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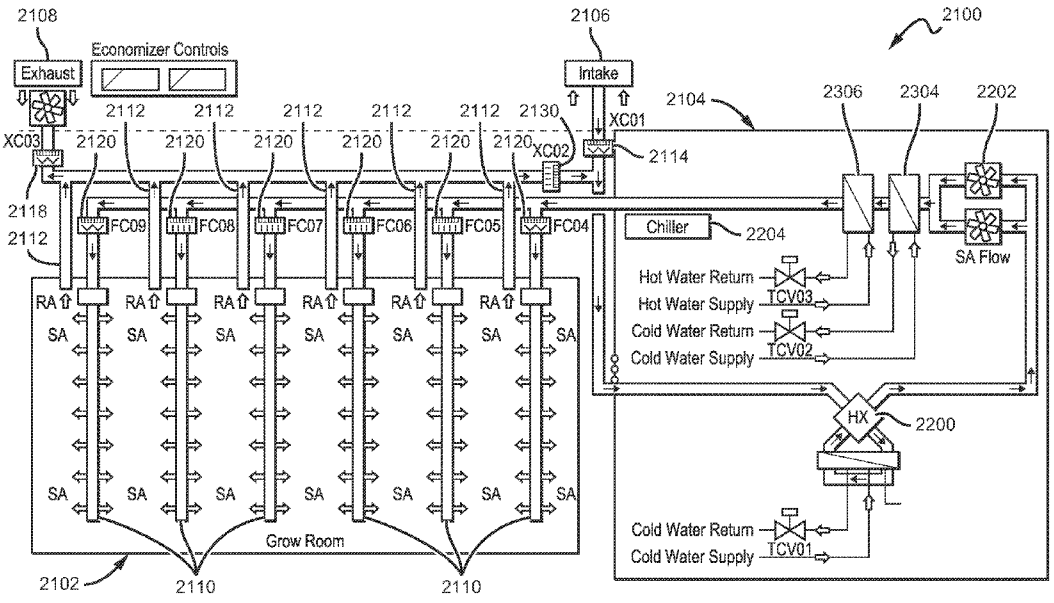


FIG. 21

(57) Abstract: Systems, methods and computer-readable media are provided for entering a fail safe mode for a controlled agricultural environment (CAE). The CAE includes movable receptacle supports for holding plants. In response to determining a fault condition in the CAE or in environmental conditioning equipment for the CAE, operation of the CAE or the environmental conditioning equipment is controlled to effect a change from a standard operating mode to a fail safe mode. The standard operating mode corresponds to desired environmental conditions in the CAE and the fail safe mode corresponds to non-ideal environmental conditions.

WO 2021/055444 A1

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FAULT HANDLING IN CONTROLLED ENVIRONMENT AGRICULTURE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of priority of US Provisional Patent Application No. 62/903,515, filed 20 September 2019, which is incorporated by reference herein in its entirety.

BACKGROUND

Field of the disclosure

[0002] The disclosure relates generally to the field of agriculture, and in particular to handling faults within a controlled agricultural environment.

Description of the related art

[0003] The subject matter discussed in the background section should not be assumed to be prior art merely as a result of its mention in the background section. Similarly, a problem mentioned in the background section or associated with the subject matter of the background section should not be assumed to have been previously recognized in the prior art. The subject matter in the background section merely represents different approaches, which in and of themselves may also correspond to implementations of the claimed technology.

[0004] During the twentieth century, agriculture slowly began to evolve from a conservative industry to a fast-moving high-tech industry in order to keep up with world food shortages, climate change, and societal changes. Farming began to move away from manually-implemented agricultural techniques toward computer-implemented technologies. Conventionally, farmers only have one growing season to produce the crops that would determine their revenue and food production for the entire year. However, this is changing. With indoor growing as an option, and with better access to data processing technologies and other advanced techniques, the science of agriculture has become more agile. It is adapting and learning as new data is collected and insights are generated.

[0005] Advancements in technology are making it feasible to control the effects of nature with the advent of "controlled indoor agriculture," otherwise known as "controlled environment agriculture." Improved efficiencies in space utilization and lighting, a better understanding of hydroponics, aeroponics, and crop cycles, and advancements in environmental control systems have allowed humans to better recreate environments conducive for agriculture crop growth with the goals of greater harvest weight yield per square foot, better nutrition and lower cost.

[0006] US Patent Publication Nos. 2018/0014485 and 2018/0014486, both assigned to the assignee of the present disclosure and incorporated by reference in their entirety herein, describe environmentally controlled vertical farming systems. The vertical farming structure (e.g., a vertical column) may be moved about an automated conveyance system in an open or closed-loop fashion, exposed to precision-controlled lighting, airflow and humidity, with ideal nutritional support.

[0007] US Patent Pub. No. US 2017/0055460 ("Brusatore") describes a system for continuous automated growing of plants. A vertical array of plant supporting arms extends radially from a central axis. Each arm includes pot receptacles which receive the plant seedling, and liquid nutrients and water. The potting arms are rotated beneath grow lamps and pollinating arms. However, the spacing between plants appears to be fixed.

[0008] For an indoor farm, ideally optimum growth conditions are determined for the plants and the HVAC system is adjusted to obtain those optimum growth conditions. Of course, for a particular crop the optimum growth conditions are usually those desired for an indoor farm. However, a number of factors may hamper implementation of desired conditions, including faults within the indoor farm itself or within environmental conditioning equipment for the indoor farm. For example, a chiller used in dehumidifying the air may become non-operational or operate below standard, the irrigation system may fail, or excess water may collect in the grow space. At times, the fault can be so substantial that the farm must be shut down.

[0009] A typical approach to avoiding undesired conditions due to faults is to provide redundant, backup equipment, such as an extra chiller or other equipment. However, this approach is expensive and may be unnecessary.

SUMMARY OF THE DISCLOSURE

[0010] This disclosure provides alternative approaches to anticipating and dealing with faults in controlled environment agriculture. Instead of requiring redundant equipment or shutting down the farm, embodiments of the disclosure provide a fail safe mode in which operating environmental conditions for the plants may not be ideal, but they at least maintain plant survival. Experimental observations and optimizations known in the art inform the ideal environmental conditions (e.g., setpoints) conducive to optimum performance (e.g., harvest weight) for many plants grown in indoor farms such as leaf vegetables, fruiting vegetables, flowering crops, fruits, and the like. Similarly, experimental observations and optimizations inform the non-ideal, "fail safe" conditions in which survival of such plants may be maintained, although they may not optimally thrive.

[0011] The disclosure describes systems, methods and computer-readable media storing instructions for entering a fail safe mode in a controlled agricultural environment (CAE), e.g., a grow space. This summary describes methods of embodiments of the disclosure as examples. The CAE includes plants growing in a plurality of movable receptacle supports. According to embodiments of the disclosure, in response to determining a fault condition in the CAE or in environmental conditioning equipment for the CAE, the method controls operation of the CAE or the environmental conditioning equipment to effect a change from a standard operating mode to a fail safe mode in which at least one fail safe condition in the CAE is achieved. According to embodiments of the disclosure, the standard operating mode corresponds to desired environmental conditions in the CAE and the fail safe mode corresponds to non-ideal environmental conditions. According to embodiments of the disclosure, the non-ideal conditions maintain survival of the plants.

[0012] According to embodiments of the disclosure, the fault condition includes a chiller fault, and the method comprises enabling external air to circulate in the CAE in the fail safe mode.

According to embodiments of the disclosure, the fault condition includes an irrigation fault, and the method comprises reducing illumination in the CAE in the fail safe mode. According to embodiments of the disclosure, the CAE includes a plurality of zones, the fault condition includes an irrigation fault in at least one zone, and the method comprises reducing illumination in the at least one zone in the fail safe mode.

[0013] According to embodiments of the disclosure, the fault condition includes detecting an irrigation fault for a first time period, and the method reduces illumination in the CAE after the first time period. According to embodiments of the disclosure, the fault condition includes detecting an irrigation fault for a first time period, the method reduces illumination in the CAE after the first time period, and turns off illumination after detection of the irrigation fault during a second time period after the first time period.

[0014] According to embodiments of the disclosure, the fault condition includes detecting an undesired water level in a gutter of the CAE, and the method activates a sump pump and decreases a supply pump flow in the fail safe mode. According to embodiments of the disclosure, the method further comprises increasing a return pump flow in the fail safe mode.

[0015] According to embodiments of the disclosure, the fault condition includes detecting a misalignment of a receptacle support with an irrigation source, and the method comprises preventing water flow from the irrigation source in the fail safe mode.

[0016] According to embodiments of the disclosure, the method comprises: irrigating the plurality of receptacle supports; and delaying movement of the receptacle supports along a grow line until after lapse of a first time period, wherein the first time period is based upon a time to allow for drainage of irrigation water from the receptacles supports.

[0017] According to embodiments of the disclosure, a supply tank for provides water to a plant propagation area, and the method comprises: recirculating water to the supply tank while it receives nutrients; and stopping recirculation and directing the water from the supply tank to the propagation table in response to determining that the water quality of the water is satisfactory.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] Figure 1 is a functional block diagram illustrating an example controlled environment agriculture system.

[0019] Figure 2 is a perspective view of an example controlled environment agriculture system.

[0020] Figures 3A and 3B are perspective views of an example grow tower.

[0021] Figure 4A is a top view of an example grow tower; Figure 4B is a perspective, top view of an example grow tower; Figure 4C is an elevation view of a section of an example grow tower; and Figure 4D is a sectional, elevation view of a portion of an example grow tower.

[0022] Figure 5A is a perspective view of a portion of an example grow line.

[0023] Figure 5B is a perspective view of an example tower hook.

[0024] Figure 6 is an exploded, perspective view of a portion of an example grow line and reciprocating cam mechanism.

[0025] Figure 7A is a sequence diagram illustrating operation of an example reciprocating cam mechanism.

[0026] Figure 7B illustrates an alternative cam channel including an expansion joint.

[0027] Figure 8 is a profile view of an example grow line and irrigation supply line.

[0028] Figure 9 is a side view of an example tower hook and integrated funnel structure.

[0029] Figure 10 is a profile view of an example grow line.

[0030] Figure 11A is perspective view of an example tower hook and integrated funnel structure; Figure 11B is a section view of an example tower hook and integrated funnel structure; and Figure 11C is a top view of an example tower hook and integrated funnel structure.

[0031] Figure 12 is an elevation view of an example carriage assembly.

[0032] Figure 13 is a functional block diagram illustrating an irrigation loop according to embodiments of the disclosure.

[0033] Figure 14A illustrates an example gutter according to embodiments of the disclosure; Figure 14B is a side elevation view of a collector end structure of the gutter; Figure 14C is a perspective view of the collector end structure; Figure 14D is a perspective view of a gutter section; and Figure 14E is a side elevation view of the gutter section.

[0034] Figure 15A is a perspective view of an example irrigation skid; and Figure 15B is a side elevation view of the irrigation skid.

[0035] Figure 16A is a sectional view of an irrigation line including a nozzle; Figure 16B is a perspective view of an irrigation line and nozzle; Figure 16C is a sectional view of a nozzle disposed within an aperture of the irrigation line; and Figure 16D is a side view of an alternative nozzle.

[0036] Figure 17A is a sectional view of an irrigation line including a nozzle with an air-bleed element; Figure 17B is a perspective view of an irrigation line and nozzle with an air-bleed element; and Figure 17C is a sectional view of a nozzle with an air-bleed element disposed within an aperture of the irrigation line.

[0037] Figure 18 is a schematic diagram of an irrigation line according to embodiments of the disclosure.

[0038] Fig. 19 illustrates a grow space and an environmental conditioning system for conditioning air and fluid in the grow space, according to embodiments of the disclosure.

[0039] Fig. 20 illustrates an example of a computer system that may be used to execute instructions stored in a non-transitory computer readable medium (e.g., memory) in accordance with embodiments of the disclosure.

[0040] Fig. 21 illustrates an enhanced HVAC system including an economizer subsystem and an air conditioning subsystem, according to embodiments of the disclosure.

[0041] Fig. 22 illustrates a top view of the lighting assembly for a number of grow lines of receptacle supports (e.g., towers), according to embodiments of the disclosure.

[0042] Fig. 23 illustrates an irrigation subsystem according to embodiments of the disclosure.

[0043] Fig. 24 illustrates an irrigation system for propagation tables, according to embodiments of the disclosure.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE DISCLOSURE

[0044] The present description is made with reference to the accompanying drawings, in which various example embodiments are shown. However, many different example embodiments may be used, and thus the description should not be construed as limited to the example embodiments set forth herein. Rather, these example embodiments are provided so that this disclosure will be thorough and complete. Various modifications to the exemplary embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments and applications without departing from the spirit and scope of the disclosure. Thus, this disclosure is not intended to be limited to the disclosed embodiments, but is to be accorded the widest scope consistent with the claims and the principles and features disclosed herein.

[0045] Exemplary indoor agricultural system

[0046] The following describes a vertical farm production system configured for high density growth and crop yield. Although embodiments of the disclosure will primarily be described in the context of a vertical farm in which plants are grown in towers, those skilled in the art will recognize that the principles described herein are not limited to a vertical farm or the use of grow towers, but rather apply to plants grown in any structural arrangement.

[0047] Figs. 1 and 2 illustrate a controlled environment agriculture system 10, according to embodiments of the disclosure. At a high level, the system 10 may include an environmentally-controlled growing chamber 20, a vertical tower conveyance system 200 that is disposed within the growing chamber 20 and configured to convey vertical grow towers with crops disposed therein, and a central processing facility 30. The plant varieties

that may be grown may be gravitropic/geotropic, phototropic, hydroponic, or some combination thereof. The varieties may vary considerably and include various leaf vegetables, fruiting vegetables, flowering crops, fruits, and the like. The controlled environment agriculture system 10 may be configured to grow a single crop type at a time or to grow multiple crop types concurrently.

[0048] The system 10 may also include conveyance systems for moving the grow towers in a circuit throughout the crop's growth cycle, the circuit comprising a staging area configured to load the grow towers into and out of the vertical tower conveyance mechanism 200. The central processing system 30 may include one or more conveyance mechanisms for directing grow towers to stations in the central processing system 30, e.g., stations for loading plant plugs into, and harvesting crops from, the grow towers. The vertical tower conveyance system 200 is configured to support and translate one or more grow towers 50 along grow lines 202. According to embodiments of the disclosure, the grow towers 50 hang from the grow lines 202.

[0049] Each grow tower 50 is configured to contain plant growth media that supports a root structure of at least one crop plant growing therein. Each grow tower 50 is also configured to releasably attach to a grow line 202 in a vertical orientation and move along the grow line 202 during a growth phase. Together, the vertical tower conveyance mechanism 200 and the central processing system 30 (including associated conveyance mechanisms) can be arranged in a production circuit under control of one or more computing systems.

[0050] The growth environment 20 may include light emitting sources positioned at various locations between and along the grow lines 202 of the vertical tower conveyance system 200. The light emitting sources can be positioned laterally relative to the grow towers 50 in the grow line 202 and configured to emit light toward the lateral faces of the grow towers 50, which include openings from which crops grow. The light emitting sources may be incorporated into a water-cooled, LED lighting system as described in U.S. Publication No. 2017/0146226Al, the disclosure of which is incorporated by reference in its entirety herein. In such an embodiment, the LED lights may be arranged in a bar-like structure. The bar-like

structure may be placed in a vertical orientation to emit light laterally to substantially the entire length of adjacent grow towers 50. Multiple light bar structures may be arranged in the growth environment 20 along and between the grow lines 202. Other lighting systems and configurations may be employed. For example, the light bars may be arranged horizontally between grow lines 202.

[0051] The growth environment 20 may also include a nutrient supply system configured to supply an aqueous crop nutrient solution to the crops as they translate through the growth chamber 20. The nutrient supply system may apply aqueous crop nutrient solution to the top of the grow towers 50. Gravity may cause the solution travel down the vertically-oriented grow tower 50 and through the length thereof to supply solution to the crops disposed along the length of the grow tower 50. The growth environment 20 may also include an airflow source that is configured to, when a tower is mounted to a grow line 202, direct airflow in the lateral growth direction of growth and through an under-canopy of the growing plant, so as to disturb the boundary layer of the under-canopy of the growing plant. In other implementations, airflow may come from the top of the canopy or orthogonal to the direction of plant growth. The growth environment 20 may also include a control system, and associated sensors, for regulating at least one growing condition, such as air temperature, airflow speed, relative air humidity, and ambient carbon dioxide gas content. The control system may for example include such sub-systems as HVAC units, chillers, fans and associated ducting and air handling equipment. Grow towers 50 may have identifying attributes (such as bar codes or RFID tags). The controlled environment agriculture system 10 may include corresponding sensors and programming logic for tracking the grow towers 50 during various stages of the farm production cycle or for controlling one or more conditions of the growth environment. The operation of control system and the length of time towers remain in the growth environment can vary considerably depending on a variety of factors, such as crop type and other factors.

[0052] The grow towers 50 with newly transplanted crops or seedlings are transferred from the central processing system 30 into the vertical tower conveyance system 200. Vertical tower conveyance system 200 moves the grow towers 50 along respective grow lines 202 in growth environment 20 in a controlled fashion. Crops disposed in grow towers 50 are exposed to the

controlled conditions of the growth environment (e.g., light, temperature, humidity, air flow, aqueous nutrient supply, etc.). The control system is capable of automated adjustments to optimize growing conditions within the growth chamber 20 and make continuous improvements to various attributes, such as crop yields, visual appeal and nutrient content. In addition, US Patent Publication Nos. 2018/0014485 and 2018/0014486, incorporated by reference herein, describe application of machine learning and other operations to optimize grow conditions in a vertical farming system. In some implementations, environmental condition sensors may be disposed on grow towers 50 or at various locations in the growth environment 20. When crops are ready for harvesting, grow towers 50 with crops to be harvested are transferred from the vertical tower conveyance system 200 to the central processing system 30 for harvesting and other processing operations.

[0053] Central processing system 30 may include processing stations directed to injecting seedlings into towers 50, harvesting crops from towers 50, and cleaning towers 50 that have been harvested. Central processing system 30 may also include conveyance mechanisms that move towers 50 between such processing stations. For example, as Figure 1 illustrates, central processing system 30 may include harvester station 32, washing station 34, and transplanter station 36. Harvester station 32 may deposit harvested crops into food-safe containers and may include a conveyance mechanism for conveying the containers to post-harvesting facilities (e.g., preparation, washing, packaging and storage).

[0054] Controlled environment agriculture system 10 may also include one or more conveyance mechanisms for transferring grow towers 50 between growth environment 20 and central processing system 30. In the implementation shown, the stations of central processing system 30 operate on grow towers 50 in a horizontal orientation. In one implementation, an automated pickup (loading) station 43, and associated control logic, may be operative to releasably grasp a horizontal tower from a loading location, rotate the tower to a vertical orientation and attach the tower to a transfer station for insertion into a selected grow line 202 of the growth environment 20. On the other end of growth environment 20, automated laydown (unloading) station 41, and associated control logic, may be operative to releasably grasp and move a vertically oriented grow tower 50 from a buffer location, rotate the grow tower 50 to a horizontal orientation and place it on a conveyance system for loading into

harvester station 32. In some implementations, if a grow tower 50 is rejected due to quality control concerns, the conveyance system may bypass the harvester station 32 and carry the grow tower to washing station 34 (or some other station). The automated laydown and pickup stations 41 and 43 may each comprise a six-degrees of freedom robotic arm, such as a FANUC robot. The stations 41 and 43 may also include end effectors for releasably grasping grow towers 50 at opposing ends.

[0055] Growth environment 20 may also include automated loading and unloading mechanisms for inserting grow towers 50 into selected grow lines 202 and unloading grow towers 50 from the grow lines 202. According to embodiments of the disclosure, a load transfer conveyance mechanism 47 may include a powered and free conveyor system that conveys carriages each loaded with a grow tower 50 from the automated pickup station 43 to a selected grow line 202. Vertical grow tower conveyance system 200 may include sensors (such as RFID or bar code sensors) to identify a given grow tower 50 and, under control logic, select a grow line 202 for the grow tower 50. The load transfer conveyance mechanism 47 may also include one or more linear actuators that pushes the grow tower 50 onto a grow line 202. Similarly, the unload transfer conveyance mechanism 45 may include one or more linear actuators that push or pull grow towers from a grow line 202 onto a carriage of another powered and free conveyor mechanism, which conveys the carriages 1202 from the grow line 202 to the automated laydown station 41.

[0056] Fig. 12 illustrates a carriage 1202 that may be used in a powered and free conveyor mechanism. In the implementation shown, carriage 1202 includes hook 1204 that engages hook 52 of grow tower 50. A latch assembly 1206 may secure the grow tower 50 while it is being conveyed to and from locations in the system. In one implementation, one or both of load transfer conveyance mechanism 47 and unload transfer conveyance mechanism 45 may be configured with a sufficient track distance to establish a zone where grow towers 50 may be buffered. For example, unload transfer conveyance mechanism 45 may be controlled such that it unloads a set of towers 50 to be harvested unto carriages 1202 that are moved to a buffer region of the track. On the other end, automated pickup station 43 may load a set of towers to be inserted into growth environment 20 onto carriages 1202 disposed in a buffer region of the track associated with load transfer conveyance mechanism 47.

[0057] Grow Towers

[0058] Grow towers 50 provide the sites for individual crops to grow in the system. As Figs. 3A and 3B illustrate, a tower 50 includes a hook 52 at the top. Hook 52 allows grow tower 50 to be supported by a grow line 202 when it is inserted into the vertical tower conveyance system 200. In one implementation, a grow tower 50 measures 5.172 meters long, where the extruded length of the tower is 5.0 meters, and the hook is 0.172 meters long. The extruded rectangular profile of the grow tower 50, in one implementation, measures 57mm x 93mm (2.25" x 3.67"). The hook 52 can be designed such that its exterior overall dimensions are not greater than the extruded profile of the grow tower 50. The dimensions of grow tower 50 can be varied depending on a number of factors, such as desired throughput, overall size of the system, and the like.

[0059] Grow towers 50 may include a set of grow sites 53 arrayed along at least one face of the grow tower 50. In the implementation shown in Fig. 4A, grow towers 50 include grow sites 53 on opposing faces such that plants protrude from opposing sides of the grow tower 50. Transplanter station 36 may transplant seedlings into empty grow sites 53 of grow towers 50, where they remain in place until they are fully mature and ready to be harvested. In one implementation, the orientation of the grow sites 53 are perpendicular to the direction of travel of the grow towers 50 along grow line 202. In other words, when a grow tower 50 is inserted into a grow line 202, plants extend from opposing faces of the grow tower 50, where the opposing faces are parallel to the direction of travel. Although a dual-sided configuration is preferred, the invention may also be utilized in a single-sided configuration where plants grow along a single face of a grow tower 50.

