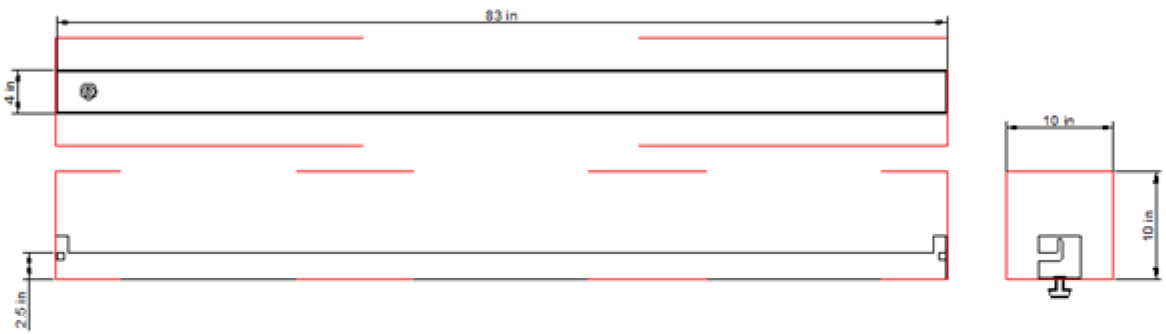


Figure 11: Final design with space constraints.

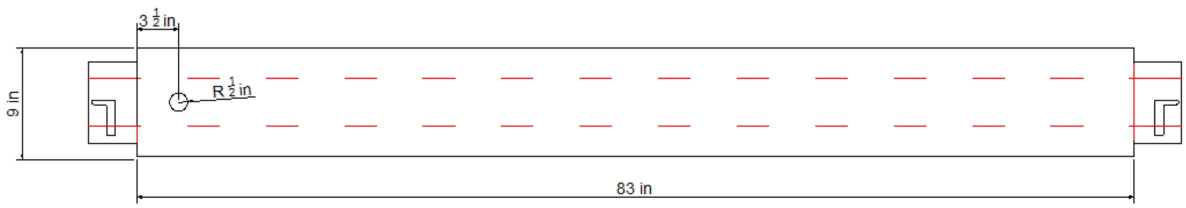


Figure 12: Tray as sheet with bending demarcation (Prior to bending).

Tray Ends:

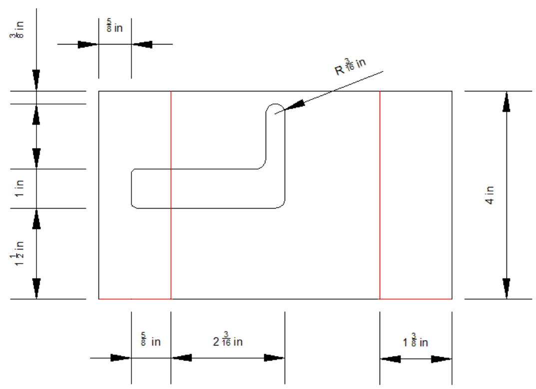


Figure 13: Tray end with dimensions.

Tray cover:

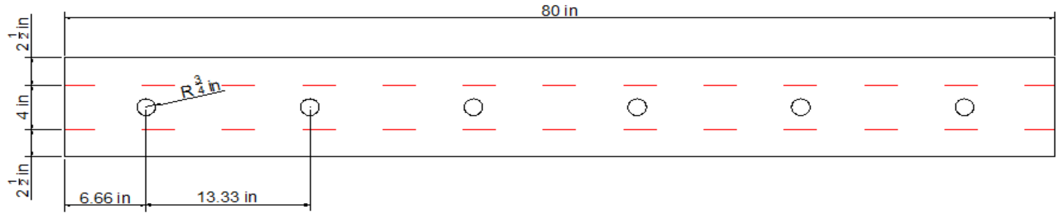


Figure 14: Tray as sheet with dimensions and bending demarcation (Prior to bending).

Final trainer support design:

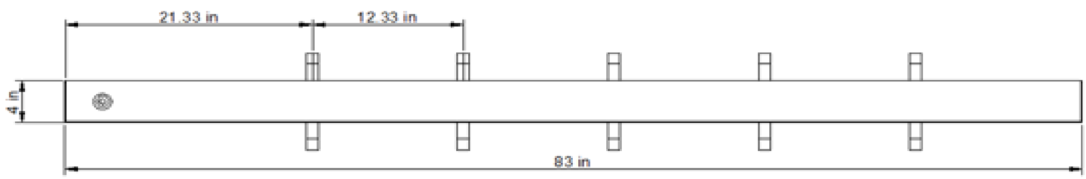


Figure 15: Tray with stainless steel supports.

