

TREE-TYPE PLANT CULTIVATION DEVICE WITH CONTROLLABLE IRRIGATION FUNCTION FOR IMPROVING LAND UTILIZATION EFFICIENCY

FIELD OF INVENTION

5 The present invention relates broadly to a tree-type plant cultivation device to be applied in the greenhouse and an approach of controllably irrigating all the plants cultivated on this device, referred specifically to a soil-based tree-type plant cultivation device for improving land utilization efficiency.

BACKGROUND

10 Due to its capabilities to accommodate beneficial and controllable growing conditions, as well as to prevent plants from pest invasion and thus minimize the usage of pesticide, greenhouse farming has become a popular and characteristic farm practice with sheltered construction for cultivating plants, through the application of transparent or semitransparent materials to adjust appropriate sunlight intensity to reach plants for photosynthesis. Traditional greenhouse farming practice employs the method of flat planting, or ridge planting, for growing crops or desirable plants. Its advantages are to
15 facilitate all the plants cultivated on the ground to uniformly receive the sunlight, and to enable easier farming managements such as irrigation and harvest, however, the major disadvantage such as low crop productivity achieved is also obvious, which leads to low land utilization efficiency and is a critical issue to be concerned under the circumstance when available land for cultivation becomes quite limited. An effective solution is to develop vertical cultivation technology by
20 designing properly perpendicular device that can solve the issues of uniform light distribution and controllable irrigation simultaneously.

The perpendicular device is the basic structure that can achieve the distribution of cultivated plants in the vertical manner. For decades, typical perpendicular devices, including board/wall-type, pillar/column/tower-type, board-tower-combined-type and A-frame type, have been fully developed
25 (DiGiacinto, 1977; von Bertrab Erdmann, 1988; Koerper, 1992; Gottlieb et al., 2009; Bribach et al., 2012; Lin, 2012; Ng, 2012; Omid, 2012; Nemec, 2015; Peterson et al., 2016; Smith, 2016; Billingsley, 2018; Storey, 2021).

Board/wall-type perpendicular device was the main vertical cultivation apparatus widely applied in recent decades. Referred to the said traditional vertical board device, a plant-cultivation board (US
30 1992/5,099,606) was invented for vertical epiphyte cultivated in the plant substrate. This invention was characterized by a board space constructed by a back wall and an opening-contained front wall, to allow the substrate to keep within the board space and the plants to penetrate the opening for photosynthesis (Koerper, 1992). Sometimes soft and permeable material may play the role of pot to support plant growth on the board/wall, US 2012/8,141,294 B2 depicted a planter wall with
35 perpendicularly-arranged fabric-made knife pleats for growing living plants in the vertical manner (Bribach et al., 2012). Another similar example was from US 2012/0066972 A1, which described a perpendicular planting apparatus which contained a water storage tank followed by an n-shaped vertical frame erected upwardly from one side of the tank. A bag-contained water permeating layer was hanged within the frame, in which these water permeable bags were

employed for growing plants(Lin, 2012). Alternatively, pots for supporting plant growth could be as the detachable components to attach to the board/wall, rather than as an entirety nested into the wholeperpendicular device. EP 2015/2885963 A1 presented a vertical board-type garden device for applying exteriors and interiors. This invention was characterized by its water troughs
5 interconnected horizontally and vertically, which were further attached to the building wall, wherein the inclined flower pots for plants and soil were attached to the water trough and the plants within were irrigated by using an irrigation wick element for the transportation of water to the pot(Nemec, 2015). In the recent design, pot's shape might be stretched as a row, to attach to the board/wall, for simultaneously growing an array of plants.US 2018/9,986,694 B2 related to a board-type vertical
10 planter containing a planter system with horizontal rows for growing plants, while each row was installed vertically and parallel to the other rows. This planter system included a vertical support, a container support and the planter containers(Billingsley, 2018).

Pillar/column/tower-type perpendicular device was another popular vertical cultivation apparatus developed in the vertical farming field. A majority of this shape was in the nested/stackable
15 manner.For example, US 1988/4,736,543 showed a pillar-type horticultural tree, which was composed of a multi-tray perpendicular planter with rotating function, as well as a closed water deposit with supporting structure to hold the planter(von Bertrab Erdmann, 1988). Normally two, four or six plant-cultivated pots in per nested/stackable were designed.US 2012/0167460 A1 invented a stackable cultivation tower system for cultivating plants.Each plant holder module was
20 available for only two plants(Omidi, 2012). In the four-pot case,US 2009/7,516,574 B2 demonstrated a vertical garden planter using a nutrient-liquid-contained reservoir as the bottom support basis, where the small modular planters with four radiating planter port for growing plants were nested and secured together above the reservoir, via a perpendicularly extending tubular pipe passing through the central openings located in these modular planters(Gottlieb et al., 2009).
25 Similarly, US D758,917 S designed a stackable pillar-type ornamental planter, each plant holder module was arranged four pot outlets available for the cultivation of four plants (Smith, 2016).For six-pot example,US 2016/9,521,811 B2 depicted a stackable multi-level plant tower composed by the vertically nested plant container modules, which included a water bowl at the top for collecting water, followed by each water tray located between the adjacent stacked plant container modules
30 (Peterson et al., 2016).

The combination of board and tower type applied in vertical cultivation apparatus has also been reported.US 2021/10,888,054 B2 depicted a vertical hydroponic tower array fixture system for growing plants, this invention was characterized by its flexibility to insert or remove individual towers from the array, while the arrangement of towers was in the board/wall manner(Storey, 2021).

A-frame type of vertical cultivation apparatus was also one of the choices applied in the vertical
35 farming field. US 1977/4,059,922 developed a sprayer hydroponic grower with A-frame construction that could support hydroponically-grown plants by penetrating the plants through side wall apertures, to expose plant root part within the interior of A-frame construction(DiGiacinto, 1977). Another example was from WO 2012/030298 A1, it described a rotating vertical racking
40 system (Sky Greens) for cultivating plants. This system included an A-shape racking-tray-contained frame, followed by a drive mechanism to drive the vertical rotation of the racking trays by means of electricity, to let the plants uniformly receive sunlight from the system top(Ng, 2012).