~~[0001]~~ U.S. Application Ser. No. 15/968,425 filed on May 1, 2018, which is incorporated by reference herein for all purposes, discloses an example tower structure configuration that can be used in connection with various embodiments of the disclosure. In the implementation shown, grow towers 50 may each comprise three extrusions which snap together to form one structure. As shown, the grow tower 50 may be a dual-sided hydroponic tower, where the tower body 103 includes a central wall 56 that defines a first tower cavity 54a and a second tower cavity 54b. Fig. 4B provides a perspective view of an exemplary dual-sided, multi-

piece hydroponic grow tower 50 in which each front face plate 101 is hingeably coupled to the tower body 103. In Fig. 4B, each front face plate 101 is in the closed position. The cross-section of the tower cavities 54a, 54b may be in the range of 1.5 inches by 1.5 inches to 3 inches by 3 inches, where the term "tower cavity" refers to the region within the body of the tower and behind the tower face plate. The wall thickness of the grow towers 50 maybe within the range of 0.065 to 0.075 inches. A dual-sided hydroponic tower, such as that shown in Figures 4A and 4B, has two back-to-back cavities 54a and 54b, each preferably within the noted size range. In the configuration shown, the grow tower 50 may include (i) a first V-shaped groove 58a running along the length of a first side of the tower body 103, where the first V-shaped groove is centered between the first tower cavity and the second tower cavity; and (ii) a second V-shaped groove 58b running along the length of a second side of the tower body 103, where the second V-shaped groove is centered between the first tower cavity and the second tower cavity. The V-shaped grooves 58a, 58b may facilitate registration, alignment and/or feeding of the towers 50 by one or more of the stations in central processing system 30.

~~[0002]~~ U.S. Application Ser. No. 15/968,425 discloses additional details regarding the construction and use of towers that may be used in embodiments of the disclosure. Another attribute of V-shaped grooves 58a, 58b is that they effectively narrow the central wall 56 to promote the flow of aqueous nutrient solution centrally where the plant's roots are located. Other implementations are possible. For example, a grow tower 50 may be formed as a unitary, single extrusion, where the material at the side walls flex to provide a hinge and allow the cavities to be opened for cleaning.

[0060] As Figs. 4C and 4D illustrate, grow towers 50 may each include a plurality of receptacles 105, for example cut-outs 105 as shown, for use with a compatible growth module 158, such as a plug holder. Each plug holder holds a plant of a given variety. Plug holder 158 may be ultrasonically welded, bonded, or otherwise attached to tower face 101. As shown, the growth modules 158 may be oriented at a 45-degree angle relative to the front face plate 101 and the vertical axis of the grow tower 50. It should be understood, however, that tower design disclosed in the present application is not limited to use with a particular plug holder or orientation, rather, the towers disclosed herein may be used with any suitably sized or

oriented growth module. As such, cut-outs 105 are only meant to illustrate, not limit, the present tower design and it should be understood that embodiments may employ towers with other receptacle designs. In particular, receptacle supports other than towers may be used to support plants. In general, the receptacles may be part of any receptacle support structure for supporting plants within the grow space. For example, the receptacles may be laid out in rows and columns in a horizontal plane. The receptacle support may comprise a member (e.g., a tray, a table, an arm) holding multiple receptacles in a longitudinal (e.g., row) direction. The receptacles may be conveyed during their growth cycle in the longitudinal direction.

[0061] The use of a hinged front face plate simplifies manufacturing of grow towers, as well as tower maintenance in general and tower cleaning in particular. For example, to clean a grow tower 50 the face plates 101 are opened from the body 103 to allow easy access to the body cavity 54a or 54b. After cleaning, the face plates 101 are closed. Since the face plates remain attached to the tower body 103 throughout the cleaning process, it is easier to maintain part alignment and to insure that each face plate is properly associated with the appropriate tower body and, assuming a double-sided tower body, that each face plate 101 is properly associated with the appropriate side of a specific tower body 103. Additionally, if the planting and/or harvesting operations are performed with the face plate 101 in the open position, for the dual-sided configuration both face plates can be opened and simultaneously planted and/or harvested, thus eliminating the step of planting and/or harvesting one side and then rotating the tower and planting and/or harvesting the other side. In other embodiments, planting and/or harvesting operations are performed with the face plate 101 in the closed position.

[0062] Other implementations are possible. For example, grow tower 50 can comprise any tower body that includes a volume of medium or wicking medium extending into the tower interior from the face of the tower (either a portion or individual portions of the tower or the entirety of the tower length. For example, U.S. Patent No. 8,327,582, which is incorporated by reference herein, discloses a grow tube having a slot extending from a face of the tube and a grow medium contained in the tube. The tube illustrated therein may be modified to

include a hook 52 at the top thereof and to have slots on opposing faces, or one slot on a single face.

[0063] Vertical Tower Conveyance System

[0064] Fig. 5A illustrates a portion of a grow line 202 in the vertical tower conveyance system 200. According to embodiments of the disclosure, the vertical tower conveyance system 200 includes grow lines 202 arranged in parallel. As discussed elsewhere herein, automated loading and unloading mechanisms 45, 47 may selectively load and unload grow towers 50 from a grow line 202 under automated control systems. As shown, each grow line 202 supports a plurality of grow towers 50. In one implementation, a grow line 202 may be mounted to the ceiling (or other support) of the grow structure by a bracket for support purposes. Hook 52 hooks into, and attaches, a grow tower 50 to a grow line 202, thereby supporting the tower in a vertical orientation as it is translated through the vertical tower conveyance system 200. A conveyance mechanism moves towers 50 attached to respective grow lines 202.

[0065] Figure 10 illustrates the cross section or extrusion profile of a grow line 202, according to embodiments of the disclosure. The grow line 202 may be an aluminum extrusion. The bottom section of the extrusion profile of the grow line 202 includes an upward facing groove 1002. As Figure 9 shows, hook 52 of a grow tower 50 includes a main body 53 and corresponding member 58 that engages groove 1002 as shown in Figures 5A and 8. These hooks allow the grow towers 50 to hook into the groove 1002 and index along the grow line 202 as discussed below. Conversely, grow towers 50 can be manually unhooked from a grow line 202 and removed from production. This ability may be necessary if a crop in a grow tower 50 becomes diseased so that it does not infect other towers. In one implementation, the width of groove 1002 (for example, 13 mm) is an optimization between two different factors. First, the narrower the groove the more favorable the binding rate and the less likely grow tower hooks 52 are to bind. Conversely, the wider the groove the slower the grow tower hooks wear due to having a greater contact patch. Similarly, the depth of the groove, for example 10 mm, may be an optimization between space savings and accidental fallout of tower hooks.

[0066] Hooks 52 may be injection-molded plastic parts. In one implementation, the plastic may be polyvinyl chloride (PVC), acrylonitrile butadiene styrene (ABS), or an Acetyl Homopolymer (e.g., Delrin® sold by DuPont Company). The hook 52 may be solvent bonded to the top of the grow tower 50 and/or attached using rivets or other mechanical fasteners. The groove-engaging member 58 which rides in the rectangular groove 1002 of the grow line 202 may be a separate part or integrally formed with hook 52. If separate, this part can be made from a different material with lower friction and better wear properties than the rest of the hook, such as ultra-high-molecular weight polyethylene or acetal. To keep assembly costs low, this separate part may snap onto the main body of the hook 52. Alternatively, the separate part also be over-molded onto the main body of hook 52.

[0067] As Figures 6 and 10 illustrate, the top section of the extrusion profile of grow line 202 contains a downward facing t-slot 1004. Linear guide carriages 610 (described below) ride within the t-slot 1004. The center portion of the t-slot 1004 may be recessed to provide clearance from screws or over-molded inserts which may protrude from the carriages 610. Each grow line 202 can be assembled from a number of separately fabricated sections. In one implementation, sections of grow line 202 are currently modeled in 5 to 6-meter lengths. Longer sections reduce the number of junctions but are more susceptible to thermal expansion issues and may significantly increase shipping costs. Additional features not captured by the figures include intermittent mounting holes to attach the grow line 202 to the ceiling structure and to attach irrigation lines. Interruptions to the t-slot 1004 may also be machined into the conveyor body. These interruptions allow the linear guide carriages 610 to be removed without having to slide them all the way out the end of a grow line 202.

[0068] At the junction between two sections of a grow line 202, a block 612 may be located in the t-slots 1004 of both conveyor bodies. This block serves to align the two grow line sections so that grow towers 50 may slide smoothly between them. Alternative methods for aligning sections of a grow line 202 include the use of dowel pins that fit into dowel holes in the extrusion profile of the section. The block 612 may be clamped to one of the grow line sections via a set screw, so that the grow line sections can still come together and move apart as the result of thermal expansion. Based on the relatively tight tolerances and small amount of material required, these blocks may be machined. Bronze may be used as the material for such blocks due to its strength, corrosion resistance, and wear properties.

[0069] In one implementation, the vertical tower conveyance system 200 utilizes a reciprocating linear ratchet and pawl structure (hereinafter referred to as a "reciprocating cam structure or mechanism") to move grow towers 50 along a grow line 202. Figures 5A, 6 and 7 illustrate one possible reciprocating cam mechanism that can be used to move grow towers 50 across grow lines 202. Pawls or "cams" 602 physically push grow towers 50 along grow line 202. Cams 602 are attached to cam channel 604 (see below) and rotate about one axis. On the forward stroke, the rotation is limited by the top of the cam channel 604, causing the cams 602 to push grow towers 50 forward. On the reserve or back stroke, the rotation is unconstrained, thereby allowing the cams to ratchet over the top of the grow towers 50. In this way, the cam mechanism can stroke a relatively short distance back and forth, yet grow towers 50 always progress forward along the entire length of a grow line 202. A control system, in one implementation, controls the operation of the reciprocating cam mechanism of each grow line 202 to move the grow towers 50 according to a programmed growing sequence. In between movement cycles, the actuator and reciprocating cam mechanism remain idle.

[0070] The pivot point of the cams 602 and the means of attachment to the cam channel 604 consists of a binding post 606 and a hex head bolt 608; alternatively, detent clevis pins may be used. The hex head bolt 608 is positioned on the inner side of the cam channel 604 where there is no tool access in the axial direction. Being a hex head, it can be accessed radially with a wrench for removal. Given the large number of cams needed for a full-scale farm, a high-volume manufacturing process such as injection molding is suitable. ABS is suitable material given its stiffness and relatively low cost. All the cams 602 for a corresponding grow line 202 are attached to the cam channel 604. When connected to an actuator, this common beam structure allows all cams 602 to stroke back and forth in unison. The structure of the cam channel 604, in one implementation, is a downward facing u-channel constructed from sheet metal. Holes in the downward facing walls of cam channel 604 provide mounting points for cams 602 using binding posts 606.

[0071] Holes of the cam channel 604, in one implementation, are spaced at 12.7 mm intervals. Therefore, cams 602 can be spaced relative to one another at any integer multiple of 12.7 mm, allowing for variable grow tower spacing with only one cam channel. The base of the cam channel 604 limits rotation of the cams during the forward stroke. All degrees of

freedom of the cam channel 604, except for translation in the axial direction, are constrained by linear guide carriages 610 (described below) which mount to the base of the cam channel 604 and ride in the t-slot 1004 of the grow line 202. Cam channel 604 may be assembled from separately formed sections, such as sections in 6-meter lengths. Longer sections reduce the number of junctions but may significantly increase shipping costs. Thermal expansion is generally not a concern because the cam channel is only fixed at the end connected to the actuator. Given the simple profile, thin wall thickness, and long length needed, sheet metal rolling is a suitable manufacturing process for the cam channel. Galvanized steel is a suitable material for this application.

[0072] Linear guide carriages 610 are bolted to the base of the cam channels 604 and ride within the t-slots 1004 of the grow lines 202. In some implementations, one carriage 610 is used per 6-meter section of cam channel. Carriages 610 may be injection molded plastic for low friction and wear resistance. Bolts attach the carriages 610 to the cam channel 604 by threading into over molded threaded inserts. If select cams 602 are removed, these bolts are accessible so that a section of cam channel 604 can be detached from the carriage and removed.

[0073] Sections of cam channel 604 are joined together with pairs of connectors 616 at each joint; alternatively, detent clevis pins may be used. Connectors 616 may be galvanized steel bars with machined holes at 20 mm spacing (the same hole spacing as the cam channel 604). Shoulder bolts 618 pass through holes in the outer connector, through the cam channel 604, and thread into holes in the inner connector. If the shoulder bolts fall in the same position as a cam 602, they can be used in place of a binding post. The heads of the shoulder bolts 618 are accessible so that connectors and sections of cam channel can be removed.

[0074] In one implementation, cam channel 604 attaches to a linear actuator, which operates in a forward and a back stroke. A suitable linear actuator may be the T13-B4010MS053-62 actuator offered by Thomson, Inc. of Redford, Virginia; however, the reciprocating cam mechanism described herein can be operated with a variety of different actuators. The linear actuator may be attached to cam channel 604 at the off-loading end of a grow line 202, rather than the on-boarding end. In such a configuration, cam channel 604 is under tension when loaded by the towers 50 during a forward stroke of the actuator (which pulls the cam channel 604) which reduces risks of buckling. Figure 7A illustrates operation of the reciprocating

cam mechanism according to embodiments of the disclosure. In step A, the linear actuator has completed a full back stroke; as Figure 7A illustrates, one or more cams 602 may ratchet over the hooks 52 of a grow tower 50. Step B of Figure 7A illustrates the position of cam channel 604 and cams 602 at the end of a forward stroke. During the forward stroke, cams 602 engage corresponding grow towers 50 and move them in the forward direction along grow line 202 as shown. Step C of Figure 7A illustrates how a new grow tower 50 (Tower 0) may be inserted onto a grow line 202 and how the last tower (Tower 9) may be removed. Step D illustrates how cams 602 ratchet over the grow towers 50 during a back stroke, in the same manner as Step A. The basic principle of this reciprocating cam mechanism is that reciprocating motion from a relatively short stroke of the actuator transports towers 50 in one direction along the entire length of the grow line 202. More specifically, on the forward stroke, all grow towers 50 on a grow line 202 are pushed forward one position. On the back stroke, the cams 602 ratchet over an adjacent tower one position back; the grow towers remain in the same location. As shown, when a grow line 202 is full, a new grow tower may be loaded and a last tower unloaded after each forward stroke of the linear actuator. In some implementations, the top portion of the hook 52 (the portion on which the cams push), is slightly narrower than the width of a grow tower 50. As a result, cams 602 can still engage with the hooks 52 when grow towers 50 are spaced immediately adjacent to each other. Figure 7A shows 9 grow towers for didactic purposes. A grow line 202 can be configured to be quite long (for example, 40 meters) allowing for a much greater number of towers 50 on a grow line 202 (such as 400-450). Other implementations are possible. For example, the minimum tower spacing can be set equal to or slightly greater than two times the side-to-side distance of a grow tower 50 to allow more than one grow tower 50 to be loaded onto a grow line 202 in each cycle.

[0075] Still further, as shown in Figure 7A, the spacing of cams 602 along the cam channel 604 can be arranged to effect one-dimensional plant indexing along the grow line 202. In other words, the cams 602 of the reciprocating cam mechanism can be configured such that spacing between towers 50 increases as they travel along a grow line 202. For example, spacing between cams 602 may gradually increase from a minimum spacing at the beginning of a grow line to a maximum spacing at the end of the grow line 202. This may be useful for spacing plants apart as they grow to increase light interception and provide spacing, and,

through variable spacing or indexing, increasing efficient usage of the growth chamber 20 and associated components, such as lighting. In one implementation, the forward and back stroke distance of the linear actuator is equal to (or slightly greater than) the maximum tower spacing. During the back stroke of the linear actuator, cams 602 at the beginning of a grow line 202 may ratchet and overshoot a grow tower 50. On the forward stroke, such cams 602 may travel respective distances before engaging a tower, whereas cams located further along the grow line 202 may travel shorter distances before engaging a tower or engage substantially immediately. In such an arrangement, the maximum tower spacing cannot be two times greater than the minimum tower spacing; otherwise, a cam 602 may ratchet over and engaging two or more grow towers 50. If greater maximum tower spacing is desired, an expansion joint may be used, as illustrated in Figure 7B. An expansion joint allows the leading section of the cam channel 604 to begin traveling before the trailing end of the cam channel 604, thereby achieving a long stroke. In particular, as Figure 7B shows, expansion joint 710 may attach to sections 604a and 604b of cam channel 604. In the initial position (702), the expansion joint 710 is collapsed. At the beginning of a forward stroke (704), the leading section 604a of cam channel 604 moves forward (as the actuator pulls on cam channel 604), while the trailing section 604b remains stationary. Once the bolt bottoms out on the expansion joint 710 (706), the trailing section 604 of cam channel 604 begins to move forward as well. On the back stroke (708), the expansion joint 710 collapses to its initial position.

[0076] Other implementations for moving vertical grow towers 50 may be employed. For example, a lead screw mechanism may be employed. In such an implementation, the threads of the lead screw engage hooks 52 disposed on grow line 202 and move grow towers 50 as the shaft rotates. The pitch of the thread may be varied to achieve one-dimensional plant indexing. In another implementation, a belt conveyor include paddles along the belt may be employed to move grow towers 50 along a grow line 202. In such an implementation, a series of belt conveyors arranged along a grow line 202, where each belt conveyor includes a different spacing distance among the paddles to achieve one-dimensional plant indexing. In yet other implementations, a power-and-free conveyor may be employed to move grow towers 50 along a grow line 202.

[0077] Other configurations for grow line 202 are possible. For example, although the grow line 202 illustrated in the various figures is horizontal to the ground, the grow line 202 may be sloped at a slight angle, either downwardly or upwardly relative to the direction of tower travel. Still further, while the grow line 202 described above operates to convey grow towers in a single direction, the grow line 202 may be configured to include multiple sections, where each section is oriented in a different direction. For example, two sections may be perpendicular to each other. In other implementations, two sections may run parallel to each other, but have opposite directions of travel, to form a substantially u-shaped travel path. In such an implementation, a return mechanism can transfer grow towers from the end of the first path section to the onload end of the second path section of the grow line.

[0078] Irrigation & Aqueous Nutrient Supply System

[0079] Figure 13 is a functional block diagram setting forth the components of an irrigation system according to embodiments of the disclosure. In the implementation shown, the irrigation system 1300 is a closed-loop system comprising a recirculation tank 1302 that both supplies nutrient solution to grow towers 50 and receives excess or remaining nutrient solution returning from the grow towers 50. In the particular implementation shown, supply pump 1304 pumps aqueous nutrient solution from recirculation tank 1302 to one or more irrigation lines 1306 disposed above grow towers 1308. Gutter 1310 recovers excess aqueous nutrient solution that drops from grow towers 1308. A return pump 1312 returns excess aqueous nutrient solution to the screen filter, which then returns clean water to the recirculation tank 1302.

[0080] As Figure 13 illustrates, irrigation system 1300 may include one or more components for conditioning or treating the aqueous nutrient solution, as well as sensing conditions at various points in the irrigation loop. For example, return filter 1314 may filter debris and other particulate matter prior to returning excess aqueous nutrient solution to the recirculation tank 1302. In one implementation, return filter may be a 150 micrometer, parabolic screen filter; however, other filters, such as media and disc filters, can be used depending on the particular application and expected particle size and quantity in excess aqueous nutrient solution. In some implementations, recirculation tank 1302 may include cooling cools. Chiller loop 1330

supplies cooling fluid through the coils to facilitate achieving a target temperature for the aqueous nutrient solution to be supplied to irrigation line 1306.

[0081] Crops in grow towers 50 will generally take up nutrients from aqueous nutrient solution, thereby lowering nutrient levels in the excess nutrient solution returning to recirculation tank 1302. Irrigation system 1300 may also include nutrient and pH dosing system 1340, ion sensor 1342 and tank level sensor 1344. During operation, ion sensor 1342 may sample the nutrient solution at a predefined interval. During sampling, ion sensor 1342 may check the ion levels of 8 separate nutrients and compare them to desired nutrient levels. Ion sensor 1342 may be an 8-ion analyzer offered by CleanGrow Sensors of Wolverhampton, United Kingdom. Responsive to detected nutrient levels, nutrient and pH dosing system 1350 may inject a single element type dose to be delivered to the recirculation tank 1302, based on the nutrient mix desired, and the room available in the tank (as sensed by tank level sensor 1344, for the water needed to transport the dose). In some implementations, nutrient and pH dosing system 1350 may use the sensed nutrient data and a desired nutrient recipe to calculate a nutrient adjustment mix to adjust the nutrient levels of recirculation tank 1302, using the smallest available volume in the tank. Nutrient and pH dosing system 1340 may include one or more venturi injectors for dosing particular nutrient solutions into the irrigation loop. In one implementation, nutrient and pH dosing system 1340 is an AMI Penta Fertilizer Mixer unit offered by Senmatic A/S of Sanderso, Denmark.

[0082] Irrigation system 1300 may also include pressure transducer 1314 and flow sensor 1316 to monitor irrigation loop conditions and control the operation of supply pump 1304. Irrigation system 1300 may also use water from condensate collection mechanism 1348, in one implementation as a primary source of water for the nutrient water. Condensate collection mechanism 1348 recaptures condensate in the air contained within growth environment 20 using, in one implementation, mechanical dehumidification. Reverse osmosis system 1346 filters water received from an external water source, such as a municipal water system, to the extent irrigation system 1300 requires additional water. In some implementations, reverse osmosis system 1346 may also filter water received from condensate collection mechanism 1346. Irrigation system 1300 may also include components for ozone treatment and cleaning of aqueous nutrient solution. For example, ozone pump 1352 supplies aqueous nutrient solution to ozone treatment tank 1356 filtered by

filter 1354. Bypass valve 1358 can be used to redirect ozone injected water to treat the screen filter.

[0083] Irrigation system 1300 may also include in-line pH dosing system 1318 and 5-in-1 sensor 1320. 5-in-1 sensor samples temperature, pH, Electrical Conductivity (EC), dissolved oxygen and oxidization reduction potential of aqueous nutrient solution. In-line pH dosing system 1318 can make micro-adjustments to pH levels based on sensed pH in the irrigation loop. The cooling loop 1380 may be controlled based on the temperature that is read by 5-1 sensor 1320. Irrigation system 1300 may also include bypass valve 1322 to allow the irrigation supply, sensing components, and/or the filter to run without aqueous nutrient solution reaching irrigation line 1306. Bypass valve 1322 can be used to test irrigation system 1300 and/or use bypass valve 1322 to divert aqueous nutrient solution from irrigation line 1306 until desired pH and other conditions are met.