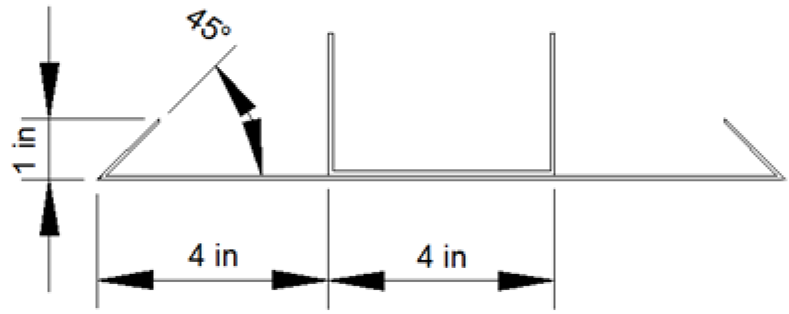


Figure 16: Support with dimensions

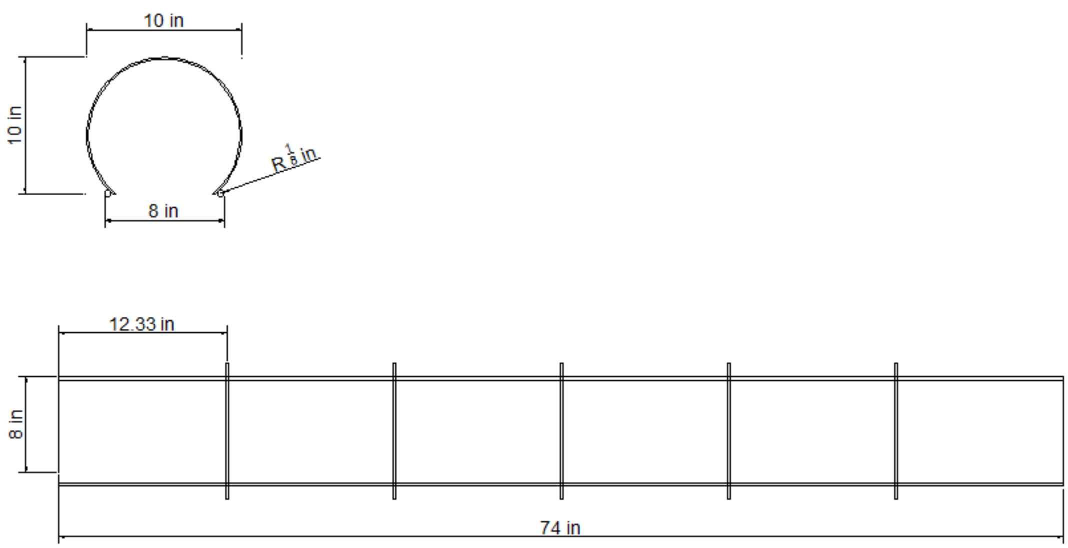


Figure 17: Trainer dimensions.

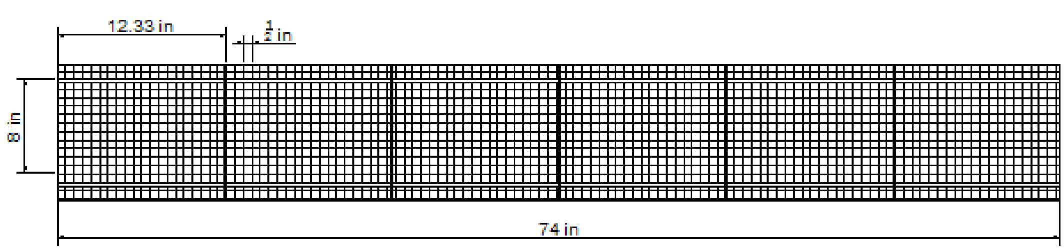


Figure 18: Trainer with ½ in. mesh.

References

Anderson, L. 1980. Leaf Variations Among Cannabis Species From a Controlled Garden". *Botanical Museum Leaflets*. Vol 28.1: pp. 61-69.

Baddoo, N. R. 2008. Stainless steel in construction: A review of research, applications, challenges and opportunities. *Journal of Constructional Steel Research* Vol. 64.11: pp. 1199-1206.

Carazo, N., Lopez, D., Mancilla, S., Martinez, A, Caceres, R Marfa O., 2005. Oxifertigation and Foliar Nutrient Contents of Closed Soilless Rose Crop. *Acta Hort*. 697, 493,497.

Clarke, R.C. 1981. *Marijuana Botany: An Advanced Study, the Propagation and Breeding of Distinctive Cannabis*. Berkeley, California. *Ronin Publishing.*

Cohen, P.J. 2009. Medical Marijuana: The Conflict Between Scientific Evidence And Political Ideology. *Utah Law Review*. Vol 23.1: pp. 72-76.

Green, G. 2010. *The Cannabis Grow Bible: The Definitive Guide to Growing Marijuana for Recreational and Medical Use*. 2nd ed. San Francisco, California.*Green Candy Publishing.*

Hillig, K., & Mahlberg, P. 2004. A Chemotaxonomic Analysis of Cannabinoid Variation in Cannabis. *American Journal of Botany*, Vol. 91.6: pp. 966-75.

Inden, H., & Torres, A. 2004. Comparison of Four Substrates on the Growth and Quality of Tomatoes. *Acta Horticulturae*, Vol. 644, pp. 205-210.

Morard, P. lacoste, L and Silvestre. 2000. Effect of oxygen deficiency on uptake of water and mineral nutrients by tomato plants in soilless culture. *Plant Nutr*. Vol 2, pp. 1063 -1078.

Resh, H. M. 2013. *Hydroponic food production: A definitive guidebook for the advanced home gardener and the commercial hydroponic grower*. 7th Edition. Boca Raton, FL.: CRC Press.

Smith, D.L. 1986. *Rockwool in Horticulture*, Grower Books No. 3, London, United Kingdom. p. 92.

Schwarz, M. 1995. *Soilless Culture Management*. Berlin, Germany. Heidelberg: Springer Berlin Heidelberg. Vol. 24.

Viraraghavan, T., K. S. Subramanian, and B. Venkata Rao. 1999. Impact of household plumbing fixtures on drinking water quality—a review. *International Journal of Environmental Studies* Vol. 56.5: pp. 717-743.