Looking into the irrigation approaches applied in these inventions, several manners, including trickle irrigation, sub-irrigation, flooding irrigation and hydroponic irrigation, were found (DiGiacinto, 1977; von Bertrab Erdmann, 1988; Gottlieb et al., 2009; Bribach et al., 2012; Lin, 2012; Ng, 2012; Omidi, 2012; Nemec, 2015; Peterson et al., 2016; Billingsley, 2018; Storey, 2021).

5 Trickle irrigation is widely applied in the vertical planters combined with different types. The gravity-aided trickle irrigation was adopted as the irrigation system in a vertical board-type garden panel (US 2012/8,141,294 B2), which arranged the watering of plants from the irrigation tubing located at the top of the panel, and subsequently collected the excessive water into a channeled frame and removed them by a water outlet at the bottom, where a water pump was used to circulate
10 water in the system (Bribach et al., 2012). In another example, the application of water on the plants grown in a vertical n-shaped (board-type) planting apparatus (US 2012/0066972 A1) was achieved by pumping the irrigation water from the storage tank to the top of frame and distributing downwardly by the aligned penetrating holes. The irrigation water was then permeated through the permeating layer and down to each bag, and subsequently permeated out of bags and sequentially
15 down to the bottom of frame and finally down to the storage tank (Lin, 2012). For pillar/column/tower case, the implementation of irrigation in a pillar-type plant tower (US 2016/9,521,811 B2) was through the water bowl as a reservoir in fluid communication with each weep-hole-contained water tray, to manage water flow to pass through all the modules (Peterson et al., 2016). In the board-tower-combined-type example, the means of irrigation in a vertical
20 board-tower-combined-type hydroponic tower array fixture system (US 2021/10,888,054 B2) was provided through transporting water to the upper bracket and letting it trickle down through respective hydroponic towers to the lower bracket, and eventually collecting it by a reservoir (Storey, 2021).

Sometimes the upward transportation of water under trickle irrigation approach did not turn to water
25 pump, while resorted to air lift method by using air pump. The irrigation of plants in a vertical garden invention (US 2009/7,516,574 B2) was achieved by firstly connecting an external air pump with the air inlet port of a manifold within the reservoir, and subsequently flowing the compressed air together with nutrient liquid via the manifold and up to a diffuser plate at the top, afterwards, such nutrient liquid was trickled down and soaked the plant substrate in the upper planter ports, the
30 transudatory liquid was then further trickled down and soaked the substrate in the lower ones via gravity (Gottlieb et al., 2009).

Sub-irrigation is also a popular way of irrigation. As found, the irrigation on plants in the invention (US 1988/4,736,543) has recourse to capillary action to transport water from the deposit to reach the trays (von Bertrab Erdmann, 1988). A more popular sub-irrigation approach was by combining
35 with champagne tower theory, to guarantee that each module planter in the vertical cultivation apparatus could equally receive water. In EP 2015/2885963 A1, the transportation of water among different rows was executed by an overflow tube connected to each higher row, which allowed water to be carried to the lower rows of water troughs under the occurrence of overflow, the distribution of water among the water troughs at the same row was achieved by having an opening
40 on the sidewall of each water trough and connecting it to the adjacent trough (Nemec, 2015).

Flooding irrigation is the traditional irrigation approach. In the currently-developed vertical cultivation apparatus, flooding irrigation could be achieved by applying water from the top

container/pot, then let it successively down through all the below containers/pots by means of gravity. For example, the watering of plants in US 2018/9,986,694 B2 was executed by applying water from the top planter container to the lower container by means of a water guide, and finally down to a moisture receptacle located at the bottom (Billingsley, 2018). Another way in this category was through applying water to each module planter via water pump. In US 2012/0167460 A1, there was a circulating irrigation system including reservoir, master irrigation feed line, water return pipe and pump contained in this invention to provide water to stackable plant modules at different height (Omidi, 2012).

Hydroponic irrigation is the way particularly used in hydroponic cultivation. The irrigation could be achieved by immersing the roots into the water, such as the case on WO 2012/030298 A1, which irrigated plants in this system by pumping water into an elevated tank and let plant roots underneath the tray immerse and through the water in the tank when the plant-contained trays were rotating (Ng, 2012). Another manner under this category was by using the spraying device to directly spray on the roots. In US 1977/4,059,922, a spraying device was simultaneously arranged on the bottom pan to spray liquid nutrient solution upwardly onto the roots to facilitate absorption (DiGiacinto, 1977).

Although many prior related inventions have been introduced through the past several decades, several disadvantages which are yet to be overcome are still existed. Firstly, the different configurations of inventions such as board/wall-type and vertical pillar/column/tower-type may significantly affect the uniform light distribution on the apparatus, if applying them outdoors when the position of sunlight source is changing periodically. For example, the plant on the board/wall-type vertical cultivation apparatus could only fully receive sunlight when it is not blocked by the adjacent plants, normally speaking, the plants on the upper module planter of the vertical pillar/column/tower-type apparatus would largely shade the plants grown on the lower module planters while sunlight source is overhead the device. Secondly, the irrigation approaches adopted by the majority of the inventions all required the participation of pump, which inevitably consumed electricity during the cultivation, and thus increased the production/operation cost. Thirdly, all the prior inventions seemed not to consider the mosquito-breeding issue when the irrigated water is directly exposed to the air.

Embodiments of the present invention seek to address at least one of the above problems.

SUMMARY

In accordance with the first aspect of the present invention, there is provided a tree-type plant cultivation device with controllable irrigation function comprising:

a cone-shape main frame having multi-story of stack-up cultivation layers;

all the cultivation layers having the similarly circular appearance in the multi-story structure stacking up and gradually decreasing their diameters till the top layer where only the place for one standardized pot is accommodated;

each cultivation layer having an annular sandwich structure reservoir for storing water for sub-irrigation purpose;

the upper surface of each cultivation layer having the cavities that are uniformly distributed along the circumference of the layer; and

each reservoir cavity having the identical size of circular shape that is adaptable to the standardized pot for cultivating plant;

- 5 the side of each standardized pot attached by a sponge-made ring configuration to fully cover the reservoir cavity to prevent water from evaporation and mosquito from breeding inside the sandwich structure reservoir;

wherein the combination of champagne tower theory and sub-irrigation, adopted as the irrigation approach in this invention, is a controllable way for watering all the plants cultivated in this
10 tree-type plant cultivation device.