[0084] Figure 8 illustrates how an irrigation line 802 may be attached to grow line 202 to supply an aqueous nutrient solution to crops disposed in grow towers 50 as they translate through the vertical tower conveyance system 200. Irrigation line 802, in one implementation, is a pressurized line with spaced-apart apertures disposed at the expected locations of the grow towers 50 as they advance along grow line 202 with each movement cycle. For example, the irrigation line 802 may be a polyvinyl chloride (PVC) pipe having an inner diameter of 0.75 inches and holes having diameters of 0.125 inches. The irrigation line 802 may be approximately 40 meters in length spanning the entire length of a grow line 202. To ensure adequate pressure across the entire line, irrigation line 802 may be broken into shorter sections, each connected to a manifold, so that pressure drop is reduced and to achieve consistent flow rate across a line. Nutrient water delivery to the sections can be controlled with solenoid or on/off valves to allow for water to be supplied to only some subset of the grow towers 50 in a grow line 202.

[0085] As Figure 8 shows, a funnel structure 902 collects aqueous nutrient solution from irrigation line 802 and distributes the aqueous nutrient solution to the cavity(ies) 54a, 54b of the grow tower 50 as discussed in more detail below. Figures 9 and 11A illustrate that the funnel structure 902 may be integrated into hook 52. For example, the funnel structure 902 may include a collector 910, first and second passageways 912 and first and second slots 920. As Figure 9 illustrates, the groove-engaging member 58 of the hook may disposed at a

centerline of the overall hook structure. The funnel structure 902 may include flange sections 906 extending downwardly opposite the collector 910 and on opposing sides of the centerline. The outlets of the first and second passageways are oriented substantially adjacent to and at opposing sides of the flange sections 906, as shown. Flange sections 906 register with central wall 56 of grow tower 50 to center the hook 52 and provides additional sites to adhere or otherwise attach hook 52 to grow tower 50. In other words, when hook 52 is inserted into the top of grow tower 50, central wall 56 is disposed between flange sections 906. In the implementation shown, collector 910 extends laterally from the main body 53 of hook 52.

[0086] As Figure 11B shows, funnel structure 902 includes a collector 910 that collects nutrient fluid and distributes the fluid evenly to the inner cavities 54a and 54b of tower through passageways 912. Passageways 912 are configured to distribute aqueous nutrient solution near the central wall 56 and to the center back of each cavity 54a, 54b over the ends of the plug holders 158 and where the roots of a planted crop are expected. As Figure 11C illustrates, in one implementation, the funnel structure 902 includes slots 920 that promote the even distribution of nutrient fluid to both passageways 912. For nutrient solution to reach passageways 912, it must flow through one of the slots 920. Each slot 920 may have a V-like configuration where the width of the slot opening increases as it extends from the substantially flat bottom surface 922 of collector 910. For example, each slot 920 may have a width of 1 millimeter at the bottom surface 922. The width of slot 920 may increase to 5 millimeters over a height of 25 millimeters. The configuration of the slots 920 causes nutrient fluid supplied at a sufficient flow rate by irrigation line 802 to accumulate in collector 910, as opposed to flowing directly to a particular passageway 912, and flow through slots 920 to promote even distribution of nutrient fluid to both passageways 912.

[0087] Other implementations are possible. For example, the funnel structure may be configured with two separate collectors that operate separately to distribute aqueous nutrient solution to a corresponding cavity 54a, 54b of a grow tower 50. In such a configuration, the irrigation supply line can be configured with one hole for each collector. In other implementations, the towers may only include a single cavity and include plug containers only on a single face 101 of the towers. Such a configuration still calls for a use of a funnel structure that directs

aqueous nutrient solution to a desired middle and back portion of the tower cavity, but obviates the need for separate collectors or other structures facilitating even distribution.

[0088] In operation, irrigation line 802 provides aqueous nutrient solution to funnel structure 902 that evenly distributes the water to respective cavities 54a, 54b of grow tower 50. The aqueous nutrient solution supplied from the funnel structure 902 irrigates crops contained in respective plug containers 158 as it trickles down. In one implementation, a gutter disposed under each grow line 202 collects excess aqueous nutrient solution from the grow towers 50 for recycling. In one implementation, the width of the gutter can be configured to be larger than the width of the grow towers 50 but narrow enough to act as a guide to prevent grow towers 50 from swinging. For example, the width of the gutter can be 0.5 inches larger than the width of the grow towers 50, and the walls of the gutter can be configured to extend an inch or more higher than the bottom of grow towers 50.

[0089] The apertures of irrigation line 802 can simply be holes drilled (or otherwise machined) into the pipe structure. Water, however, has a propensity to wick onto the surface of the pipe as it exits the apertures causing water to run along the pipe and drip down outside the funnel structure of the grow towers. In some implementations, the apertures can include structures directed to reducing or controlling possible leakage caused by the foregoing. For example, the apertures may be drilled holes with slotted spring pins pressed in, drilled holes with coiled spring pins pressed in, and drilled holes with a custom machined feature around the circumference made from a custom mill tool. All three of the solutions above are intended to create a sharp lip at the exit of the hole such that water cannot run along the pipe. Still further, separate emitters can be used at the select positions along the grow line 202.

[0090] Other solutions are possible. For example, an injection molded part with a sharp lip may be configured to snap into the aperture or hole drilled into the irrigation line pipe. Figure 16A is a section view of an irrigation line 802 including a nozzle 1602 attached to and extending from an aperture in irrigation line 802. Figures 16B is a perspective view of nozzle 1602 attached to a section of irrigation line 802. Figure 16C is a section view of nozzle 1602. As shown in Figures 16A and 16B, nozzle 1602 may include flanges 1604 to facilitate location and placement of nozzle 1602 in the apertures of irrigation line 802. In one implementation, nozzle 1602 may also include a small ridge or detent that engages the edge of the aperture at the inner surface of irrigation line 802 to allow nozzle 1602 to be snapped

into place. Adhesives or ultrasonic welding can be used in addition to, or in lieu of, the small ridge to secure nozzle 1602. As the various figures show, nozzle 1602 includes a chamfered edge at the tip 1606 of nozzle 1602 to create a sharp transition to reduce water from wicking onto the outer surface of nozzle 1602. The upper portion 1608 of nozzle 1602 extending within irrigation line 802 may include a notch or slot 1610 to facilitate flow of nutrient solution out of irrigation line 802. Other implementations are possible. As shown in Figure 16D for example, instead of pressing into a hole in the irrigation line 802, a nozzle 1603 may include threads 1605 which thread into a tapped hole of irrigation line 802. A seal may be formed between the threads of the nozzle and the line 802 and aided by a PTFE sealant (either thread tape or a paste). Such a nozzle 1603 may have a hexagonal portion 1607 extending along its body which allows it to be installed with a hexagonal drive tool.

[0091] In one implementation, each aperture of irrigation line 802 may be fitted with nozzle 1602. In other implementations, the apertures at the second end (the end opposite the first end) of an irrigation line 802 (or the end of a section of irrigation line 802) may include an alternative nozzle 1702 including an air-bleed feature illustrated in Figures 17A, 17B and 17C. The air-bleed feature promotes consistent flow throughout irrigation line 802, as discussed in more detail below. In the implementation shown, the lower portion of nozzle 1702 is substantially the same as nozzle 1602. The upper portion 1708 of nozzle 1702 extends further into the interior of irrigation line 802 and includes slot 1810 and slit 1712. The extended upper portion 1708 facilitates bleeding air from irrigation line 802. Slit 1712 affords more room for water and air to facilitate their flow out of nozzle 1702.

[0092] Figure 18 is a schematic diagram illustrating an irrigation line for purposes of describing operation of the air-bleed feature described above. In various implementations, the irrigation system runs on a periodic basis in that the irrigation system is at rest between irrigation cycles. Between irrigation cycles, air fills the irrigation line 802 as the nutrient solution has drained off. At the beginning of an irrigation cycle (as the nutrient flow front moves into a section of irrigation line 802), air is pushed out of each nozzle 1602 until the nutrient solution passes a given nozzle. Once the front passes a given nozzle 1602, the nutrient solution starts to flow through the nozzle 1602 (instead of air). Nozzle N is the last nozzle to switch from air flow to nutrient flow. With this model for the nutrient flow when the irrigation cycle is started, the air flow though nozzle N should be the same if the upper portion of the last

nozzle is short (i.e., matching nozzles (1602) 1, 2, …, N-1) or tall (to permit air venting) up to the time just before the nutrient front reaches nozzle N.

[0093] When the irrigation cycle begins and nutrient solution enters irrigation line 802, the solution pushes the air in the irrigation line 802 to the end of the line where it builds as one large pocket. With a nozzle having a shorter upper portion 1608, some of this air exits, but as the air is pushed out, water begins to cover the last (N) nozzle driving the air pocket above the water and above the last aperture. A new equilibrium is then obtained with water trickling out of the last aperture and a pocket of air sitting above the water. The air is then trapped and continues to exist in the line. Because the air takes up a volume, it prevents water from fully filling the irrigation line 802 thus creating flow out for the last aperture which is much less than at all other sites. Depending on the size of this air pocket, this weaker flow may exist for apertures (N-1, N-2, etc.) prior to the last (N) as well. The taller upper portion 1708 of nozzle 1702 allows for air to be constantly drained (i.e., small volumes of air at more frequent intervals). Because the top of the nozzle 1702 is at the top of inner surface of irrigation line 802 were the air pocket is located, air can always drain from this nozzle independently from the amount of water in the line. Unlike the shorter nozzle where a pocket of air may be trapped above the water in the line 802 and never able to exit (driving poor flow behavior), the longer nozzle 1702 allows air to more freely exit. In one implementation, the irrigation system supplies nutrient solution at a first end of the irrigation line 802. In such an implementation, nozzle 1702 is attached proximal to the second end of irrigation line 802 (or section of irrigation line 802). In other implementations, the irrigation system supplies nutrient solution to a middle portion of the irrigation line 802. In such an implementation, nozzle 1702 may be installed at both ends of irrigation line 802 (or sections thereof).

[0094] Figure 14A illustrates an example gutter 1402 that can be disposed under a grow line 202 to collect excess aqueous nutrient solution from grow towers 50 attached to the grow line 202. In the implementation shown, gutter 1402 has a gradually-sloped (e.g., a 0.5% slope) bottom that causes excess nutrient solution to collect at end basin structure 1404. Figures 14B and 14C show end structure 1404 in more detail. As Figures 14B and 14C illustrate, basin structure 1404 couples to the low end of gutter 1402 and includes an outlet 1406 to which a pipe, barb, or other structure attaches. As Figure 13 illustrates, return pump 1312 operably connects with a hose, or pipe, to end structure 1404 to pump excess aqueous

nutrient solution back to recirculation tank 1302, as discussed above. The return pump 1312 may be controlled by utilizing an ultrasonic sensor to maintain a certain water level in the gutter as well as a pump outlet pressure in order for the nutrient solution to return to the filter on the skid.

[0095] Gutter 1402 may consist of multiple separate sections that are joined together to form a unitary structure. Figures 14D and 14E illustrate an example gutter section 1408 according to embodiments of the disclosure. Gutter section 1408 may comprise a main body 1410 and flanges 1412. As Figure 14E illustrates, the bottom 1414 of gutter section is sloped. As Figure 14A shows, multiple gutter sections are joined at respective flanges 1412 to create gutter 1402. In one implementation, gaskets between flanges of adjoining gutter sections can be used to achieve a water tight seal. Flanges 1412 may also include feet sections to facilitate securing the gutter to a floor or other structure. As Figure 14A further illustrates, gutter sections are similar to each other, but not identical. For example, the initial height of bottom 1414 of a given gutter section 1408 substantially matches the ending height of the bottom of an adjoining gutter structure. Similarly, the ending height of bottom 1414 of the gutter structure 1408 substantially matches the initial height of the adjoining gutter section. In this manner, the overall structure achieves a substantially continuous slope causing excess aqueous nutrient solution to flow to end structure 1404 for recirculation or disposal.

[0096] In one implementation, each grow line 202 is supported by a separate irrigation loop or zone that operates independently of irrigation loops associated with other grow lines in growth environment 20. In one implementation, each irrigation loop is supported by an irrigation skid that includes many of the components set forth in Figure 13. Use of an irrigation skid allows for partial fabrication of the irrigation loop off site to lower overall costs of creating the crop production system. Figures 15A and 15B illustrate an irrigation skid 1500 according to embodiments of the disclosure. As Figures 15A and 15B illustrate, irrigation skid 1500 includes a frame 1502 onto which various irrigation components are mounted, such as recirculation tank 1504. In one implementation, irrigation skid 1500 also includes supply pump 1506, ozone supply pump 1508, and in-line pH dosing pump 1510. Irrigation skid 1500 also includes plumbing, valves, sensors, a filter, cooling coil, electrical and control components to connect and operate the irrigation loop. In one implementation, other components illustrated in Figure 13 may operate or support multiple irrigation skids.

For example, while irrigation skid 1500 includes ozone supply pump 1508 and associated plumbing, the remaining ozone cleaning components are separate from the skid and can be used to support multiple irrigation skids.

[0097] Nutrient and pH dosing system 1340, in one implementation, is operably connected to multiple irrigation skids 1500 by associated plumbing, valves and other controls. An irrigation control system controls valves and associated plumbing components as needed to interface nutrient and pH dosing system 1340, and associated sensors, with a given irrigation skid 1500. The Nutrient and pH dosing system has the ability to purge and rinse between dosing intervals, in order to prevent mixing of nutrient water from one recirculating loop to another. During operation, the nutrient solution in each recirculating irrigation loop is sampled on a predefined interval for that specific loop. During sampling, the ion levels of 8 separate nutrients may be checked and compared to the desired nutrient levels for that specific loop. Nutrient and pH dosing system 1340 may inject a nutrient dose to be delivered to the recirculation tank 1504 for that loop, based on the nutrient mix required and the room available in the tank for the water needed to transport the dose.

[0098] Fig. 19 illustrates a plant growing environment 20 and an environmental conditioning system 302 for conditioning air and fluid (e.g., water) in the grow space 20, according to embodiments of the disclosure. The plant growing environment 20 includes at least one receptacle support structure 304 (such as a tower 50) having receptacles for holding plants 306, and a fluid-cooled light fixture 308, according to embodiments of the disclosure.

[0099] An irrigation pump 309 circulates water and nutrients through the plant support structure 304. Carbon dioxide supply equipment 311 provides carbon dioxide to the plants. The irrigation pump 309 and carbon dioxide supply equipment 311 may be considered as part of the conditioning system 302, according to embodiments of the disclosure.

[00100] According to embodiments of the disclosure, the conditioning system 302 includes a dehumidifier 310, a fluid (e.g., water) conditioning system 312, and a heating coil 314 in heat exchanger 315. The dehumidifier 310 receives return air A from the grow space 101. The conditioning system 302 provides supply air B, having a temperature and relative

humidity that is controlled to meet setpoints for desired operating conditions of the plants in the environment 20.

[00101] The fluid conditioning system 312 receives return fluid C from the fluid-cooled light fixture 308. According to embodiments of the disclosures, the fluid conditioning system 312 can control the fluid temperature by varying the fluid flow rate through the light fixtures 308. The fluid conditioning system 312 supplies to the fluid-cooled light fixture 308 a supply fluid D, having a temperature that is controlled to meet set points for desired operating conditions of the plants in the environment 20.

[00102] According to embodiments of the disclosure, waste heat from the fluid passing through fluid conditioning system 312 may be provided to the heating coil 314 in the heat exchanger 315 to heat air E that is output from the dehumidifier 310. The air heated by the coil 314 is output as heated air B to the grow space 20.

[00103] The controller 203 may control all the elements of the conditioning system 302, according to embodiments of the disclosure. The controller 203 may be implemented using programmed logic, such as a computer, a microcontroller, or an ASIC. The controller 203 may receive sensed parameters from sensors distributed throughout the plant growing environment 101 and the air and water conditioning system 302, according to embodiments of the disclosure. The sensors 204 may include sensors that sense environmental conditions such as temperature; humidity; air flow; CO_2; irrigation flow rate; pH, EC, DO, and nutrient levels of irrigation water; and light intensity, spectrum, and schedule. The controller 203 may use the sensed parameters as feedback to instruct the conditioning system 302 to control environmental treatments (e.g., temperature, humidity) of the plant growing environment 101, according to embodiments of the disclosure.

[00104] Fault handling

[00105] *Chiller fault*

[00106] Fig. 21 illustrates an enhanced HVAC system 2100 including an economizer subsystem 2102 and an air conditioning subsystem 2104, according to embodiments of the

disclosure. The economizer subsystem 2102 includes an intake vent 2106, an exhaust fan 2108, supply air ducts 2110, and return air ducts 2112. Each pair of supply and return air ducts 2110, 2112 circulate air within a zone in the grow room 20. Each supply air duct 2110 provides supply air SA. Each return air duct 2112 receives return air RA. The supply air ducts 2110 run down the aisle between pairs of grow lines 202 (not shown in this figure) of hanging grow towers 50, according to embodiments of the disclosure. (Those skilled in the art will recognize that "tower" and "receptacle support" may be used interchangeably herein as appropriate.)

[00107] The economizer 2102 includes an economizer intake damper XC01 2114 and an economizer exhaust damper XC03 2118. HVAC dampers FC04-FC09 2120 control the supply of air from air conditioning subsystem 2104 to the grow room zones. According to embodiments of the disclosure, the controller 203 may close the end dampers FC04 2120 and FC09 2120 at certain times of the day to drive more airflow at different canopy positions for specific plants. Air conditioning subsystem 2104 operates similarly to conditioning system 302 of Fig. 19. Air conditioning subsystem 2104 includes heat exchangers and HVAC supply fans 2202. A chiller 2204 provides hot and cold water to a dehumidifier system in the air conditioning subsystem.

[00108] If the chiller 2204 indicates a fault or the chiller is taken out of service for, e.g., maintenance, the controller 203 may enable economization mode. According to embodiments of the disclosure, in that mode and when a CO_2 setpoint drops below a threshold (e.g., 400 ppm), if outside air (OA) enthalpy is above supply air (SA) set point enthalpy OR the outside air humidity ratio is above an SA set point humidity ratio for a given period of time (e.g., 5 minutes), the controller maintains a recirculation mode in which: the RA damper XC02 2130 stays open at 100%, the exhaust fan 2108 remains off, and external air dampers XC01 2114 and XC03 2118 stay closed.

[00109] If, however, OA enthalpy is below a SA set point enthalpy (e.g., 2 kJ/kg) AND OA humidity ratio is below a SA set point humidity ratio (e.g., 0.001 kg/kg) for a period of time (e.g., 5 minutes), the controller 203 moves the XC03 damper 2118 to 100% open, partially opens the XC01 damper 2114 (e.g., to 20%), and turns on the exhaust fan 2108

(e.g,.by setting the fan variable frequency drive to 15 Hz), according to embodiments of the disclosure. This results in a blend of air as input to the air conditioning unit 2104. The controller 203 continues to modulate the XC02 2130 and XC01 2114 dampers in tandem to maintain the return air humidity ratio as measured by a return air sensor. The controller 203 controls the exhaust fan 2108 to track the XC03 2118 air flow rate to maintain a neutral pressure in the grow room.

[00110] If the controller 203 determines that the sensed fault conditions are no longer present, then it returns the system to normal operation by which economizer mode is disabled, closing dampers XC01 2114 and XC03 2118 and turning off the exhaust fan 2108.

[00111] Normal state of operation for the chiller 2204 is that it provides both warm and cold water to the dehumidifier unit. Within the dehumidification unit are three proportional valves (TCV03, TCV02, and TCV01) that control flow of warm and cold water to three heat exchangers 2306, 2304, 2200 that are used to heat (TCV03), cool (TCV02), and dehumidify (TCV01). The fans 2202 (SA Flow fans) blow air to the grow room 20, and dampers FC04 – FC09 2120 are used to control the air flow to each of the supply ducting outputs of the line. Return Air is moved across the dehumidification coils to dehumidify the air. In normal operation mode, XC01 2114 and XC03 2118 are closed and XC02 2130 is open and no blending with outside air using economization is utilized.

[00112] *Irrigation fault*

[00113] Fig. 22 illustrates a top view of the lighting assembly for a number of grow lines of receptacle supports (e.g., towers), according to embodiments of the disclosure. The figure shows five grow lines 202 horizontally. According to embodiments of the disclosure, linear arrays of lights are disposed on each side of a grow line 202. According to embodiments of the disclosure, the lights shine down from above the receptacle supports to illuminate the plants growing out of the sides of the receptacle supports. As shown, the lights may be grouped into sections (e.g., sections 2204, 2206).

[00114] Fig. 23 illustrates an irrigation subsystem 2300 according to embodiments of the disclosure, including a water supply tank 2302, a supply pump 2304, a return pump 2306, a

flow sensor, a supply line 2310, a zone master valve 2312, a lateral, main irrigation line 2314 from which branch irrigation lines 2316 branch off (shown for eight grow room sections), and a gutter 2318. The main irrigation line 2314 runs parallel to and above the grow line of vertical receptacle supports (e.g., towers). A nozzle at the end of each branch irrigation line 2316 allows water to spray down into a funnel disposed at the top of the vertical receptacle support, thus enabling irrigation of the plants supported by the receptacle support, according to embodiments of the disclosure. The gutter 2318 includes a gutter water level sensor and a sump pump 2320.

[00115] In operation, the supply pump 2320 pumps nutrient-enriched water from the supply tank 2302 through the supply line 2310 to the branch irrigation lines 2316 via the main irrigation line 2314. The water flows from the nozzles into the receptacle supports. Any water not retained in the receptacle supports flows into the gutter 2318.

[00116] The flow sensor monitors flow rate in the supply line 2310. The supply pump 2304, like many commercial supply pumps, provides an error signal in case of a pump malfunction. In response to an irrigation fault condition (e.g., the error signal or the flow rate falling below a desired threshold (e.g., 200 liters per minute)), the controller 203 executes an irrigation fail safe protocol, as follows according to embodiments of the disclosure: dim the lights (e.g., down to 10% of standard illumination) if the irrigation fault condition persists for a given time period, e.g., 10 minutes; turn off the lights if the irrigation fault condition persists for a further time period, e.g., 30 minutes more. According to embodiments of the disclosure, if the fault condition ends, the controller 203 turns the lights back on.

[00117] This fault handling routine can be applied at different levels of spatial granularity. For example, flow sensors can sense flow not just at the main supply line, but at the branch main irrigation lines 2316 for different grow room zones. In response to an insufficient flow for a zone, the controller 203 can dim or turn off the lights according to protocol for that zone.

[00118] *Gutter overflow prevention*

[00119] Referring to Fig. 23, embodiments of the disclosure prevent undesirable water buildup in the gutter 2318. Excess water can be caused by overly rapid filling of the gutter 2318 or by a drainage failure. According to embodiments of the disclosure, an ultrasonic sensor measures the water level (CV) in the gutter, and the controller 203 compares the sensed level to threshold (reference) levels. This example shows four reference levels: high-high (HIHI), high (HI), low (LO), and low-low (LOLO).

[00120] According to embodiments of the disclosure, the water level is maintained between LO and HI during normal, steady state operation. According to embodiments of the disclosure, the controller 203 does so by operating the return pump 2306 in response to feedback of the sensed water level. If, however, the sensed water level reaches HIHI or the controller 203 detects a return pump 2306 failure, this represents a fault condition and the controller activates the sump pump 2320 and deactivates the supply pump 2304, according to embodiments of the disclosure. According to embodiments of the disclosure, in the case that the sensed water level reaches HIHI and the return pump 2306 is operational, the controller 203 also activates the return pump 2306.

[00121] According to embodiments of the disclosure, the controller 203 controls the pumps in response to gutter-related conditions as shown in the following table:

Level exceeded	return pump	sump pump	supply pump
LOLO	Should be Deactivated already	Off	Off
LO	Off	(If Draining Gutter) Activate	Off
HI	Turns on and ramps up proportionally to control loop based on feedback from ultrasonic sensor.	None	Ramps Down proportionally to control loop
HIHI	Should already be on.	Activate	Deactivate
Return pump failure	Off	Activate	Off
Gutter Empty	Off	Deactivate	Off

[00122] *Prevention of water on grow room floor due to nozzle-tower misalignment*

[00123] As noted elsewhere herein, according to embodiments of the disclosure under normal operation, the irrigation nozzles are aligned with funnels disposed at the upper end of the receptacle supports (e.g., towers). Occasionally, however, the towers may become misaligned with the nozzles, resulting in water spraying directly onto the floor of the grow room, or splattering off the edge of a funnel and finding its way to the floor. Misalignment may occur in a number of instances due to improper spacing between the hanging towers—e.g., a gap under a nozzle between towers in the grow line due to failure to place the correct number of towers within that linear space along the grow line, or a doubling up of towers in which adjacent towers are too close to one another, thereby leaving a gap under an adjacent nozzle.

[00124] A tower tracking system monitors location of the towers along the grow line. In response to the tracking system detecting a tower misalignment, e.g., due to gapping or doubling, the controller turns off the supply pump. According to embodiments of the disclosure, after towers are transplanted and inserted into the grow room they stop at each grow line where a scanner scans the barcode on the towers and determines onto what line the tower should be loaded. The physical location of each tower is stored in a database. The controller may query the database to determine if there are any doubles or gaps within the grow room.

[00125] *Prevention of water on grow room floor due to wet towers*

[00126] The towers are loaded onto one end of the grow line, moved (indexed) along the grow line during the growth period, and unloaded from the other end of the grow line for harvesting. During the growth cycle, the irrigation system provides nutrient-enriched water to the towers.

[00127] The towers (e.g., soil plugs) hold water and require time to sufficiently drain before dripping a substantial amount of water on the floor of the grow room. (A tower may be considered sufficiently drained if it is draining at less than 0.1 liters/minute, for example.) When the towers are moved along the grow line, they are moved one at a time so that the last tower at the end of the grow line enters the unload transfer conveyance mechanism 45 (a pre-harvest area). According to embodiments of the disclosure, the grow line lies over a gutter 2318. However, according to embodiments of the disclosure, the gutter does not extend past the grow line into the pre-harvest area. It is desired not to transfer a tower into the pre-harvest area if the tower is still draining a substantial amount of water. Thus, according to embodiments of the disclosure, the controller 203 employs a drip timer function to delay tower indexing until lapse of the timer, e.g., allow at least 30 minutes before indexing the tower.

[00128] *Nutrient priming sequence prior to irrigation*

[00129] Fig. 24 illustrates an irrigation system for propagation tables, according to embodiments of the disclosure. According to embodiments of the disclosure, before loading

plants into towers 50 (e.g., loading plugs containing plants into tower receptacles), the plants may be germinated in soil in trays on a propagation table (labeled "Level 1" 2402 or "Level 2" 2404 in the figure). The irrigation of seeds and seedlings in the trays may be performed using any conventional layout of irrigation lines in the trays.

[00130] A supply pump 2406 pumps water from a supply tank 2408 via a supply line 2410 to the propagation tables 2402, 2404. According to embodiments of the disclosure, a three-way recirculation valve 2412 controls whether the water from the supply tank 2408 is directed back to the tank 2408 or allowed to pass on to the propagation tables 2402, 2404.

[00131] Water sensors 2414 are coupled to the supply line 2412 to measure pH, dissolved oxygen, ozone, temperature and electrical conductivity, nutrients such as calcium, phosphorus, and nitrates, among other parameters to determine water quality. A nutrient injector valve 2416 controls the flow of nutrients into the supply tank 2408.

[00132] Before redirecting the recirculation valve 2412 to allow water to flow to the propagation tables 2402, 2404, the controller 203 controls the recirculation valve 2412 to recirculate water to the tank 2408 until the sensors 2414 detect that water quality is within specification. Example specification ranges are shown in the table below.

Parameter	Acceptable Low Range	Acceptable High Range
pH	5	6.7
Temperature (Celsius)	5	30
Dissolved oxygen (mg/liter)	5	575
Ozone (mg/liter)	16	30

[00133] During recirculation, the controller 203 causes nutrients to be supplied to the supply tank in the following manner:

- A pump doses acid from a reservoir directly into the tank.

- A wash valve 2420 is use to recirculate the water in the tank 2408 to an ozone generator to control the Oxidation-Reduction Potential (ORP) value,
- A dissolved oxygen system provides a constant stream of ozone to the system.

[00134] In response to the controller 203 determining that the parameters are within acceptable ranges, it switches the three-way recirculation valve 2412 to direct water flow to the propagation tables 2402, 2404. The controller 203 continues to monitor water quality to determine whether to switch back to nutrient injection and recirculation.

[00135] Machine Learning

[00136] Embodiments of the disclosure may apply machine learning ("ML") techniques, e.g, to learn the relationship between the given parameters (e.g., environmental conditions such as temperature, humidity) and observed outcomes (e.g., experimental data concerning yield and energy consumption). Embodiments may use ML models, e.g., Decision Trees, to determine feature importance. In general, machine learning may be described as the optimization of performance criteria, e.g., parameters, techniques or other features, in the performance of an informational task (such as classification or regression) using a limited number of examples of labeled data, and then performing the same task on unknown data. In supervised machine learning such as an approach employing linear regression, the machine (e.g., a computing device) learns, for example, by identifying patterns, categories, statistical relationships, or other attributes exhibited by training data. The result of the learning is then used to predict whether new data will exhibit the same patterns, categories, statistical relationships or other attributes.

[00137] Embodiments of this disclosure may employ unsupervised machine learning. Alternatively, some embodiments may employ semi-supervised machine learning, using a small amount of labeled data and a large amount of unlabeled data. Embodiments may also employ feature selection to select the subset of the most relevant features to optimize performance of the machine learning model. Depending upon the type of machine learning approach selected, as alternatives or in addition to linear regression, embodiments may employ for example, logistic regression, neural networks, support vector machines (SVMs),

decision trees, hidden Markov models, Bayesian networks, Gram Schmidt, reinforcement-based learning, cluster-based learning including hierarchical clustering, genetic algorithms, and any other suitable learning machines known in the art. In particular, embodiments may employ logistic regression to provide probabilities of classification along with the classifications themselves.

[00138] Embodiments may employ graphics processing unit (GPU) or Tensor processing units (TPU) accelerated architectures that have found increasing popularity in performing machine learning tasks, particularly in the form known as deep neural networks (DNN). Embodiments of the disclosure may employ GPU-based machine learning, such as that described in GPU-Based Deep Learning Inference: A Performance and Power Analysis, NVidia Whitepaper, November 2015, Dahl, et al., which is incorporated by reference in its entirety herein.

[00139] Computer system implementation

[00140] Fig. 20 llustrates an example of a computer system 2800 that may be used to execute program code stored in a non-transitory computer readable medium (e.g., memory) in accordance with embodiments of the disclosure. The computer system includes an input/output subsystem 2802, which may be used to interface with human users or other computer systems depending upon the application. The I/O subsystem 2802 may include, e.g., a keyboard, mouse, graphical user interface, touchscreen, or other interfaces for input, and, e.g., an LED or other flat screen display, or other interfaces for output, including application program interfaces (APIs). Other elements of embodiments of the disclosure, such as engine 106, control system 107, and controller 203, may be implemented with a computer system like that of computer system 2800.

[00141] Program code may be stored in non-transitory media such as persistent storage in secondary memory 2810 or main memory 2808 or both. Main memory 2808 may include volatile memory such as random access memory (RAM) or non-volatile memory such as read only memory (ROM), as well as different levels of cache memory for faster access to instructions and data. Secondary memory may include persistent storage such as solid state drives, hard disk drives or optical disks. One or more processors 2804 reads program code

from one or more non-transitory media and executes the code to enable the computer system to accomplish the methods performed by the embodiments herein. Those skilled in the art will understand that the processor(s) may ingest source code, and interpret or compile the source code into machine code that is understandable at the hardware gate level of the processor(s) 2804. The processor(s) 2804 may include graphics processing units (GPUs) for handling computationally intensive tasks.

[00142] The processor(s) 2804 may communicate with external networks via one or more communications interfaces 2807, such as a network interface card, WiFi transceiver, etc. A bus 2805 communicatively couples the I/O subsystem 2802, the processor(s) 2804, peripheral devices 2806, communications interfaces 2807, memory 2808, and persistent storage 2810. Embodiments of the disclosure are not limited to this representative architecture. Alternative embodiments may employ different arrangements and types of components, e.g., separate buses for input-output components and memory subsystems.

[00143] Those skilled in the art will understand that some or all of the elements of embodiments of the disclosure, and their accompanying operations, may be implemented wholly or partially by one or more computer systems including one or more processors and one or more memory systems like those of computer system 2800. In particular, the elements of automated systems or devices described herein may be computer-implemented. Some elements and functionality may be implemented locally and others may be implemented in a distributed fashion over a network through different servers, e.g., in client-server fashion, for example.

[00144] Although the disclosure may not expressly disclose that some embodiments or features described herein may be combined with other embodiments or features described herein, this disclosure should be read to describe any such combinations that would be practicable by one of ordinary skill in the art. Unless otherwise indicated herein, the term "include" shall mean "include, without limitation," and the term "or" shall mean non-exclusive "or" in the manner of "and/or."

[00145] All references, articles, publications, patents, patent publications, and patent applications cited herein are incorporated by reference in their entireties for all purposes to

the extent they are not inconsistent with embodiments of the disclosure expressly described herein. However, mention of any reference, article, publication, patent, patent publication, and patent application cited herein is not, and should not be taken as an acknowledgment or any form of suggestion that they constitute valid prior art or form part of the common general knowledge in any country in the world, or that they are disclose essential matter.

[00146] SELECTED EMBODIMENTS OF THE DISCLOSURE

[00147] Below is a non-exhaustive summary of embodiments of the disclosure.

Dependencies below refer back to embodiments within the same set.

[00148] Method embodiments

Set M1

1. A computer-implemented method for entering a fail safe mode in a controlled agricultural environment (CAE), wherein the CAE includes a plurality of movable receptacle supports for holding plants, the method comprising:
    a. in response to determining a fault condition in the CAE or in environmental conditioning equipment for the CAE, controlling operation of the CAE or the environmental conditioning equipment to effect a change from a standard operating mode to a fail safe mode,
    b. wherein the standard operating mode corresponds to desired environmental conditions in the CAE and the fail safe mode corresponds to non-ideal environmental conditions.
2. The method of embodiment 1, wherein the fault condition includes a chiller fault, the method comprising enabling external air to circulate in the CAE in the fail safe mode.
3. The method of embodiment 1, wherein the fault condition includes an irrigation fault, the method comprising reducing illumination in the CAE in the fail safe mode.
4. The method of embodiment 1, wherein the CAE includes a plurality of zones and the fault condition includes an irrigation fault in at least one zone of the plurality of zones, the method comprising reducing illumination in the at least one zone in the fail safe mode.
5. The method of embodiment 1, wherein the fault condition includes detecting an irrigation fault for a first time period, the method comprising reducing illumination in the CAE after the first time period
6. The method of embodiment 1, wherein the fault condition includes detecting an irrigation fault during a first time period, the method comprising reducing illumination in the CAE after the first time period, and turning off illumination after detection of the irrigation fault during a second time period after the first time period.

7. The method of embodiment 1, wherein the fault condition includes detecting an undesired water level in a gutter of the CAE, the method comprising activating a sump pump and decreasing a supply pump flow in the fail safe mode.
8. The method of embodiment 7, the method comprising increasing a return pump flow in the fail safe mode.
9. The method of embodiment 1, wherein the fault condition includes detecting a misalignment of a receptacle support with an irrigation source, the method comprising preventing water flow from the irrigation source in the fail safe mode.

10. A computer-implemented method in a controlled agricultural environment (CAE), wherein the CAE includes a plurality of movable receptacle supports for holding plants, the method comprising:
    a. irrigating the plurality of receptacle supports; and
    b. delaying movement of the receptacle supports along a grow line until after lapse of a first time period, wherein the first time period is based upon a time to allow for drainage of irrigation water from the receptacles supports.

11. A computer-implemented method for a controlled agricultural environment (CAE), wherein the CAE includes a plurality of moving receptacle supports for holding plants, the method comprising:
    a. recirculating water to a supply tank while it receives nutrients; and
    b. stopping recirculation and directing the water from the supply tank to a propagation area in response to determining that water quality of the water is satisfactory, the propagation area for propagating plants before loading into the receptable supports.

[00149] System embodiments

Set S1

1. A system for entering a fail safe mode in a controlled agricultural environment (CAE), wherein the CAE includes a plurality of movable receptacle supports for holding plants, the system comprising:

one or more processors; and

one or more memories operatively connected to the one or more processors and storing instructions, that when executed by at least one of the one or more processors, cause the system to:

a. in response to determining a fault condition in the CAE or in environmental conditioning equipment for the CAE, controlling operation of the CAE or the environmental conditioning equipment to effect a change from a standard operating mode to a fail safe mode,

c. wherein the standard operating mode corresponds to desired environmental conditions in the CAE and the fail safe mode corresponds to non-ideal environmental conditions.

2. The system of embodiment 1, wherein the fault condition includes a chiller fault, and the instructions, when executed, cause the system to enable external air to circulate in the CAE in the fail safe mode.
3. The system of embodiment 1, wherein the fault condition includes an irrigation fault, and the instructions, when executed, cause the system to reduce illumination in the CAE in the fail safe mode.
4. The system of embodiment 1, wherein the CAE includes a plurality of zones and the fault condition includes an irrigation fault in at least one zone of the plurality of zones, and the instructions, when executed, cause the system to reduce illumination in the at least one zone in the fail safe mode.
5. The system of embodiment 1, wherein the fault condition includes detecting an irrigation fault for a first time period, and the instructions, when executed, cause the system to reduce illumination in the CAE after the first time period
6. The system of embodiment 1, wherein the fault condition includes detecting an irrigation fault during a first time period, and the instructions, when executed, cause the system to reduce illumination in the CAE after the first time period, and turn off illumination after detection of the irrigation fault during a second time period after the first time period.
7. The system of embodiment 1, wherein the fault condition includes detecting an undesired water level in a gutter of the CAE, and the instructions, when executed, cause the system to activate a sump pump and decrease a supply pump flow in the fail safe mode.

8. The system of embodiment 7, wherein the instructions, when executed, cause the system to increase a return pump flow in the fail safe mode.
9. The system of embodiment 1, wherein the fault condition includes detecting a misalignment of a receptacle support with an irrigation source, and the instructions, when executed, cause the system to prevent water flow from the irrigation source in the fail safe mode.

10. A system in a controlled agricultural environment (CAE), wherein the CAE includes a plurality of movable receptacle supports for holding plants, the system comprising:
    one or more processors; and
    one or more memories operatively connected to the one or more processors and storing instructions, that when executed by at least one of the one or more processors, cause the system to:
    a. irrigate the plurality of receptacle supports; and
    b. delay movement of the receptacle supports along a grow line until after lapse of a first time period, wherein the first time period is based upon a time to allow for drainage of irrigation water from the receptacles supports.

11. A system in a controlled agricultural environment (CAE), wherein the CAE includes a plurality of movable receptacle supports for holding plants, the system comprising:
    one or more processors; and
    one or more memories operatively connected to the one or more processors and storing instructions, that when executed by at least one of the one or more processors, cause the system to:
    a. recirculate water to a supply tank while it receives nutrients; and
    b. stop recirculation and direct the water from the supply tank to a propagation area in response to determining that water quality of the water is satisfactory, the

propagation area for propagating plants before loading into the receptable supports.

[00150] Computer-readable medium embodiments

Set CRM1

1. One or more non-transitory computer-readable media storing instructions for entering a fail safe mode in a controlled agricultural environment (CAE), wherein the CAE includes a plurality of movable receptacle supports for holding plants, wherein the instructions, when executed by one or more computing devices, cause performance of:
    a. in response to determining a fault condition in the CAE or in environmental conditioning equipment for the CAE, controlling operation of the CAE or the environmental conditioning equipment to effect a change from a standard operating mode to a fail safe mode,
    a. wherein the standard operating mode corresponds to desired environmental conditions in the CAE and the fail safe mode corresponds to non-ideal environmental conditions.
2. The one or more non-transitory computer-readable media of embodiment 1, wherein the fault condition includes a chiller fault, the instructions, when executed, causing: enabling external air to circulate in the CAE in the fail safe mode.
3. The one or more non-transitory computer-readable media of embodiment 1, wherein the fault condition includes an irrigation fault, the instructions, when executed, causing: reducing illumination in the CAE in the fail safe mode.
4. The one or more non-transitory computer-readable media of embodiment 1, wherein the CAE includes a plurality of zones and the fault condition includes an irrigation fault in at least one zone of the plurality of zones, the instructions, when executed, causing: reducing illumination in the at least one zone in the fail safe mode.
5. The one or more non-transitory computer-readable media of embodiment 1, wherein the fault condition includes detecting an irrigation fault for a first time period, the

instructions, when executed, causing: reducing illumination in the CAE after the first time period

6. The one or more non-transitory computer-readable media of embodiment 1, wherein the fault condition includes detecting an irrigation fault during a first time period, the instructions, when executed, causing: reducing illumination in the CAE after the first time period, and turning off illumination after detection of the irrigation fault during a second time period after the first time period.
7. The one or more non-transitory computer-readable media of embodiment 1, wherein the fault condition includes detecting an undesired water level in a gutter of the CAE, the instructions, when executed, causing: activating a sump pump and decreasing a supply pump flow in the fail safe mode.
8. The one or more non-transitory computer-readable media of embodiment 7, the instructions, when executed, causing: increasing a return pump flow in the fail safe mode.
9. The one or more non-transitory computer-readable media of embodiment 1, wherein the fault condition includes detecting a misalignment of a receptacle support with an irrigation source, the instructions, when executed, causing: preventing water flow from the irrigation source in the fail safe mode.

10. One or more non-transitory computer-readable media storing instructions, wherein the instructions, when executed by one or more computing devices, cause performance of:
    a. irrigating a plurality of movable receptacle supports for holding plants in a controlled agricultural environment; and
    b. delaying movement of the receptacle supports along a grow line until after lapse of a first time period, wherein the first time period is based upon a time to allow for drainage of irrigation water from the receptacles supports.

11. One or more non-transitory computer-readable media storing instructions, wherein the instructions, when executed by one or more computing devices, cause performance of:
    a. recirculating water to a supply tank while it receives nutrients; and

b. stopping recirculation and directing the water from the supply tank to a propagation area in response to determining that water quality of the water is satisfactory, the propagation area for propagating plants before loading into a plurality of receptable supports for use in a a controlled agricultural environment.

CLAIMS

What is claimed is:

1. A computer-implemented method for entering a fail safe mode for a controlled agricultural environment (CAE), wherein the CAE includes a plurality of movable receptacle supports for holding plants, the method comprising:
    a. in response to determining a fault condition in the CAE or in environmental conditioning equipment for the CAE, controlling operation of the CAE or the environmental conditioning equipment to effect a change from a standard operating mode to a fail safe mode,
    b. wherein the standard operating mode corresponds to desired environmental conditions in the CAE and the fail safe mode corresponds to non-ideal environmental conditions.
2. The method of claim 1, wherein the fault condition includes a chiller fault, the method comprising enabling external air to circulate in the CAE in the fail safe mode.
3. The method of claim 1, wherein the fault condition includes an irrigation fault, the method comprising reducing illumination in the CAE in the fail safe mode.
4. The method of claim 1, wherein the CAE includes a plurality of zones and the fault condition includes an irrigation fault in at least one zone of the plurality of zones, the method comprising reducing illumination in the at least one zone in the fail safe mode.
5. The method of claim 1, wherein the fault condition includes detecting an irrigation fault for a first time period, the method comprising reducing illumination in the CAE after the first time period
6. The method of claim 1, wherein the fault condition includes detecting an irrigation fault during a first time period, the method comprising reducing illumination in the CAE after the first time period, and turning off illumination after detection of the irrigation fault during a second time period after the first time period.
7. The method of claim 1, wherein the fault condition includes detecting an undesired water level in a gutter of the CAE, the method comprising activating a sump pump and decreasing a supply pump flow in the fail safe mode.

8. The method of claim 7, the method comprising increasing a return pump flow in the fail safe mode.
9. The method of claim 1, wherein the fault condition includes detecting a misalignment of a receptacle support with an irrigation source, the method comprising preventing water flow from the irrigation source in the fail safe mode.

10. A computer-implemented method for a controlled agricultural environment (CAE), wherein the CAE includes a plurality of movable receptacle supports for holding plants, the method comprising:
    a. irrigating the plurality of receptacle supports; and
    b. delaying movement of the receptacle supports along a grow line until after lapse of a first time period, wherein the first time period is based upon a time to allow for drainage of irrigation water from the receptacles supports.