In accordance with a first aspect of the present invention, there is provided an approach of cultivating plants outdoors or in the greenhouse using the tree-type plant cultivation device of the first aspect.

BRIEF DESCRIPTION OF THE DRAWINGS

- 15 Embodiments of the invention will be better comprehended and easily apparent to one of the normal skill in the art based on the following written description, by way of example only, and together with the drawings, in which:

FIG. 1 is a three-dimensional schematic view of a tree-type plant cultivation device with controllable irrigation function according to an example embodiment.

- 20 FIG. 2 is a three-dimensional schematic view of a tree-type plant cultivation device with controllable irrigation function according to an example embodiment with all the plants(leafy vegetables) cultivated on the standardized pots, demonstrating its application in a green house.

FIG. 3 is the top view of the tree-type plant cultivation device with controllable irrigation function according to an example embodiment showing the arrangements of all the standardized pots in all
25 the cultivation layers.

FIG. 4 is the top view of the tree-type plant cultivation device with controllable irrigation function according to an example embodiment with all the plants(leafy vegetables) cultivating on all the cultivation layers.

- FIG. 5 is the top view of the floor space of the tree-type plant cultivation device with controllable
30 irrigation function according to an example embodiment, showing the arrangements of all the standardized pots, in the event of cultivation using flat planting approach (control condition).

FIG. 6 is the top view of the floor space of the tree-type plant cultivation device with controllable irrigation function according to an example embodiment with all the plants(leafy vegetables), in the event of cultivation using flat planting approach (control condition).

FIG. 7 is the cross-section view of the tree-type plant cultivation device with controllable irrigation function according to an example embodiment, demonstrating theirrigation route map of the champagne-tower-theory-based sub-irrigation approach.

5 FIG. 8 is the cross-section view of the tree-type plant cultivation device with controllable irrigation function according to an example embodiment with all the plants (leafy vegetables) cultivating on all the cultivation layers, showing the sub-irrigation approach to water the plants.

FIG. 9 is the top view of the bottom cultivation layer of the tree-type plant cultivation device with controllable irrigation function according to an example embodiment, exhibiting the arrangements of all the bottom supporting pillars to improve the stability of the device.

10 FIG. 10 is the cross-section view of the tree-type plant cultivation device with controllable irrigation function according to an example embodiment with plants(leafy vegetables) cultivating on the cultivation layers, explaining in detail the champagne tower theory.

15 FIG. 11 is the cross-section view of the tree-type plant cultivation device with controllable irrigation function according to an example embodiment, displaying the installation of the standardized pot onto the reservoir cavity of the cultivation layers for avoiding water to directly expose to the atmosphere.

FIG. 12 shows the different cone-shape configurations of the tree-type plant cultivation device with controllable irrigation function according to an example embodiment, for achieving different productivities under the same floor space.

20 DETAILED DESCRIPTION

Embodiments of the present invention provide a tree-type plant cultivation device that can largely improve land utilization efficiency by accommodating a stack-up structure to place the standardized pots for plants cultivated on it, whereby a cone-shape main frame is set up, for the purpose of preventing plants grown at lower cultivation layers from being shaded by the higher ones.

25 Additionally, embodiments of the present invention is equipped with a sub-irrigation system by means of champagne tower theory, to precisely control the full irrigation of all the plants cultivated on the device. This maximizes the water distribution on all the cultivation layers and significantly minimizes the manpower and electric energy employed for watering the plants on the device. The result is enhanced productivity of transplanted plants, more efficient utilization of land and water,

30 and thus higher profitability owing to lower operation and production costs and increased yields.

One example embodiment of the present invention normally comprises a cone-shape main frame constructed by stack-up cultivation layers, the stack-up rule is to guarantee that at least half of standardized pot mouth on the lower cultivation layer is not blocked by the adjacently upper cultivation layer, the numbers of cultivation layers applied are subjected to the height of the device

35 determined and floor space provided, and the productivity of the device can be further adjusted based on the coning angle and device height selected when floor space is fixed. The main device frame additionally providesannular sandwich structure reservoir within each cultivation layer for storing water for sub-irrigation purpose, and the upper surface of each cultivation layer is uniformly

distributed the standardized reservoir cavities for the placement of the standardized pots, and the side of each standardized pot is attached by a sponge-made ring configuration to completely cover the corresponding reservoir cavity to prevent water from evaporation and mosquito from breeding inside the sandwich structure reservoir, according to an example embodiment. To let all the cultivation layers fully receive water by transferring them into sandwich structure reservoir for sub-irrigation, tap water from faucet firstly goes through the central pillar and flows up to the top cultivation layer by means of hydraulic pressure provided by the municipal water system, the distribution of water into each sandwich structure reservoir is then achieved by champagne tower theory, meaning when the water level is full to the brim or the designated height of the reservoir in the top cultivation layer, water via the small plastic connecting pipe will flow down to the underneath reservoir of the second cultivation layer, the reservoir of the third cultivation layer can then receive water only when the reservoir of the second cultivation layer is full. The distribution procedure is therefore continued till the reservoir of the bottom cultivation layer is full. The irrigation can be terminated when water is dripped out from the small plastic connecting pipe connected from the reservoir of the bottom cultivation layer to the ground. Advantageously, embodiments of the present invention can generate an unblocked lighting environment for all the plants vertically distributed and cultivated on the device, as well as provide an electric-energy-free irrigation operation approach, thereby enhancing the land utilization efficiency, decreasing the land and production/operation costs of plant cultivation and maximizing the productivity of plant biomass.

In one example embodiment, the stability of tree-type plant cultivation device can be achieved by the synergistic actions of the central pillar, as well as the bottom supporting pillars uniformly distributed under the bottom cultivation layer, and layer supporting pillars beneath the annular sandwich structure reservoir of each cultivation layer. Under such design, embodiments of the present invention can firmly stand on the ground and remain the safe status to avoid the abrupt collapse of any cultivation layer to further hurt the operator nearby.