11. A computer-implemented method for a controlled agricultural environment (CAE), wherein the CAE includes a plurality of moving receptacle supports for holding plants, the method comprising:
    a. recirculating water to a supply tank while it receives nutrients; and
    b. stopping recirculation and directing the water from the supply tank to a propagation area in response to determining that water quality of the water is satisfactory, the propagation area for propagating plants before loading into the receptable supports.

12. A system for entering a fail safe mode for a controlled agricultural environment (CAE), wherein the CAE includes a plurality of movable receptacle supports for holding plants, the system comprising:
    one or more processors; and
    one or more memories operatively connected to the one or more processors and storing instructions, that when executed by at least one of the one or more processors, cause the system to:

a. in response to determining a fault condition in the CAE or in environmental conditioning equipment for the CAE, controlling operation of the CAE or the environmental conditioning equipment to effect a change from a standard operating mode to a fail safe mode,
b. wherein the standard operating mode corresponds to desired environmental conditions in the CAE and the fail safe mode corresponds to non-ideal environmental conditions.

13. The system of claim 12, wherein the fault condition includes a chiller fault, and the instructions, when executed, cause the system to enable external air to circulate in the CAE in the fail safe mode.
14. The system of claim 12, wherein the fault condition includes an irrigation fault, and the instructions, when executed, cause the system to reduce illumination in the CAE in the fail safe mode.
15. The system of claim 12, wherein the CAE includes a plurality of zones and the fault condition includes an irrigation fault in at least one zone of the plurality of zones, and the instructions, when executed, cause the system to reduce illumination in the at least one zone in the fail safe mode.
16. The system of claim 12, wherein the fault condition includes detecting an irrigation fault for a first time period, and the instructions, when executed, cause the system to reduce illumination in the CAE after the first time period
17. The system of claim 12, wherein the fault condition includes detecting an irrigation fault during a first time period, and the instructions, when executed, cause the system to reduce illumination in the CAE after the first time period, and turn off illumination after detection of the irrigation fault during a second time period after the first time period.
18. The system of claim 12, wherein the fault condition includes detecting an undesired water level in a gutter of the CAE, and the instructions, when executed, cause the system to activate a sump pump and decrease a supply pump flow in the fail safe mode.
19. The system of claim 18, wherein the instructions, when executed, cause the system to increase a return pump flow in the fail safe mode.

20. The system of claim 12, wherein the fault condition includes detecting a misalignment of a receptacle support with an irrigation source, and the instructions, when executed, cause the system to prevent water flow from the irrigation source in the fail safe mode.

21. A system for a controlled agricultural environment (CAE), wherein the CAE includes a plurality of movable receptacle supports for holding plants, the system comprising:

one or more processors; and

one or more memories operatively connected to the one or more processors and storing instructions, that when executed by at least one of the one or more processors, cause the system to:

a. irrigate the plurality of receptacle supports; and

b. delay movement of the receptacle supports along a grow line until after lapse of a first time period, wherein the first time period is based upon a time to allow for drainage of irrigation water from the receptacles supports.

22. A system for a controlled agricultural environment (CAE), wherein the CAE includes a plurality of movable receptacle supports for holding plants, the system comprising:

one or more processors; and

one or more memories operatively connected to the one or more processors and storing instructions, that when executed by at least one of the one or more processors, cause the system to:

a. recirculate water to a supply tank while it receives nutrients; and

b. stop recirculation and direct the water from the supply tank to a propagation area in response to determining that water quality of the water is satisfactory, the propagation area for propagating plants before loading into the receptable supports.

23. One or more non-transitory computer-readable media storing instructions for entering a fail safe mode for a controlled agricultural environment (CAE),

wherein the CAE includes a plurality of movable receptacle supports for holding plants, wherein the instructions, when executed by one or more computing devices, cause performance of:

a. in response to determining a fault condition in the CAE or in environmental conditioning equipment for the CAE, controlling operation of the CAE or the environmental conditioning equipment to effect a change from a standard operating mode to a fail safe mode,

b. wherein the standard operating mode corresponds to desired environmental conditions in the CAE and the fail safe mode corresponds to non-ideal environmental conditions.

24. The one or more non-transitory computer-readable media of claim 23, wherein the fault condition includes a chiller fault, the instructions, when executed, causing: enabling external air to circulate in the CAE in the fail safe mode.

25. The one or more non-transitory computer-readable media of claim 23, wherein the fault condition includes an irrigation fault, the instructions, when executed, causing: reducing illumination in the CAE in the fail safe mode.

26. The one or more non-transitory computer-readable media of claim 23, wherein the CAE includes a plurality of zones and the fault condition includes an irrigation fault in at least one zone of the plurality of zones, the instructions, when executed, causing: reducing illumination in the at least one zone in the fail safe mode.

27. The one or more non-transitory computer-readable media of claim 23, wherein the fault condition includes detecting an irrigation fault for a first time period, the instructions, when executed, causing: reducing illumination in the CAE after the first time period

28. The one or more non-transitory computer-readable media of claim 23, wherein the fault condition includes detecting an irrigation fault during a first time period, the instructions, when executed, causing: reducing illumination in the CAE after the first time period, and turning off illumination after detection of the irrigation fault during a second time period after the first time period.

29. The one or more non-transitory computer-readable media of claim 23, wherein the fault condition includes detecting an undesired water level in a gutter of the CAE, the

instructions, when executed, causing: activating a sump pump and decreasing a supply pump flow in the fail safe mode.

30. The one or more non-transitory computer-readable media of claim 29, the instructions, when executed, causing: increasing a return pump flow in the fail safe mode.
31. The one or more non-transitory computer-readable media of claim 23, wherein the fault condition includes detecting a misalignment of a receptacle support with an irrigation source, the instructions, when executed, causing: preventing water flow from the irrigation source in the fail safe mode.

32. One or more non-transitory computer-readable media storing instructions, wherein the instructions, when executed by one or more computing devices, cause performance of:
    a. irrigating a plurality of movable receptacle supports for holding plants in a controlled agricultural environment; and
    b. delaying movement of the receptacle supports along a grow line until after lapse of a first time period, wherein the first time period is based upon a time to allow for drainage of irrigation water from the receptacles supports.

33. One or more non-transitory computer-readable media storing instructions, wherein the instructions, when executed by one or more computing devices, cause performance of:
    a. recirculating water to a supply tank while it receives nutrients; and
    b. stopping recirculation and directing the water from the supply tank to a propagation area in response to determining that water quality of the water is satisfactory, the propagation area for propagating plants before loading into a plurality of receptable supports for use in a controlled agricultural environment.

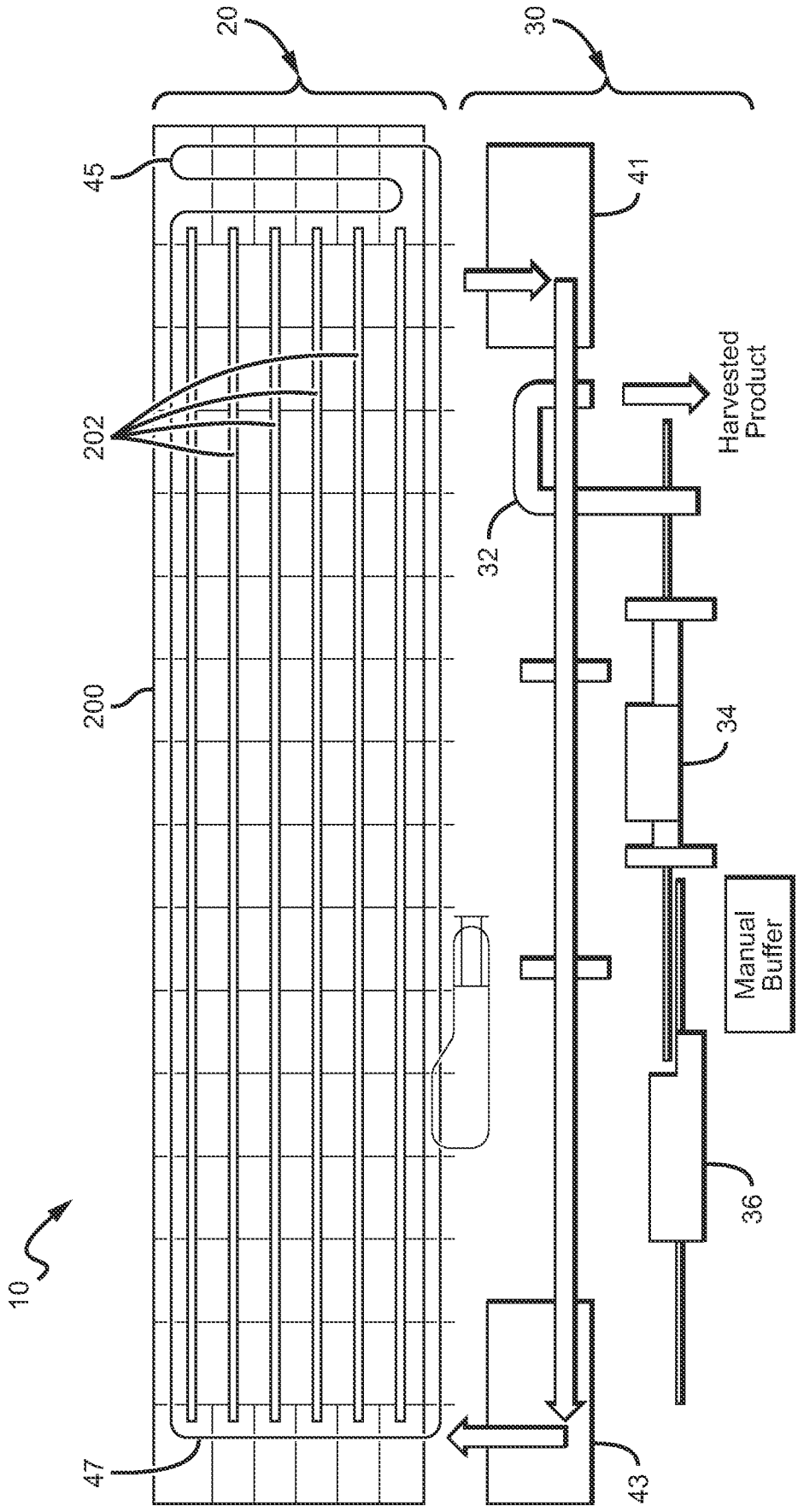

20
30
45
41
202
Harvested Product
32
200
34
Manual Buffer
36
10
47
43

FIG. 1

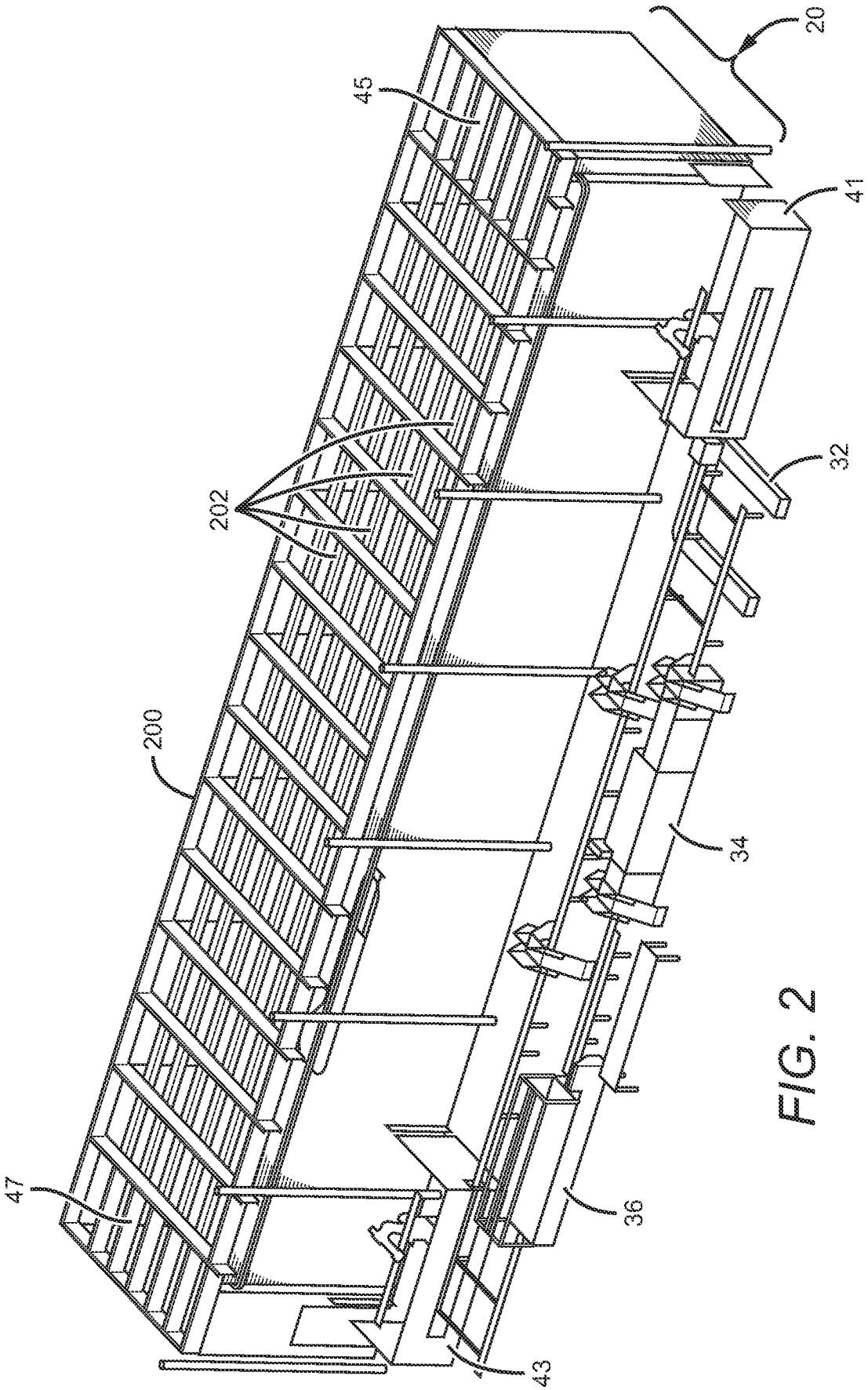


FIG. 2

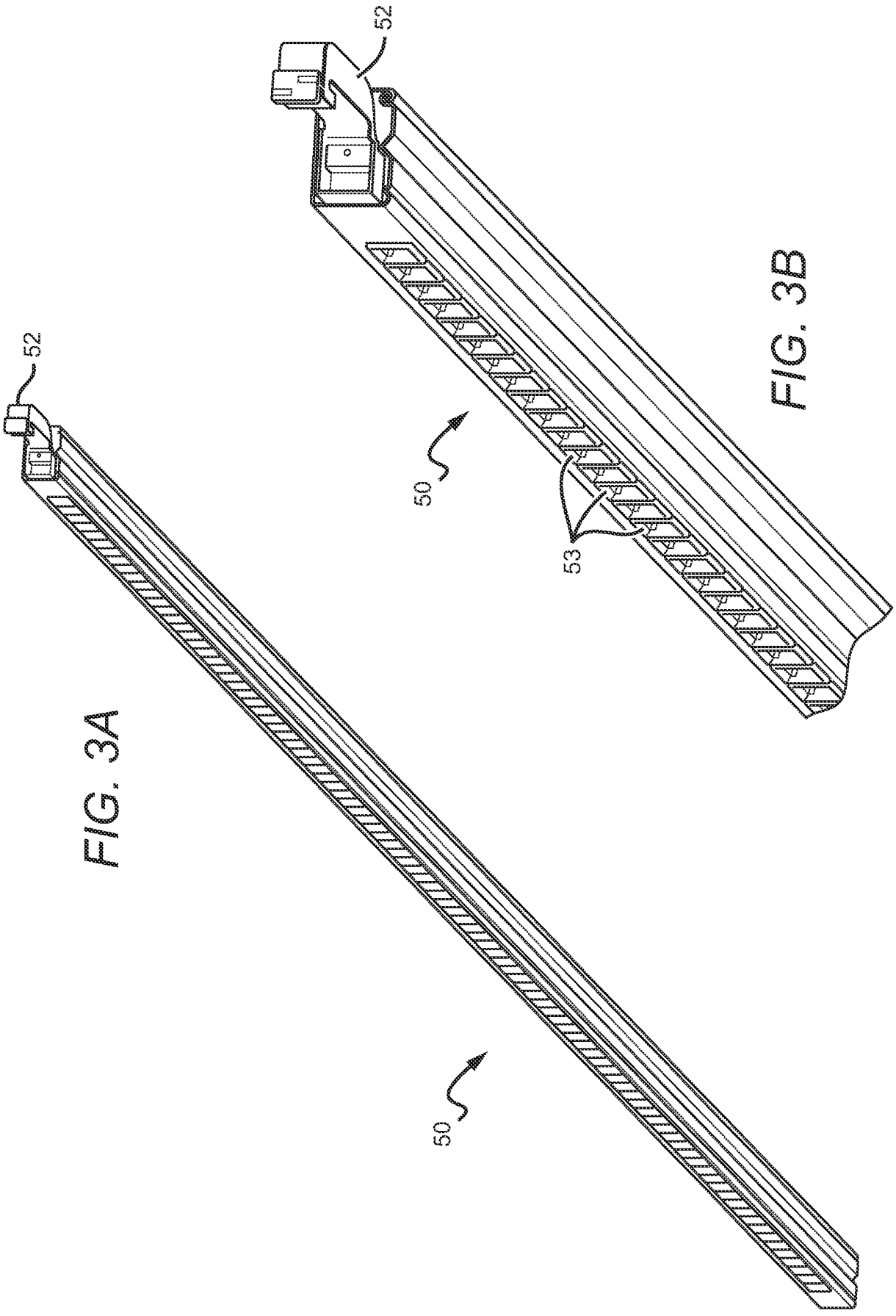


FIG. 3B

FIG. 3A

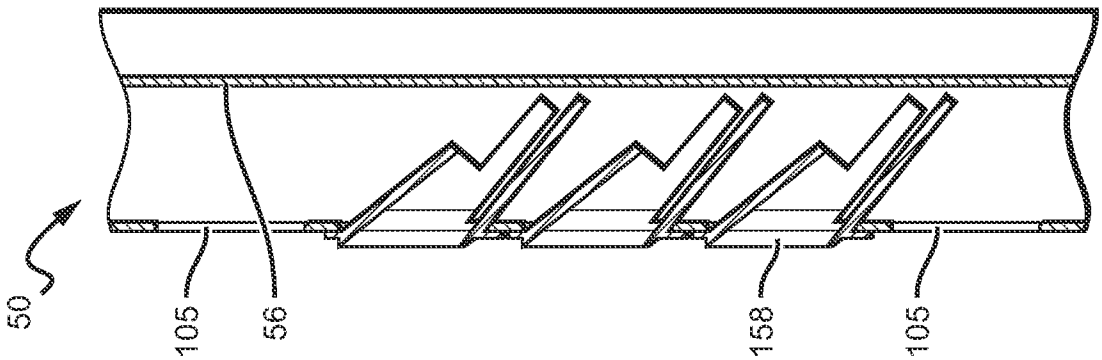


FIG. 4D

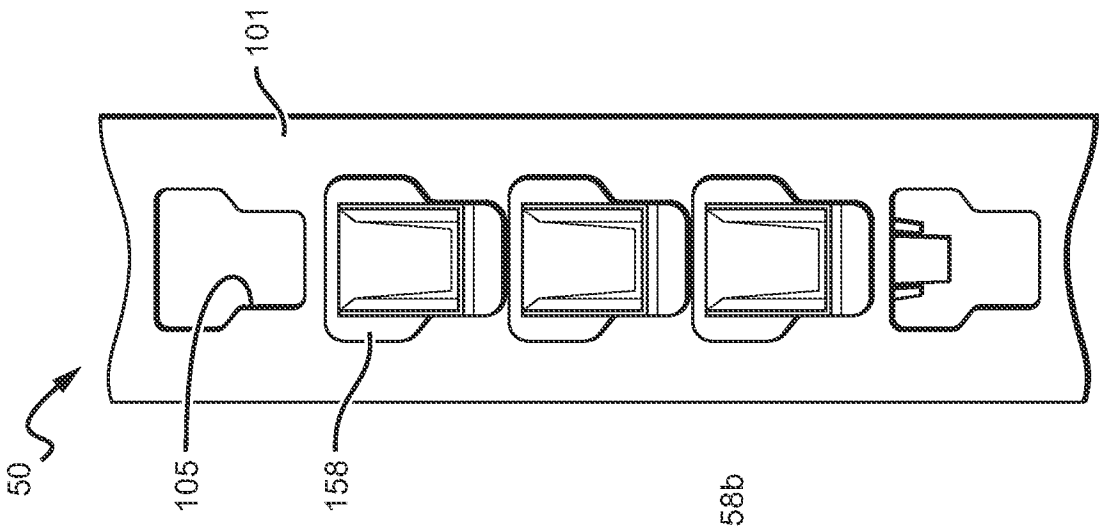


FIG. 4C

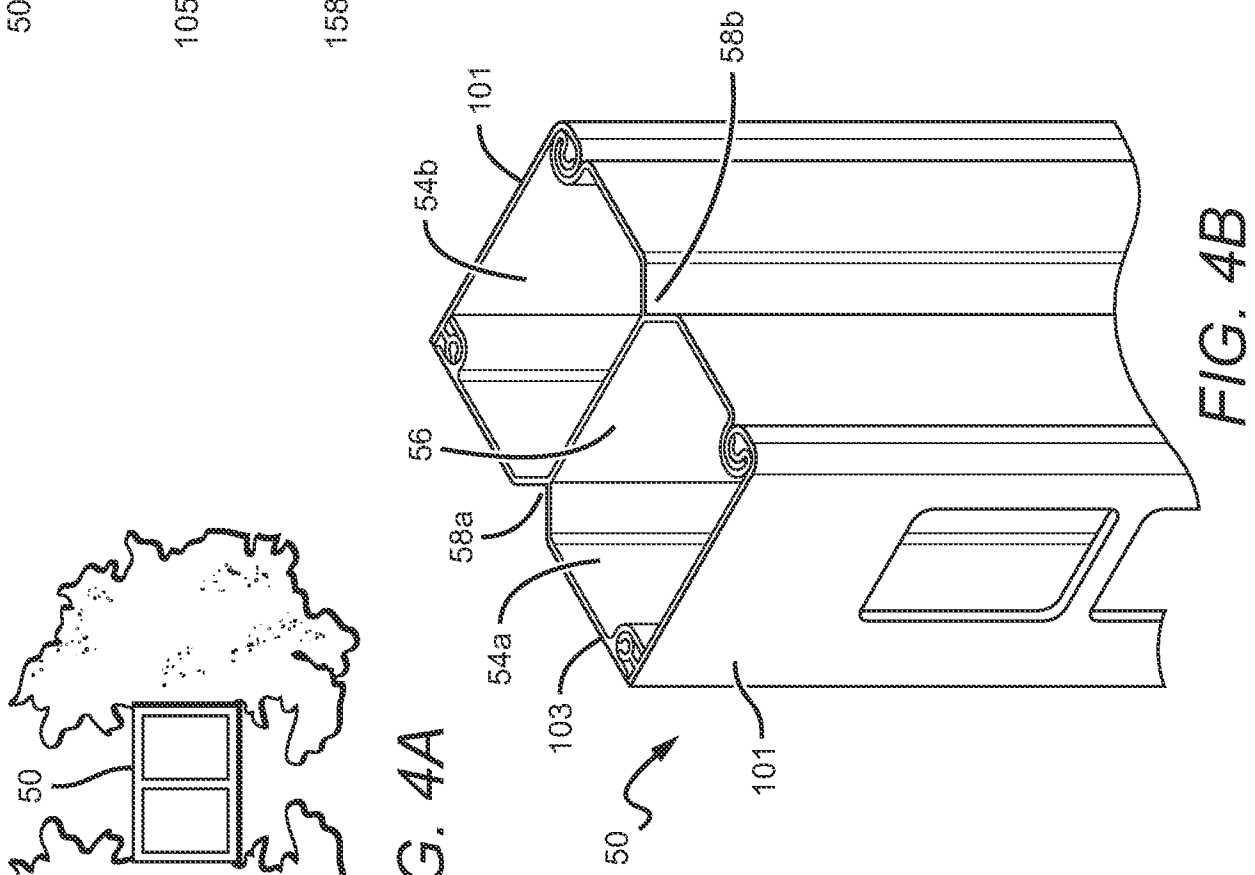


FIG. 4B

FIG. 4A

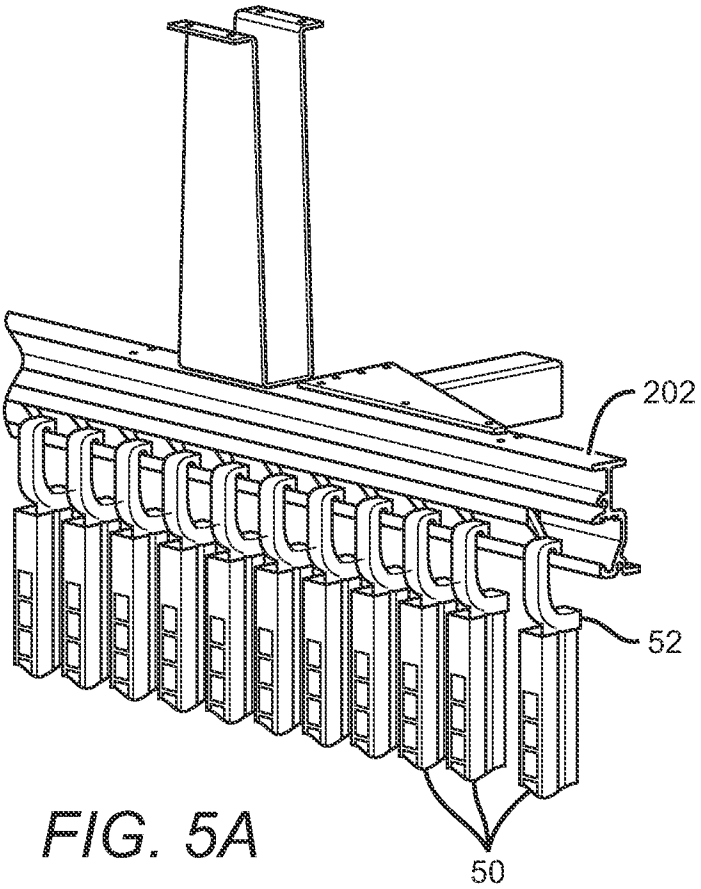


FIG. 5A

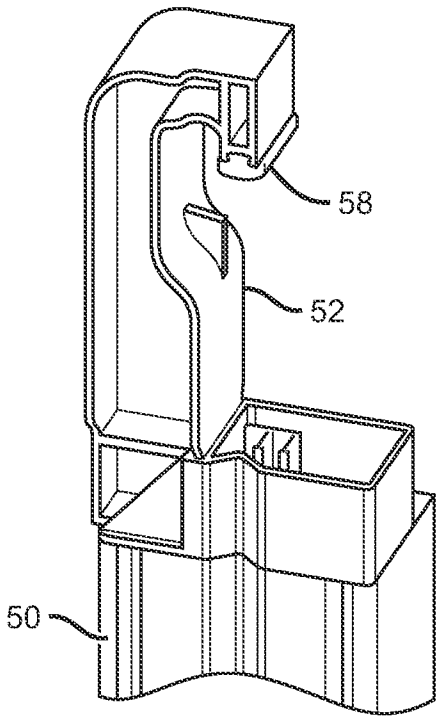


FIG. 5B

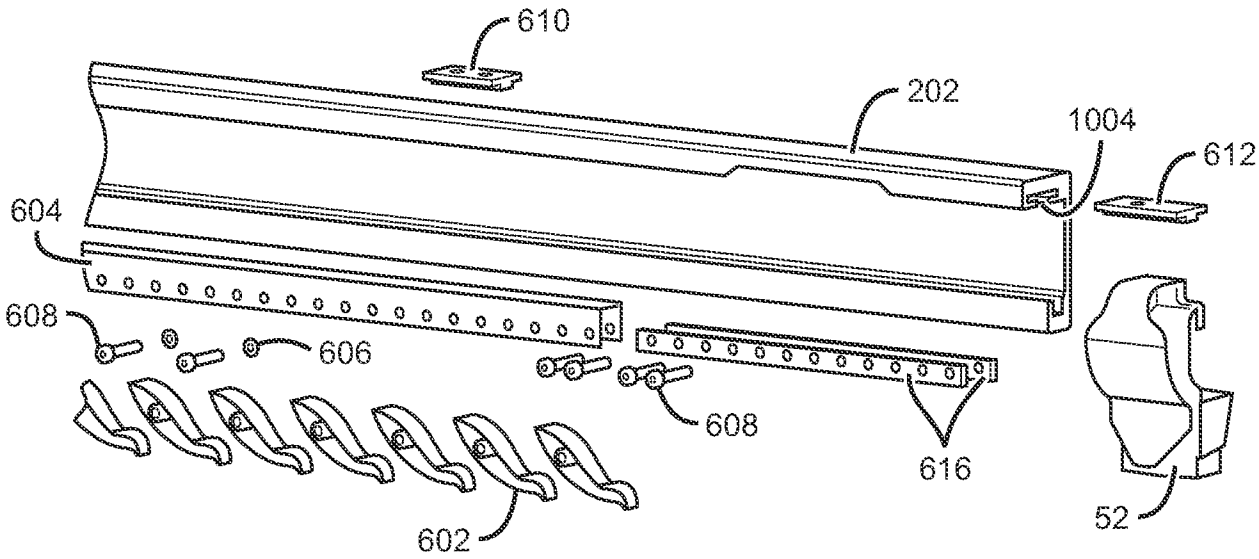


FIG. 6

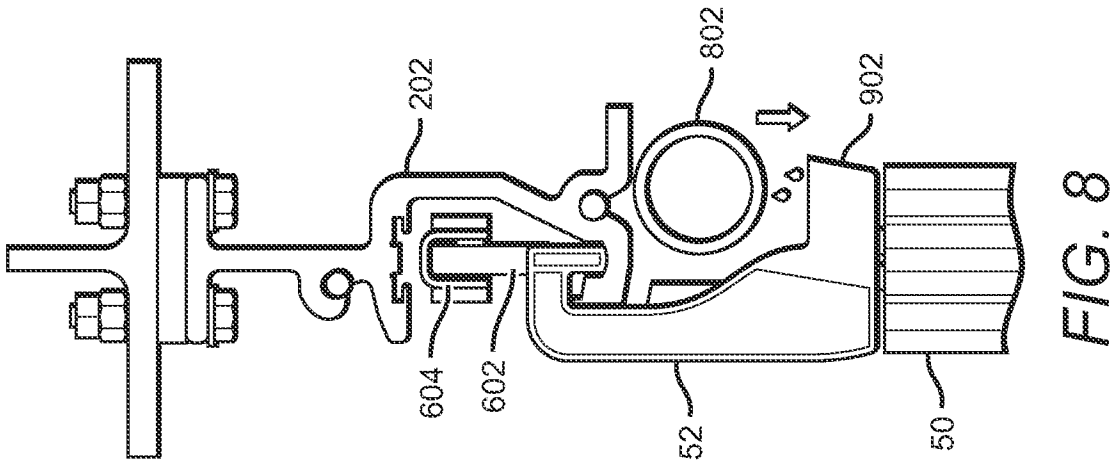


FIG. 8

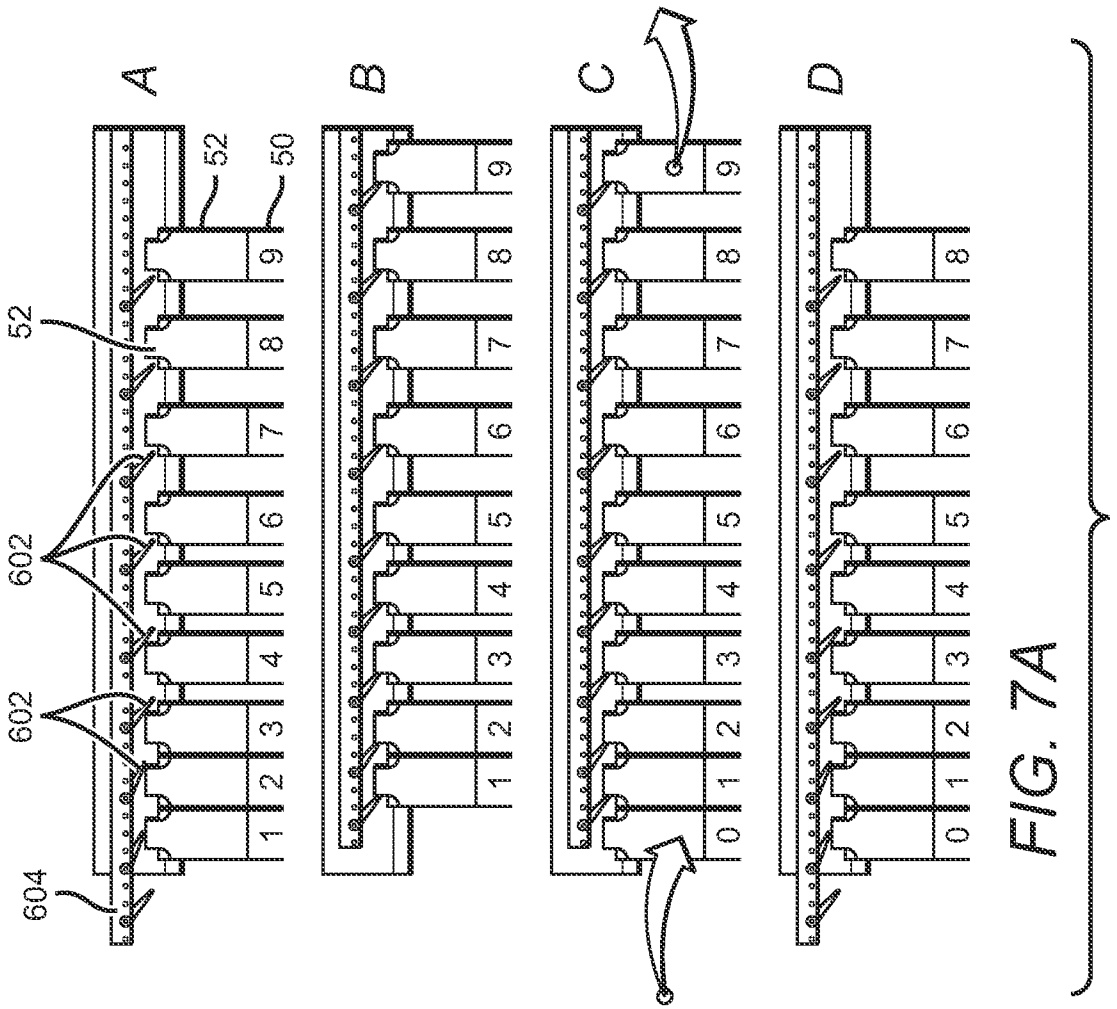


FIG. 7A

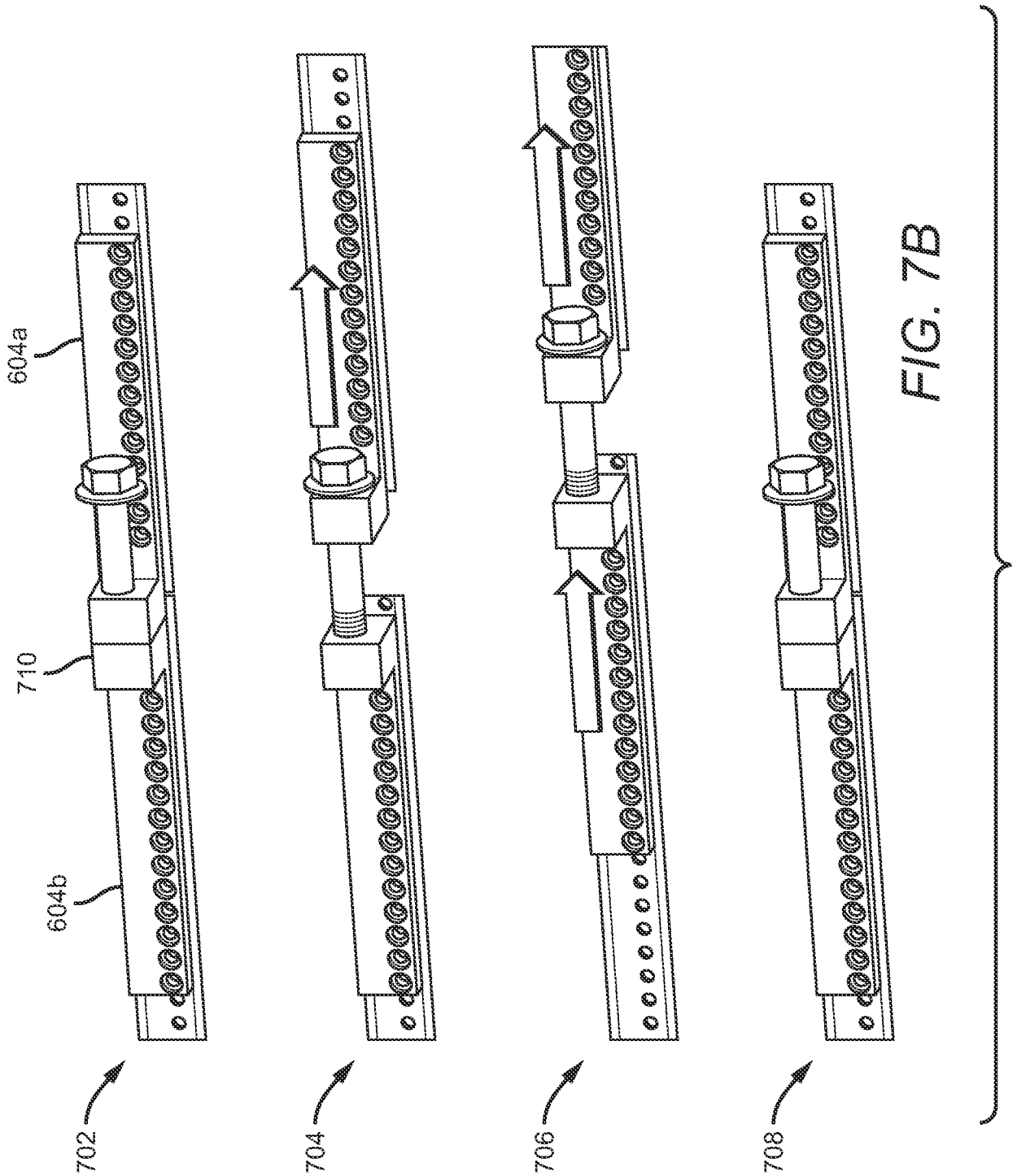


FIG. 7B

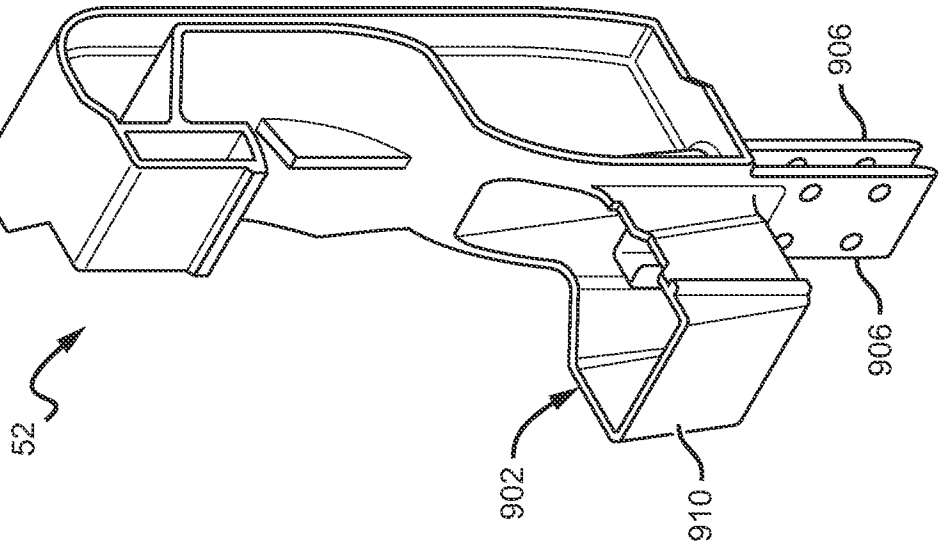


FIG. 11A

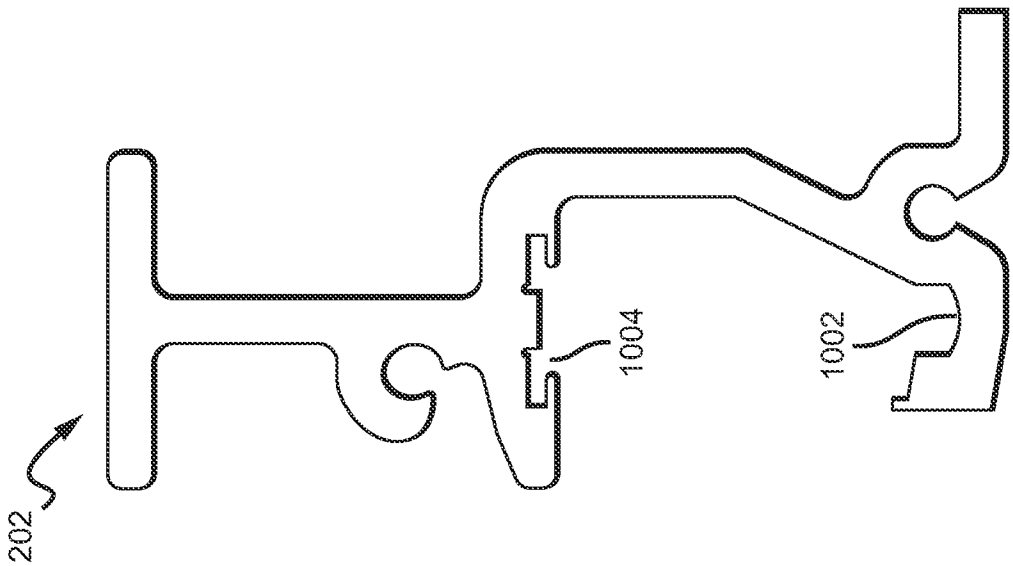


FIG. 10

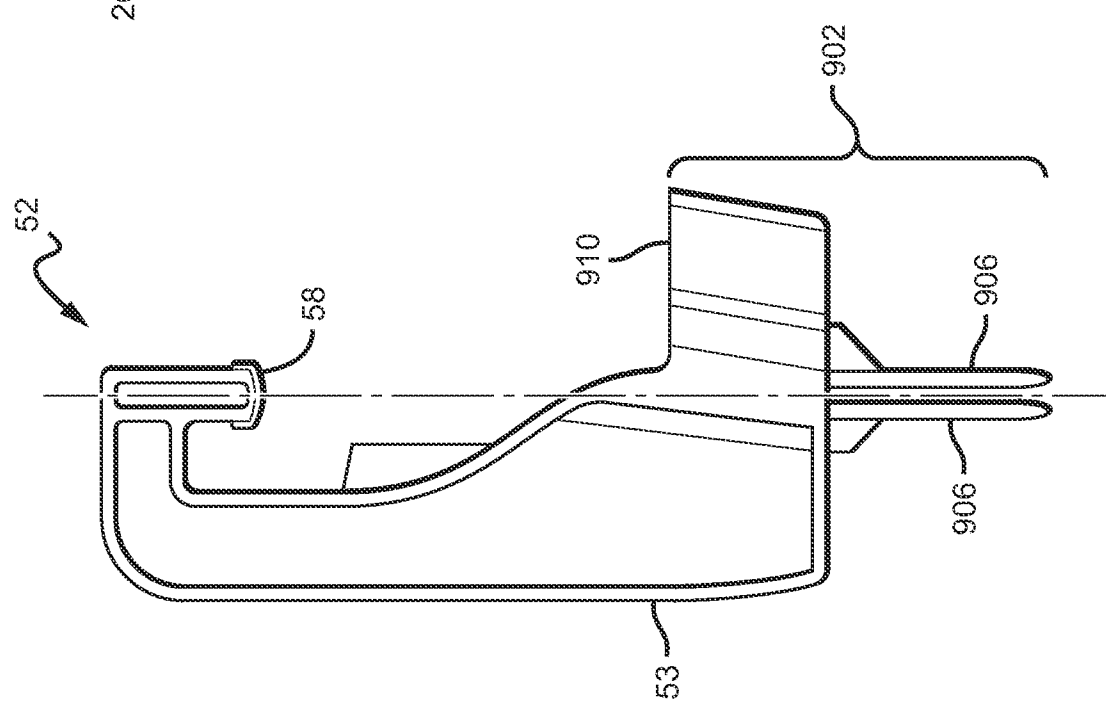
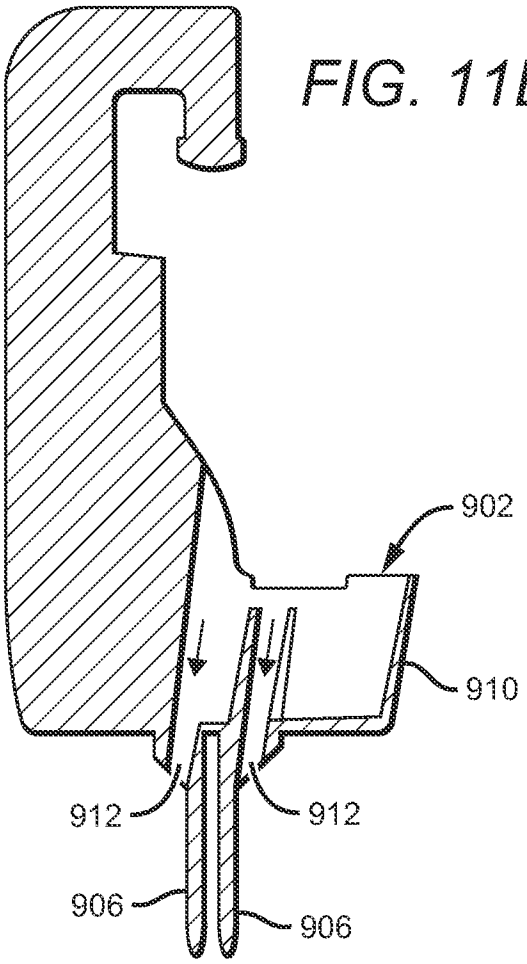