Embodiments of the present invention can provide an economical tree-type plant cultivation device that can be conveniently installed on the ground of the greenhouse. It can be used to enhance the land utilization efficiency, leading to increased plant productivity via a cone-shape stack-up structure to vertically distribute the plants cultivated on the device. In addition, the inclusion of a sub-irrigation system throughout this device, based on champagne tower theory according to an example embodiment of the present invention, can fully water all the plants cultivated on this device and simultaneously offer an electric-energy-free irrigation manner with the help of hydraulic pressure provided by the municipal water system, rather than by hand water pump which consumes electricity.

FIG. 1 is a three-dimensional schematic view of a tree-type plant cultivation device with controllable irrigation function 100 according to an example embodiment. In this specific example, eleven cultivation layers e.g. 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111 are stacked up to form a cone-shape configuration of the device through supported by a central pillar e.g. 112 and the uniformly distributed bottom supporting pillars e.g. 113 located beneath the bottom/eleventh cultivation layer 111.

Specifically, the tree-type plant cultivation device with controllable irrigation function 100, whose

first purpose is to satisfy all the plants cultivated on the device to expose to sunlight and not blocked by the proximate cultivation layer by designing the diameters of all the eleven cultivation layers e.g. 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111 involved in a progressively increasing manner, whereby the criterion is to make sure that at least half of the standardized pot mouth e.g. 3 on the bottom/lower cultivation layer such as 111 is not blocked by the adjacently upper cultivation layer e.g. 110, to allow plants to fully stretch out from the standardized pots e.g. 1, which numbers on all the eleven cultivation layers e.g. 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111 in this specific example are 1, 6, 8, 12, 16, 16, 16, 20, 20, 20, 24, respectively, a total of 159 standardized pots e.g. 1 are included (FIG. 3). Followed by the numbers of the standardized pots e.g. 1 applied on the device 100, there are the corresponding reservoir cavities e.g. 10 (FIG. 11) designed for fitting in these standardized pots e.g. 1, which positions on all the eleven cultivation layers e.g. 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111 are arranged to close to the brim of each cultivation layer as much as possible for the purpose of maximally allowing the plants to stretch out to catch sunlight for photosynthesis.

The stability of the standardized pots e.g. 1 mounted on their respective reservoir cavities e.g. 10 is further strengthened by attaching a sponge-made ring configuration e.g. 2 onto the side of the standardized pot e.g. 1, this ring configuration e.g. 2 also plays the role in fully covering the reservoir cavity e.g. 10 to prevent water from evaporation and mosquito from breeding inside the sandwich structure reservoir e.g. 6 (FIG. 10).

FIG. 2 is a three-dimensional schematic view of a tree-type plant cultivation device with controllable irrigation function 100 according to an example embodiment with all the plants (leafy vegetables) by front view e.g. 4 cultivated on the standardized pots e.g. 1, demonstrating its application in a green house.

The material utilized for fabricating the central pillar e.g. 112, as well as the bottom supporting pillars e.g. 113 and layer supporting pillars e.g. 116 in this example embodiment, is recommended as stainless steel that is high in strength and can fully stabilize and support the structure of the whole device 100 to avoid collapse, while the material to make all the cultivation layers e.g. 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111 is recommended as aluminum alloy that is about one third of the density compared with that of stainless steel, and is high in strength similar to high-quality steel, as well as cheaper in cost, compared with that of stainless-steel-made cultivation layers under the same size in different embodiments. The reason to apply aluminum alloy in all the cultivation layers e.g. 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111 is that the layers are normally stacked up and located at different heights of the device 100, thus they should be light in weight to decrease their burdens on the whole device 100, and meanwhile high in strength to fully support water contained in the sandwich structure reservoir e.g. 6 (FIG. 10) and plant by front view e.g. 4 with soil-contained standardized pot e.g. 1 on them.

FIG. 3 is the top view of the tree-type plant cultivation device with controllable irrigation function 100 according to an example embodiment, showing the arrangements of all the standardized pots e.g. 1 on all the cultivation layers e.g. 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111.

In the top view of the tree-type plant cultivation device with controllable irrigation function 100 in FIG. 3, at least half area of each of the standardized pot mouth e.g. 3 of the standardized pot e.g. 1

is visible and not blocked by any cultivation layers e.g. 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, this is based on the stack-up rule to ensure that all the plants by front view e.g. 4 (FIG. 2) cultivated on the cultivation layers can stretch out from the standardized pot mouth e.g. 3 and directly expose to sunlight for growth. As above mentioned (FIG. 1) by directly demonstrating the numbers of the standardized pots e.g. 1 on all the eleven cultivation layers 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111 from top view in FIG. 3, a total of 159 standardized pots e.g. 1 are found on this specific device 100.

FIG. 4 is the top view of the tree-type plant cultivation device with controllable irrigation function 100 according to an example embodiment with all the plants (leafy vegetables) by top view e.g. 5 cultivating on all the cultivation layers e.g. 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111.

While viewing the tree-type plant cultivation device with controllable irrigation function 100 together with full cultivated plants (leafy vegetables) by top view e.g. 5 from the top as shown in FIG. 4, it is noticed that the floor space occupied by the device 100 is completely covered by all the plants (leafy vegetables) by top view e.g. 5 cultivated, this is because the leaves of all the cultivated plants (leafy vegetables) by top view e.g. 5 on the device 100 are stacked up in a vertical distribution manner, resulting that they are not overlapped each other to block sunlight to reach some of the leaves due to the different heights they occupied, this top view evidence further proves that all the plants (leafy vegetables) by top view e.g. 5 cultivated can stretch out from the standardized pot mouth e.g. 3 (FIG. 1) and let their leaves fully catch sunlight to facilitate their healthy growth on this device 100.

FIG. 5 is the top view of the floor space, the same as that of the tree-type plant cultivation device with controllable irrigation function 100 according to an example embodiment, showing the arrangements of all the standardized pots e.g. 1 in the event of cultivation using flat planting approach (control condition).