FIG. 9

FIG. 11B



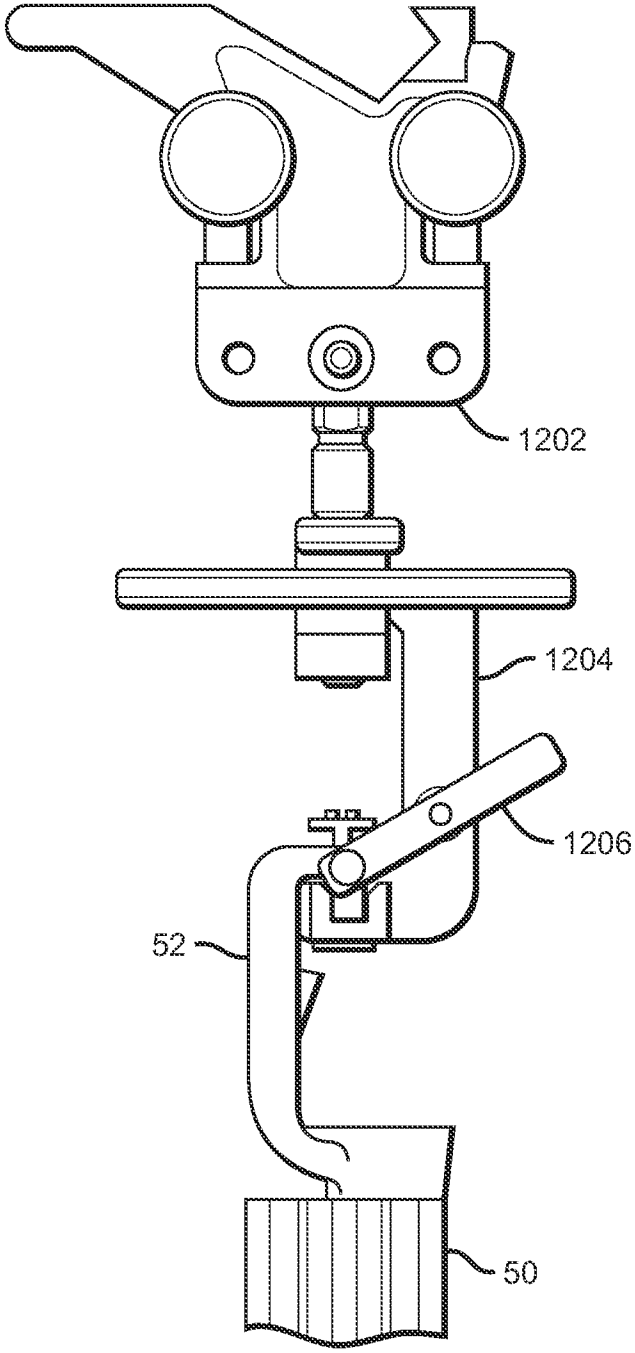


FIG. 12

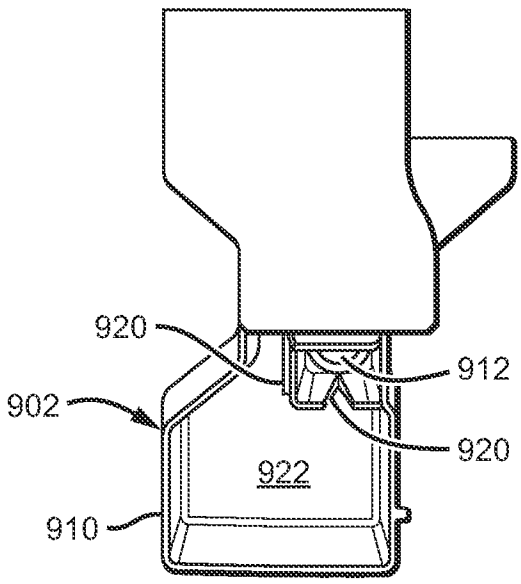


FIG. 11C

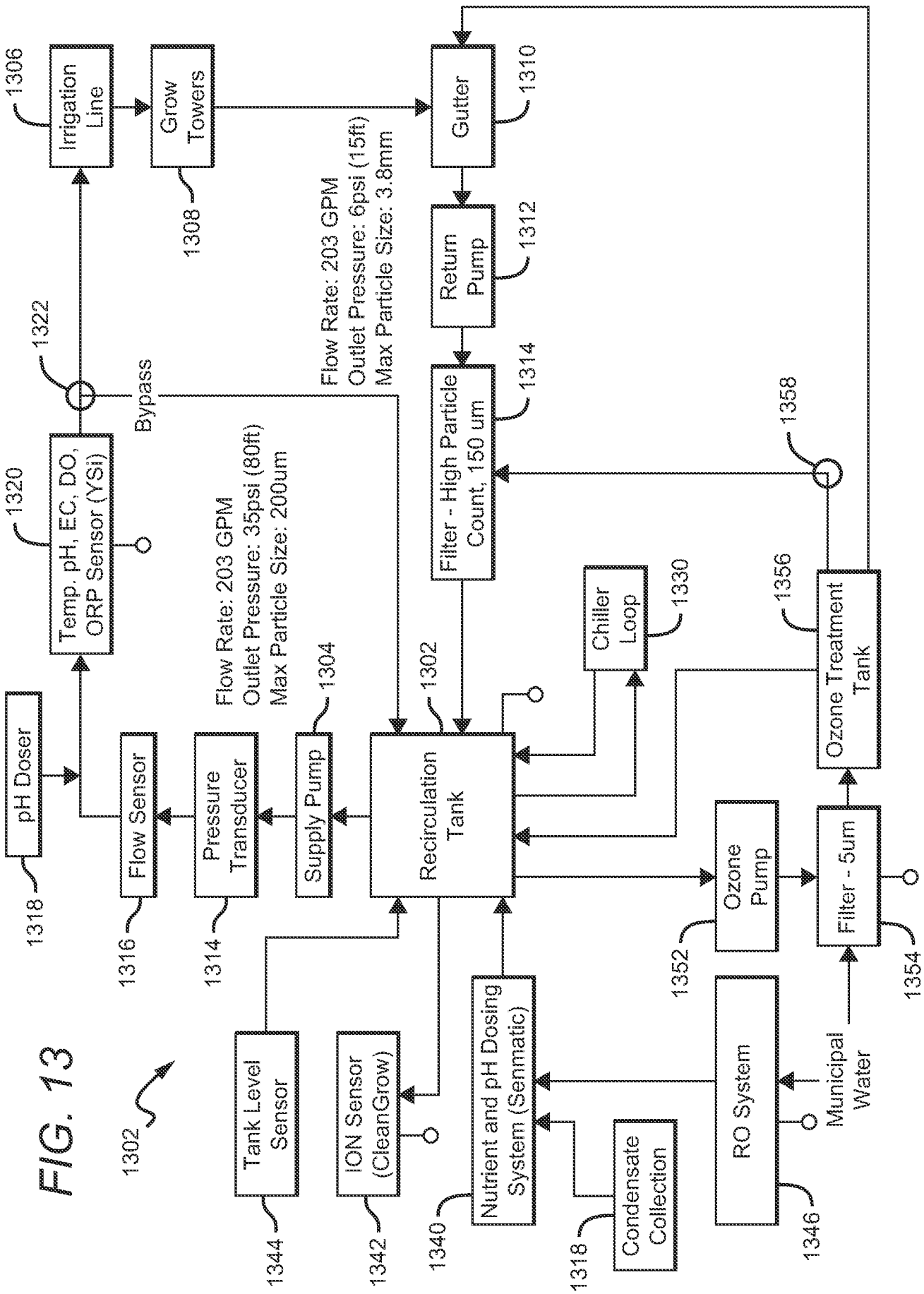

1306
Irrigation Line
Grow Towers
1308
Gutter
1310
Return Pump
1312
Filter - High Particle Count, 150 um
1314
Flow Rate: 203 GPM
Outlet Pressure: 6psi (15ft)
Max Particle Size: 3.8mm
1322
Bypass
1320
Temp. pH, EC, DO, ORP Sensor (YSi)
1358
Chiller Loop
1330
1356
Ozone Treatment Tank
pH Doser
1318
Flow Sensor
1316
Pressure Transducer
1314
Flow Rate: 203 GPM
Outlet Pressure: 35psi (80ft)
Max Particle Size: 200um
Supply Pump
1304
Recirculation Tank
1302
Ozone Pump
1352
Filter - 5um
1354
Municipal Water
Tank Level Sensor
1344
ION Sensor (CleanGrow)
1342
Nutrient and pH Dosing System (Senmatic)
1340
Condensate Collection
1318
RO System
1346
1302