Compared with the floor space of the tree-type plant cultivation device with controllable irrigation function 100, such area occupied by the traditional cultivation way like flat planting approach, can only arrange limited standardized pots e.g. 1 on it. In this specific case, a total of 64 standardized pots e.g. 1 can be arrayed into 4 of nested annular zones under the same floor space, this is by considering the reasonable distances among all the standardized pots e.g. 1 to achieve the fully stretched leaves of each plant by top view e.g. 5.

By comparing so, the multiple increase of the theoretical productivity enhanced by the tree-type plant cultivation device with controllable irrigation function 100, as compared to the traditional flat planting approach, can be figured out as $159/64 = 2.48$, which also refers to the results in FIG. 3 in this specific case, meaning that theoretically harvested plant numbers through traditional flat planting approach can be greatly improved by means of this specific device 100 by 148% via applying the identical floor space.

FIG. 6 is the top view of the floor space, the same as that of the tree-type plant cultivation device with controllable irrigation function 100 according to an example embodiment with all the plants (leafy vegetables) by top view e.g. 5 cultivated, in the event of cultivation using flat planting approach (control condition).

When viewing the floor space, the same as that of the tree-type plant cultivation device with controllable irrigation function 100 occupied, to cultivate plants (leafy vegetables) by top view e.g. 5 from the top as shown in FIG. 6, it is learnt that this floor space using traditional flat planting approach can't be fully covered by the leaves of all the leafy vegetables cultivated (plants by top view) e.g. 5, this is because all the cultivated plants (leafy vegetables) by top view e.g. 5 are on the same plane and height, a smaller planting density among the standardized pots e.g. 1 may result in the congestion among the leaves, which will unavoidably affect the healthy growth of plants (leafy vegetables) by top view e.g. 5. Compared with the control, the advantage of the tree-type plant cultivation device with controllable irrigation function 100 is obvious by remarkably increasing plant productivity of the floor space, followed by significantly improving land utilization efficiency.

FIG. 7 is the cross-section view of the tree-type plant cultivation device with controllable irrigation function 100 according to an example embodiment, demonstrating the irrigation route map of the champagne-tower-theory-based sub-irrigation approach.

For the principle of champagne tower theory, it refers to a group of champagne glasses that are arranged into a pyramid or cone shape, and champagne is then poured onto the top glass firstly until the liquid trickles down to the underneath layers of glasses, the rule is that the lower layer of glasses can only obtain champagne after all the glasses at the adjacently upper layer can fully receive champagne to their brims, this way is to guarantee that all the glasses can eventually completely gain champagne while not leading to overflow and waste of liquid.

Specifically, FIG. 7 depicts the cross-section view of the combination of the tree-type plant cultivation device with controllable irrigation function 100 and champagne-tower-theory-based sub-irrigation approach according to the example embodiment. In this specific example, the arrangement of all the cultivation layers e.g. 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111 with sandwich structure reservoirs 6 (FIG. 10) and all the standardized pots e.g. 1 installed on their respective layers are typically subjected to the cone shape required by champagne tower theory. In order to carry out champagne-tower-theory-based sub-irrigation, tap water is released firstly by opening the faucet switch e.g. 8 of the faucet e.g. 7 to go to the sandwich structure reservoir e.g. 6 of the top/first cultivation layer e.g. 101 via a major plastic connecting pipe e.g. 115 located inside the central pillar e.g. 112, by means of hydraulic pressure provided by municipal water system, water then flows down to the adjacently sandwich structure reservoir e.g. 6 of the second cultivation layer e.g. 102 when water level in the sandwich structure reservoir e.g. 6 reaches certain height, through the small plastic connecting pipe e.g. 114. It is only when water level in the sandwich structure reservoir e.g. 6 of the second cultivation layer e.g. 102 reaches the pre-set height, the sandwich structure reservoir e.g. 6 of the third cultivation layer e.g. 103 has the opportunity to receive water, water then flows down layer by layer till the sandwich structure reservoir e.g. 6 of the bottom/eleven cultivation layer e.g. 111. To check whether all the sandwich structure reservoirs e.g. 6 fully receive water, the small plastic connecting pipe e.g. 114 located beneath the bottom/eleven cultivation layer e.g. 111 is observed, the water supply is subsequently terminated when water drop e.g. 9 starts to drip down from the small plastic connecting pipe e.g. 114.

It is particularly noticed that such sub-irrigation approach does not require extra help from the handy water pump, meaning that it is an electric-energy-free way to irrigate all the plants on this device 100, through without the application of electricity. Such champagne-tower-theory-based

sub-irrigation approach is also a water-saving way by precisely controlling the usage of water.

Specifically, the layer supporting pillars e.g. 116 are further distributed beneath the sandwich structure reservoirs e.g. 6 of all the cultivation layers e.g. 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, this is the extra reinforcement measure to make sure that the whole device 100 has the capability to fully support these layers, followed by their soil-contained standardized pots e.g. 1, their plants, as well as water contained in their sandwich structure reservoirs e.g. 6.

FIG. 8 is the cross-section view of the tree-type plant cultivation device with controllable irrigation function 100 according to an example embodiment with all the plants(leafy vegetables) by front view e.g. 4 cultivating on all the cultivation layers e.g. 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, showing the sub-irrigation approach to water the plants by front view e.g. 4.

Specifically, FIG. 8 illustrates the cross-section view of the combination of the tree-type plant cultivation device with controllable irrigation function 100 and the champagne-tower-theory-based sub-irrigation approach performed by plants (leafy vegetables) by front view e.g. 4 according to the example embodiment. It is noted that the installation of the standardized pot e.g. 1 onto the cultivation layer e.g. 101 is achieved by firstly attaching a sponge-made ring configuration e.g. 2 onto the side of the standardized pot e.g. 1, this sponge-ring-attached standardized pot e.g. 1 is then mounted to the reservoir cavity e.g. 10 (FIG. 11) of the cultivation layer e.g. 101.

Through FIG. 8, it is further noticed that the canopy of each plant by front view e.g. 4, no matter cultivated on the bottom, the middle or the top cultivation layers, can fully receive sunlight and is not blocked by the adjacent plants, through the application of this cone-shape device 100, which is the essential step to facilitate the healthy growth of plants on this device 100.

FIG. 9 is the top view of the bottom (eleventh) cultivation layer e.g. 111 of the tree-type plant cultivation device with controllable irrigation function 100 according to an example embodiment, exhibiting the arrangements of all the bottom supporting pillars e.g. 113 to improve the stability of the device.

Specifically, FIG. 9 depicts that a total of 25 bottom supporting pillars e.g. 113 can be arrayed into 4 of nested annular zones in the distribution manner of 8, 7, 7, 3 beneath the bottom (eleventh) cultivation layer e.g. 111, this is very necessary to guarantee that the foundation of the device 100 is steady enough to fully support the whole device 100, including all the cultivation layers e.g. 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, as well as 159 of the standardized pots with plants and soils, along with water contained in all the sandwich structure reservoirs e.g. 6.

FIG. 10 is the cross-section view of the tree-type plant cultivation device with controllable irrigation function 100 according to an example embodiment with plants(leafy vegetables) by front view e.g. 4 cultivating in the cultivation layers e.g. 101, 102, 103, explaining in detail the champagne tower theory.

Specifically, FIG. 10 illustrates the detailed champagne tower theory operated on the device 100, which key design is to arrange the water inlet height of the small plastic connecting pipe e.g. 114 to located at the top brim or desired height of the sandwich structure reservoir e.g. 6 of the

top/firstcultivation layer e.g. 101, only to allow water to flow down to the adjacently lower cultivation layer e.g. 102 when water level in the sandwich structure reservoir e.g. 6 reaches the inlet of the small plastic connecting pipe e.g. 114. In addition, there is no particular rule for the position of the water outlet of the small plastic connecting pipe e.g. 114 and the only requirement is to let it within the sandwich structure reservoir e.g. 6 of the lower cultivation layer e.g. 102, for water guidance purpose. Following this, the distribution of water on the sandwich structure reservoirs e.g. 6 of all the underneath cultivation layer e.g. 103, 104, 105, 106, 107, 108, 109, 110, 111 is thus carried out till the appearance of water drop e.g. 9 starting to drip down from the small plastic connecting pipe e.g. 114 beneath the bottom/eleventh cultivation layer e.g. 111 (FIG. 7).

FIG. 11 is the cross-section view of the tree-type plant cultivation device with controllable irrigation function 100 according to an example embodiment, displaying the installation of the standardized pot e.g. 1 onto the cultivation layer e.g. 103 for avoiding water evaporation and preventing mosquito from breeding in the sandwich structure reservoir e.g. 6.

Specifically, FIG. 11 depicts the procedures on how to set up the standardized pot e.g. 1 onto the cultivation layer e.g. 103 to minimize water vapor to escape from the juncture between the standardized pot e.g. 1 and the reservoir cavity e.g. 10 and block mosquito to go into the sandwich structure reservoir e.g. 6 to breed. As known, water evaporation is an unavoidable phenomenon under the circumstance when water is exposed to the atmosphere, too fast speed of evaporation may thus increase the operation cost of the device 100, furthermore, mosquito breeding is a serious issue to be concerned as this kind of insect may transmit dengue virus, which can lead to severe disease threatening human's health, especially in tropical zone. To achieve the above goal, a special structure, sponge-made ring configuration e.g. 2, should be attached to the standardized pot e.g. 1. This structure is characterized by an annular configuration and is firmly attached to the side of the standardized pot e.g. 1 through the application of glue or the like. Furthermore, the installation of the standardized pot e.g. 1 onto the cultivation layer e.g. 103 should simultaneously satisfy the criterion that the distance between the low edge of the sponge-made ring configuration e.g. 2 and the bottom of the standardized pot e.g. 1 is slightly shorter than the depth of the sandwich structure reservoir e.g. 6, this is to guarantee that the juncture between the standardized pot e.g. 1 and the reservoir cavity e.g. 10 is enclosed enough because sponge possesses elasticity and can be compressed.

FIG. 12 shows the different cone-shape configurations of the tree-type plant cultivation device with controllable irrigation function 100 according to an example embodiment, for achieving different productivities under the same floor space.

Specifically, FIG. 12 illustrates the possibility to enhance the productivity of the device 100 under the fixed floor space. As found, the plants cultivated are all distributed on the lateral surface of the cone-shape device 100, thus, the current design can only fit into the fixed productivity of the device 100 under the designated floor space because lateral surface area of cone under fixed height and floor space area of cone is also fixed. Abstractly, plant productivity on this device 100 is decided by the length of generating line, the height of the cone, as well as the coning angle if the base area (BA) and radius (R) of the floor space are fixed. To simplify the expression, a relation among the generating line (GL), cone height (H), along with half of the coning angle ($\frac{\alpha}{2}$) is built as formula (1):

$$\cos \frac{\alpha}{2} = \frac{H}{GL} \quad (1)$$

Following this, the theoretical productivity multiple (TPM), as compared to the control (flat planting approach), is expressed as formula (2):

$$TPM = \frac{LSA}{BA} = \frac{\pi \cdot R \cdot GL}{\pi \cdot R^2} = \frac{GL}{R} = \frac{GL}{GL \cdot \sin \frac{\alpha}{2}} = \csc \frac{\alpha}{2} \quad (2)$$

5 where LSA stands for the lateral surface area of the cone.

According to the characteristics of cone, it is showed that the best way to increase LSA of the cone is by increasing the cone height from H in the control cone e.g. 118 to H_H in the LSA-improved cone e.g. 119, and decreasing the size of half of the coning angle from $\frac{\alpha}{2}$ to $(\frac{\alpha}{2})_H$, with longer generating line (GL_H) under the same base area. Vice versa, the way to decrease cone LSA is through reducing the cone height from H in the control cone e.g. 118 to H_L in the LSA-reduced cone e.g. 117, and increasing the size of half of the coning angle from $\frac{\alpha}{2}$ to $(\frac{\alpha}{2})_L$, with shorter generating line (GL_L) under the same base area.

By analyzing so, it is obvious that the intention to increase TPM is to elevate the height of the cone, followed by shortening the diameter differences of the two adjacent cultivation layers, however, it may result that the plants are a bit hard to fully stretch out from the standardized pot mouth e.g. 3 of the standardized pots e.g. 1. In real practice, such disadvantage can be solved by increasing the layer distance of the two adjacent cultivation layers, to allow that plants can also completely stretch in their interlayer space.

Observing Table 1, the currently demonstrated eleven cultivation layers of device 100 has a 2.48 of TPM, which is close to 24° of half of the coning angle which TPM is 2.46. Theoretically, TPM of the device 100 is recommended to reach around 5 (around 11.5° of half of coning angle), meaning 5-fold of the productivity as compared to the control. This is because although a smaller half of the coning angle may achieve a higher TPM and productivity, a higher device 100 may lead to its higher center of gravity, further resulting in its instability, on the other hand, many of higher taper devices 100 stand together may unavoidably block more of sunlight to reach the plants cultivated on the lower cultivation layers.

In the example embodiment described above with reference to Figures 1 to 12, a tree-type plant cultivation device with controllable irrigation function for enhancing land utilization efficiency and plant productivity in greenhouse or the place likewise by means of the cone-shape stack-up structure, as well as champagne-tower-theory-based sub-irrigation approach, is provided, in which all the cultivation layers stacked possess the similarly circular appearance and gradually decrease their diameters till the one-plant-contained top layer, to allow every plant grown on the device to fully receive sunlight and is not blocked by the adjacent plants. In addition, the device can simultaneously guarantee that every plant on it can receive enough water for growth through sub-irrigation approach and water distribution mechanism by champagne tower theory.

Table 1. The relation among half of the coning angle, floor space, generating line, height and productivity of the tree-type plant cultivation device

Angle ^a	Radius of floor space	Floor space	Generating line	Height	Theoretical productivity multiple ^b
$\frac{\alpha}{2}$ (°)	R (m)	A (m ²)	GL (m)	H (m)	TPM (times)
90 ^c	0.65	1.327	0.65	0.00	1.00 ^d
75 ^o	0.65	1.327	0.67	0.17	1.04
60 ^o	0.65	1.327	0.75	0.38	1.15
45 ^o	0.65	1.327	0.92	0.65	1.41
30 ^o	0.65	1.327	1.30	1.13	2.00
29 ^o	0.65	1.327	1.34	1.17	2.06
28 ^o	0.65	1.327	1.38	1.22	2.13
27 ^o	0.65	1.327	1.43	1.28	2.20
26 ^o	0.65	1.327	1.48	1.33	2.28
25 ^o	0.65	1.327	1.54	1.39	2.37
24 ^o	0.65	1.327	1.60	1.46	2.46
23 ^o	0.65	1.327	1.66	1.53	2.56
22 ^o	0.65	1.327	1.74	1.61	2.67
21 ^o	0.65	1.327	1.81	1.69	2.79
20 ^o	0.65	1.327	1.90	1.79	2.92
19 ^o	0.65	1.327	2.00	1.89	3.07
18 ^o	0.65	1.327	2.10	2.00	3.24
17 ^o	0.65	1.327	2.22	2.13	3.42
16 ^o	0.65	1.327	2.36	2.27	3.63
15 ^o	0.65	1.327	2.51	2.43	3.86
14 ^o	0.65	1.327	2.69	2.61	4.13
13 ^o	0.65	1.327	2.89	2.82	4.45
12 ^o	0.65	1.327	3.13	3.06	4.81
11 ^o	0.65	1.327	3.41	3.34	5.24
10 ^o	0.65	1.327	3.74	3.69	5.76
5 ^o	0.65	1.327	7.46	7.43	11.47
0 ^o	0.65	1.327	∞	∞	∞

^aAngle here means half of the coning angle, which is the included angle between the generating line and the height of the cone. ^bThis is the multiple of the theoretical plant productivity under certain half of the coning angle compared with the 5 control (flat planting). ^c90° is set as the control condition (flat planting) for tree-type plant cultivation device. ^d1.00 is set as the plant productivity under flat planting.

In a specific example, eleven of the aluminum-alloy-made cultivation layers with different diameters are stacked up in a cone-shape configuration, which stability is achieved by a stainless-steel-made central pillar, followed by the uniform distribution of bottom supporting pillars located beneath the bottom (eleven) cultivation layer, the steadiness of the device is further guaranteed by the layer supporting pillars evenly distributed beneath the sandwich structure reservoir of each cultivation layer other than the bottom one.

The tree-type plant cultivation device with controllable irrigation function according to the example

embodiment described above further contains the annular sandwich structure reservoir in each cultivation layer to store water for sub-irrigation purpose. These sandwich structure reservoirs located along the brim of each cultivation layer, suggested to be fabricated by aluminum alloy material, are made to be enclosed to prevent water leakage. The reservoir cavities opened on the
5 upper surface of the sandwich structure reservoir are distributed along the circumference of the circular cultivation layer.

In the example embodiment described, the connection among each sandwich structure reservoir is arranged with the small plastic connecting pipes, in which the inlet of the pipe is connected to the top brim or desired height of the sandwich structure reservoir of the upper cultivation layer, just to
10 guide water to flow down to the adjacently lower cultivation layer under the circumstance that water level in the reservoir of the upper cultivation layer reaches pipe inlet. In addition, there is a hole located at the reservoir upper surface of the adjacently lower cultivation layer, prepared for connecting to the water outlet of the small plastic connecting pipe connected from the higher cultivation layer.

In the described example embodiment, champagne tower theory is adopted as the water distribution mechanism on the device, where tap water is powered by municipal hydraulic pressure to firstly reach the top/first cultivation layer reservoir through the plastic-connecting-pipe-contained central pillar, the next-step distribution of water down to the adjacently cultivation layer reservoir is carried out when water level in the top/first cultivation layer reservoir attains required height. Water is thus
20 guided down to the bottom/eleven cultivation layer till water drop drips down from the small plastic connecting pipe connecting to the ground. Then the irrigation action is terminated, thus to implement controllable irrigation function on this device.

Applying aluminum alloy rather than stainless steel in the example embodiment is advantageous because of the manufacturing material of the cultivation layers for cutting down the manufacturing
25 cost of the invention, followed by reducing the weight burden onto the whole device.

Employing stainless steel rather than aluminum alloy in the example embodiment is advantageous as the manufacturing materials of the central and bottom/layer supporting pillars for strengthening the stability of the invention.

In the described example embodiment, the issues on how to avoid water evaporation from cultivation layer reservoir, as well as on how to prevent mosquito-breeding in the reservoir are settled down by means of a sponge-made ring configuration attached to the side of the standardized pot, to keep the juncture between the standardized pot and the reservoir cavity firmly closed.
30

Under the same floor space, plant productivity of the tree-type plant cultivation device with controllable irrigation function of the example embodiment can be improved by enhancing the height of device, followed by shortening the diameter differences of any two adjacent cultivation layers, subjected to the situation when all the plants cultivated can fully stretch out from the
35 standardized pot mouth.

The tree-type plant cultivation device with controllable irrigation function according to example embodiments may be applied in all the greenhouse involving in the cultivation of plants, for

improving their productivities and increasing land utilization efficiency in the greenhouse, meaning that the higher plant productivity of the designated floor space/the whole greenhouse may thus be achieved through this device. This is especially useful for countries like Singapore and regions such as Hong Kong, China, where their lands are limited, for developing the plant factories.

5 Also, the tree-type plant cultivation device with controllable irrigation function according to example embodiments is capable of decreasing water evaporation and consumption in the cultivation layer reservoirs, hence playing a positive role in reducing water loss and maintaining a low-carbon notion for environmental sustainability.

10 Also, the tree-type plant cultivation device with controllable irrigation function according to example embodiments is capable of preventing mosquito-breeding in the cultivation layer reservoirs, hence providing contribution on minimizing environmental hazards brought by mosquito.

15 Also, the manufacturing cost of the tree-type plant cultivation device with controllable irrigation function according to example embodiments is cost-effective as a majority of the device manufacturing material is aluminum alloy, which is one third price of that of stainless steel that is only applied in the central and the bottom/layer supporting pillars.

Also, the irrigation operation cost of the tree-type plant cultivation device with controllable irrigation function according to example embodiments is electric-energy-free because the transportation of water to the top/first cultivation layer is executed through only seeking support from hydraulic pressure provided by the municipal water system.

20 Embodiments of the present invention can have one or more of the following features and associated benefits/advantages (Table 2):

Table 2. Features and benefits/advantages of the tree-type plant cultivation device with controllable irrigation function

Feature	Benefit/Advantage
Each plant cultivated on the device can fully receive sunlight.	Each plant is not blocked by adjacently upper cultivation layer in order to maximize sunlight-catching by plant canopy.
Each plant cultivated on the device can absorb enough water.	Champagne-tower-theory-based sub-irrigation approach allows for precise regulation of irrigation to water plants.
Water transportation for irrigation by means of municipal hydraulic pressure and gravity.	Zeroelectric energy cost forirrigation
Higher plant productivity	Land utilization efficiency can be significantly enhanced, compared with flat planting approach.

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CLAIMS

1. A tree-type plant cultivation device with controllable irrigation function comprising:
a cone-shape main frame having multi-story ofstack-up cultivation layers;
each cultivation layer having an annular sandwich structure reservoir for storing water for
5 sub-irrigation purpose;
the upper surface of each cultivation layer having the cavities that are uniformly distributed along
layer circumference and adaptable to the standardized pot for cultivating plant;
each standardized pot attached by a sponge-made ring configuration to fully cover the reservoir
cavity to prevent water from evaporation and mosquito from breeding inside the sandwich structure
10 reservoir;
wherein the combination of champagne tower theory and sub-irrigation is a controllable way for
watering all the plants cultivated in this tree-type plant cultivation device.
2. The tree-type plant cultivation device with controllable irrigation function of claim 1, wherein a
cone-shape main frame requiresall the cultivation layers having the similarly circular
15 appearance in the multi-story structure, which is stacked up and which diameter is gradually
decreased till the top layer.
3. The tree-type plant cultivation device with controllable irrigation function of claim 2, wherein
each plant cultivated on the device can fully receive sunlight and is not blocked by the adjacent
plants.
- 20 4. The tree-type plant cultivation device with controllable irrigation function of claim 3, wherein
each cultivation layer contains an annular sandwich structure reservoir which is enclosed for
storing water for sub-irrigation purpose.
5. The tree-type plant cultivation device with controllable irrigation function of claim 4,
whereinthe reservoir cavities are uniformly distributed on the upper surface of each cultivation
25 layeralong the circumference.
6. The tree-type plant cultivation device with controllable irrigation function of claim 5, wherein
each reservoir cavity is adaptable to the respective standardized pot for cultivating plant.
7. The tree-type plant cultivation device with controllable irrigation function of claim 6, wherein
the side of each standardized pot is attached by a sponge-made ring configuration to fully cover
30 the corresponding reservoircavity to prevent water from evaporation and mosquito from
breeding inside the sandwich structure reservoir.
8. The tree-type plant cultivation device with controllable irrigation function of claim 7,
whereinthe synergistic action of the central pillar, as well as the bottom supporting pillars

uniformly distributed under the bottom cultivation layer, and layer supporting pillars beneath the annular reservoir of each cultivation layer, respectively, is for maintaining the stability of the whole tree-type plant cultivation device standing in the greenhouse.

- 5 9. The tree-type plant cultivation device with controllable irrigation function of claim 8, wherein aluminum alloy is preferred as the manufacturing material of the cultivation layers, while stainless steel is preferred as the manufacturing material of the central and bottom/layer supporting pillars.
- 10 10. The tree-type plant cultivation device with controllable irrigation function of claim 9, wherein the combination of champagne tower theory and sub-irrigation is a controllable way for precise regulation of watering all the plants cultivated in this tree-type plant cultivation device.
11. The tree-type plant cultivation device with controllable irrigation function of claim 10, wherein the irrigation operation cost is free through the application of hydraulic pressure provided by the municipal water system.
- 15 12. An approach of improving land utilization efficiency in the greenhouse using the tree-type plant cultivation device with controllable irrigation function of any one of the preceding claims.