FIG. 13

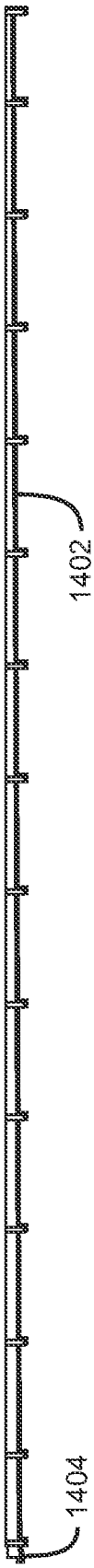


FIG. 14A

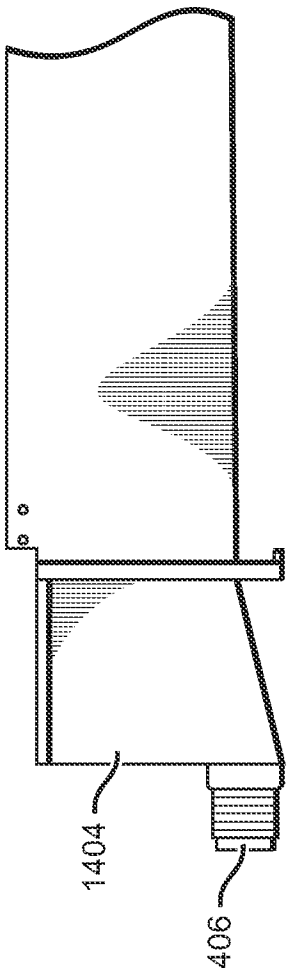


FIG. 14B

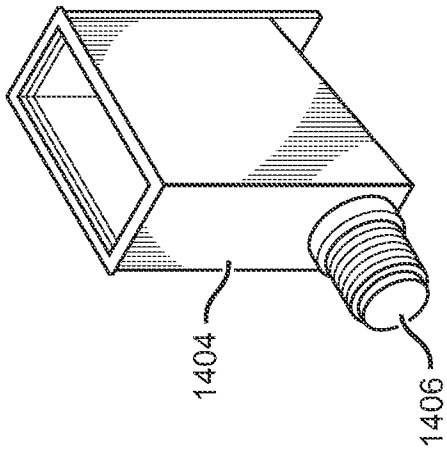


FIG. 14C

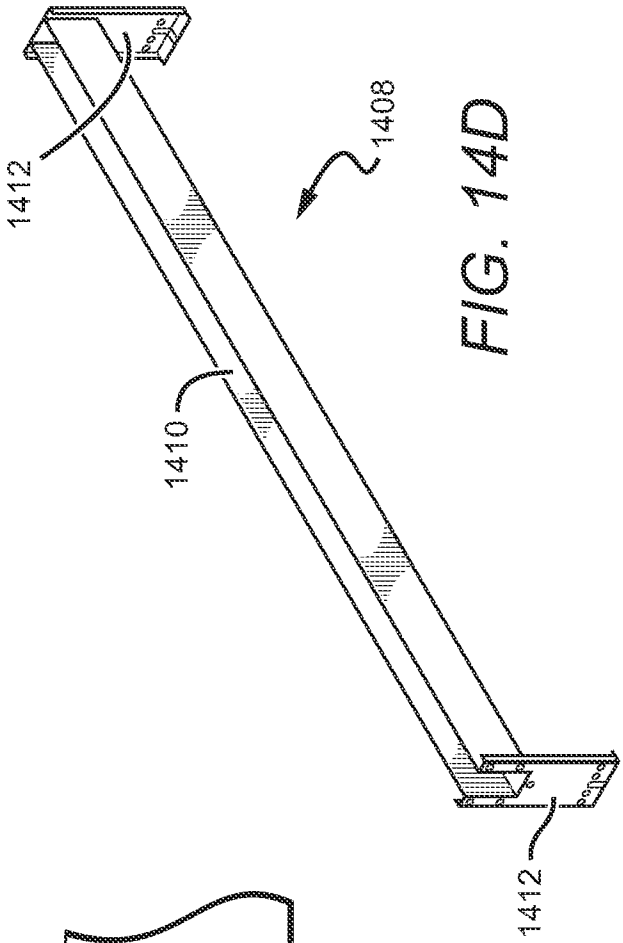


FIG. 14D

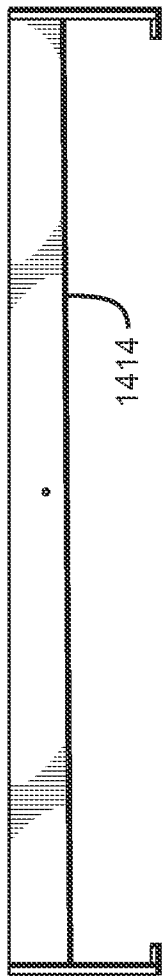


FIG. 14E

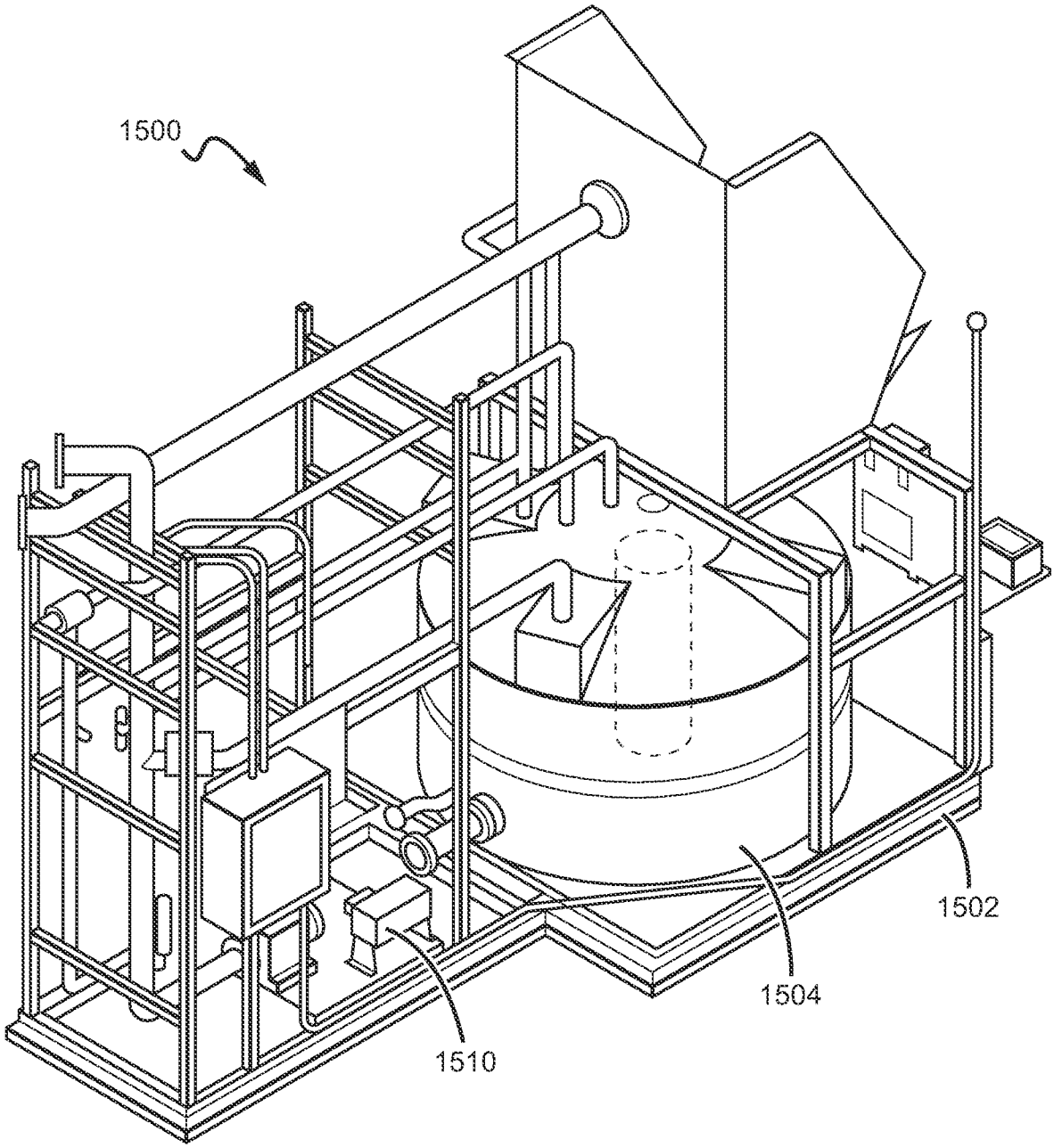


FIG. 15A

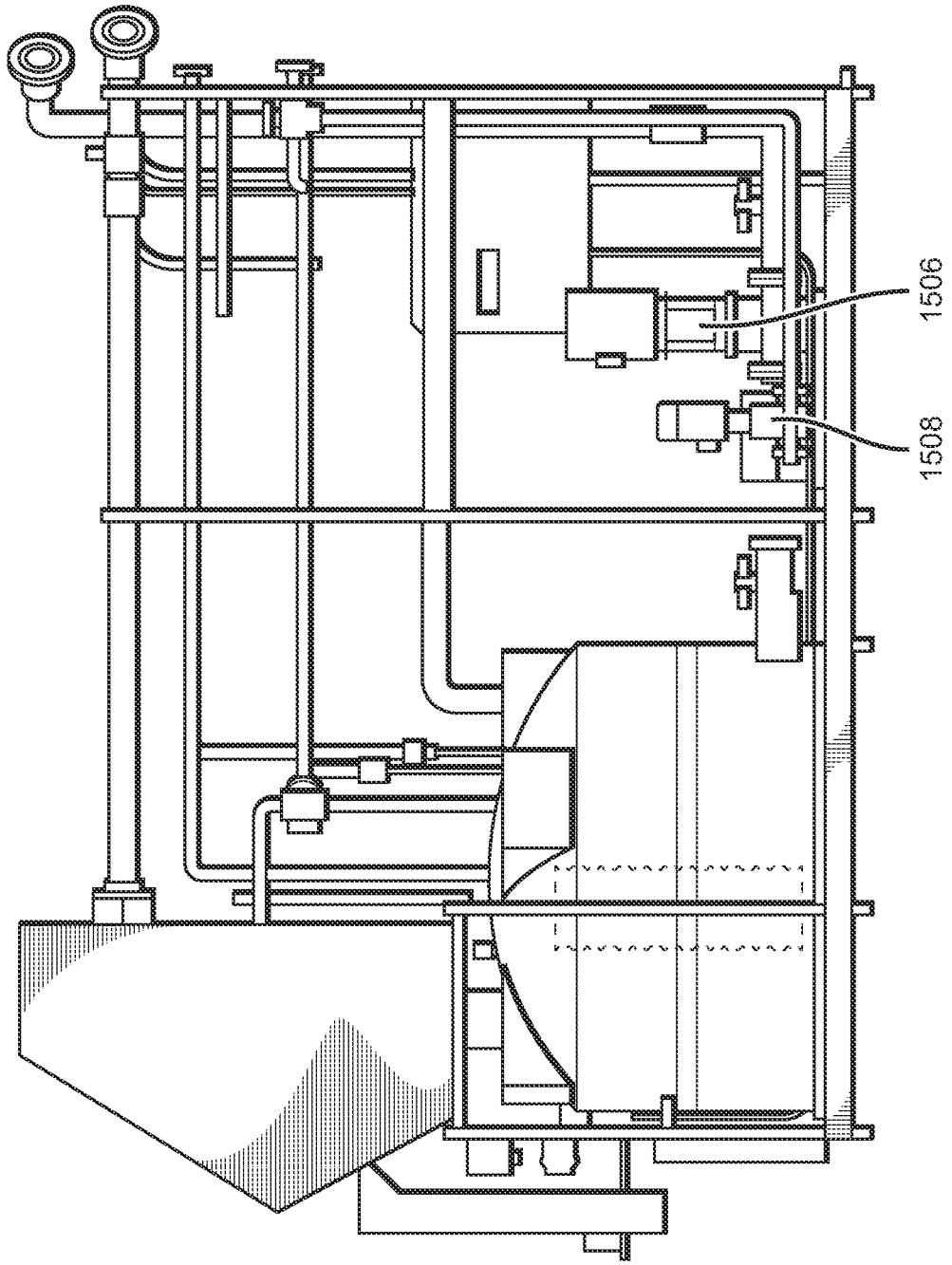


FIG. 15B

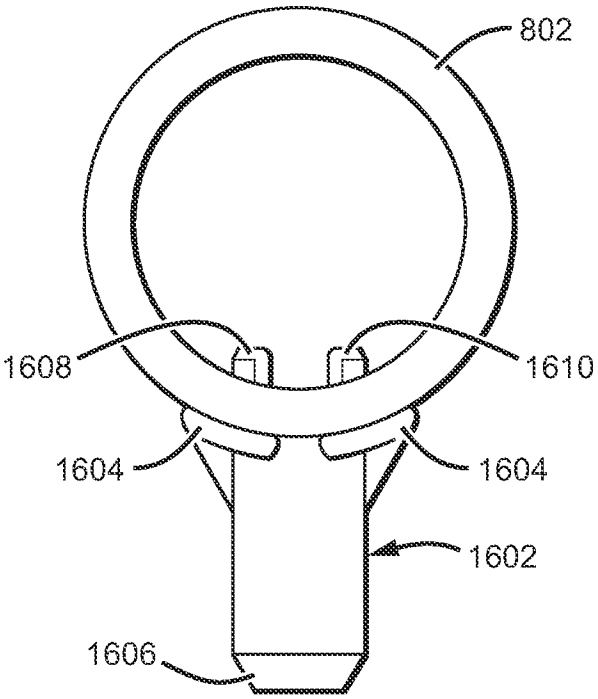


FIG. 16A

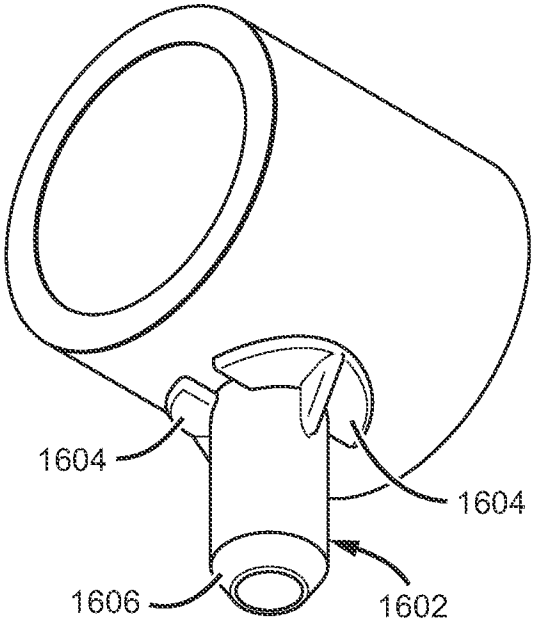


FIG. 16B

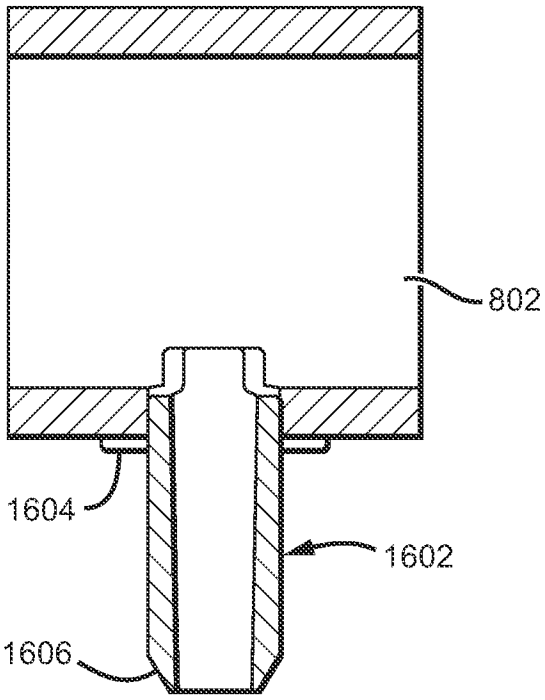


FIG. 16C

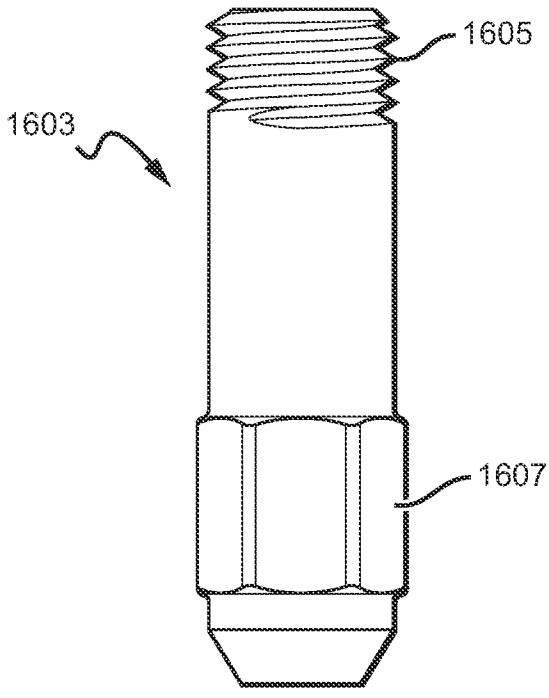


FIG. 16D

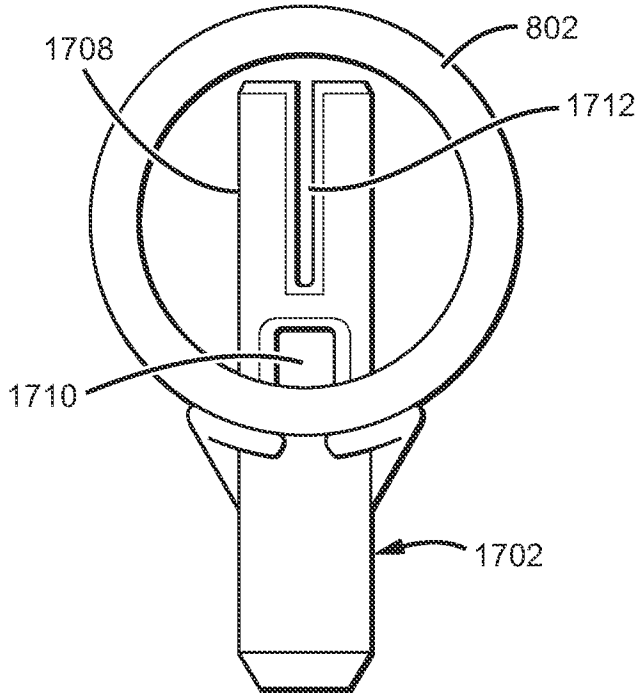


FIG. 17A

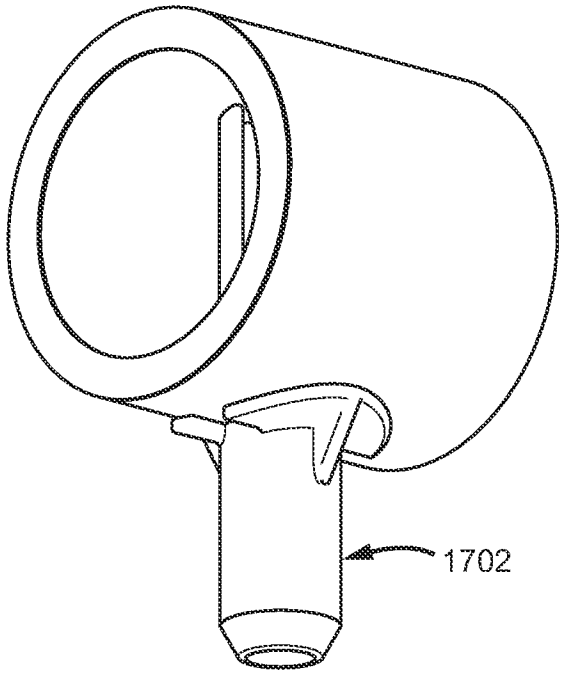


FIG. 17B

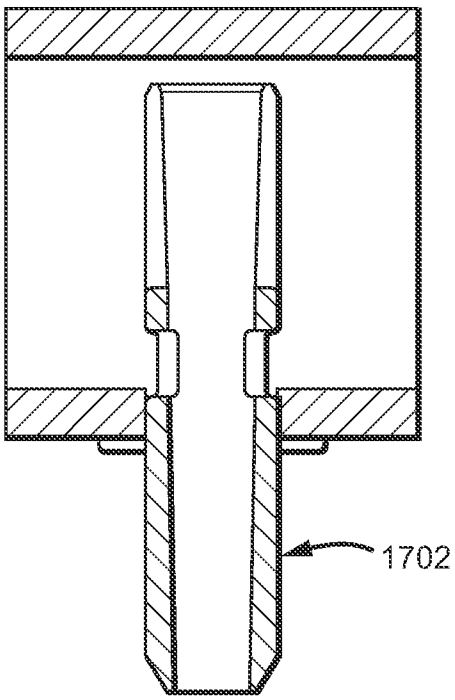


FIG. 17C

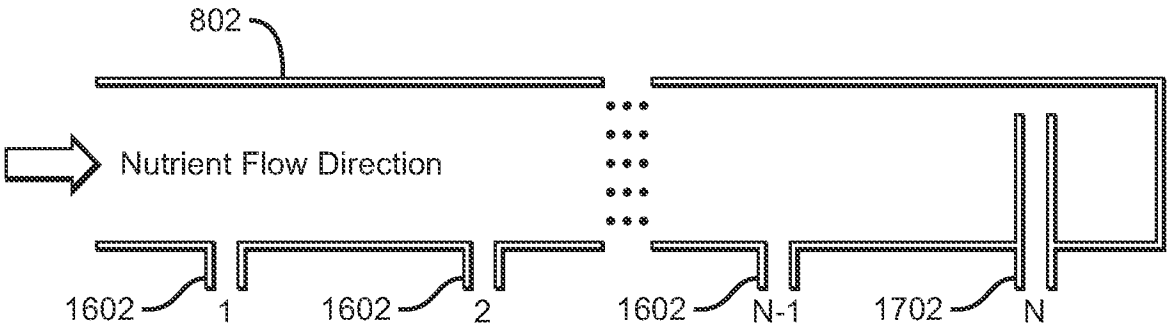

802
Nutrient Flow Direction
1602
1
1602
2
1602
N-1
1702
N

FIG. 18

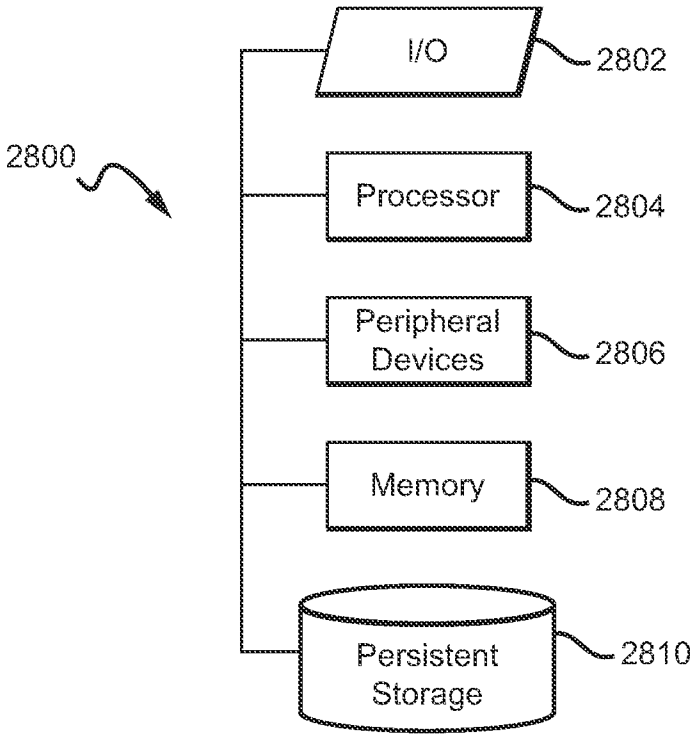

2800
I/O
2802
Processor
2804
Peripheral Devices
2806
Memory
2808
Persistent Storage
2810

FIG. 20

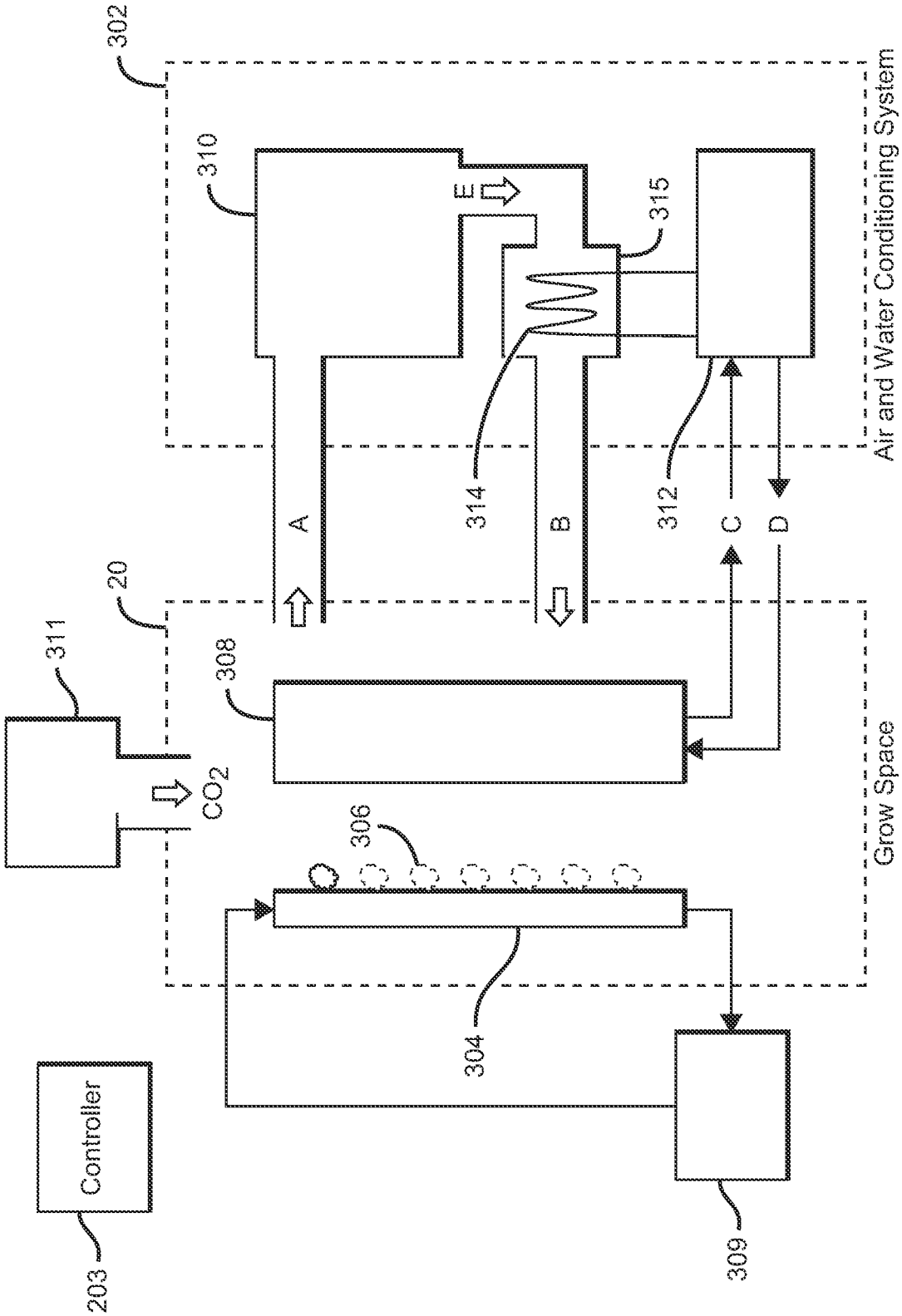

302
310
E
315
Air and Water Conditioning System
A
314
B
312
C
D
20
311
308
CO_2
306
Grow Space
304
Controller
203
309

FIG. 19

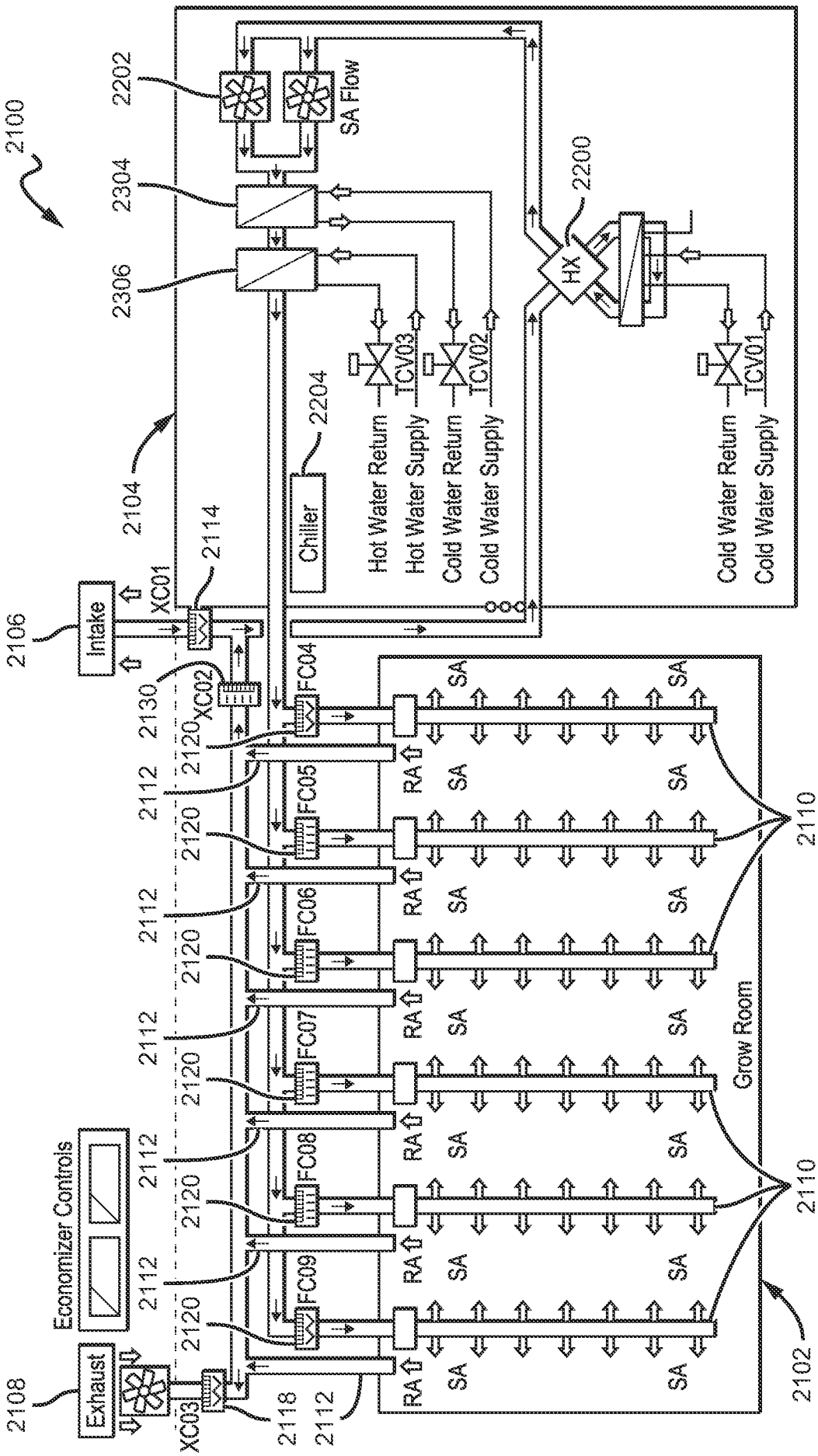

2100
2202
SA Flow
2304
2306
2200
HX
2104
2204
Chiller
Hot Water Return
Hot Water Supply
Cold Water Return
Cold Water Supply
TCV03
TCV02
TCV01
2114
XC01
2106
Intake
2130
XC02
FC04
FC05
FC06
FC07
FC08
FC09
2120
2112
RA
SA
2110
Grow Room
2102
Economizer Controls
2108
Exhaust
XC03
2118

FIG. 21

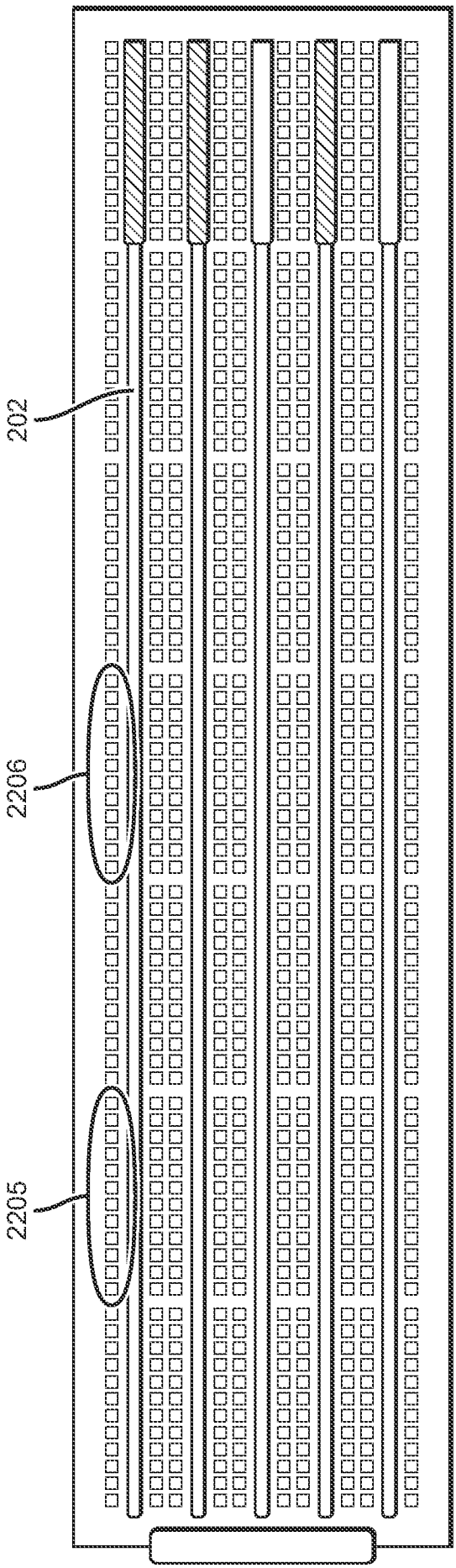


FIG. 22

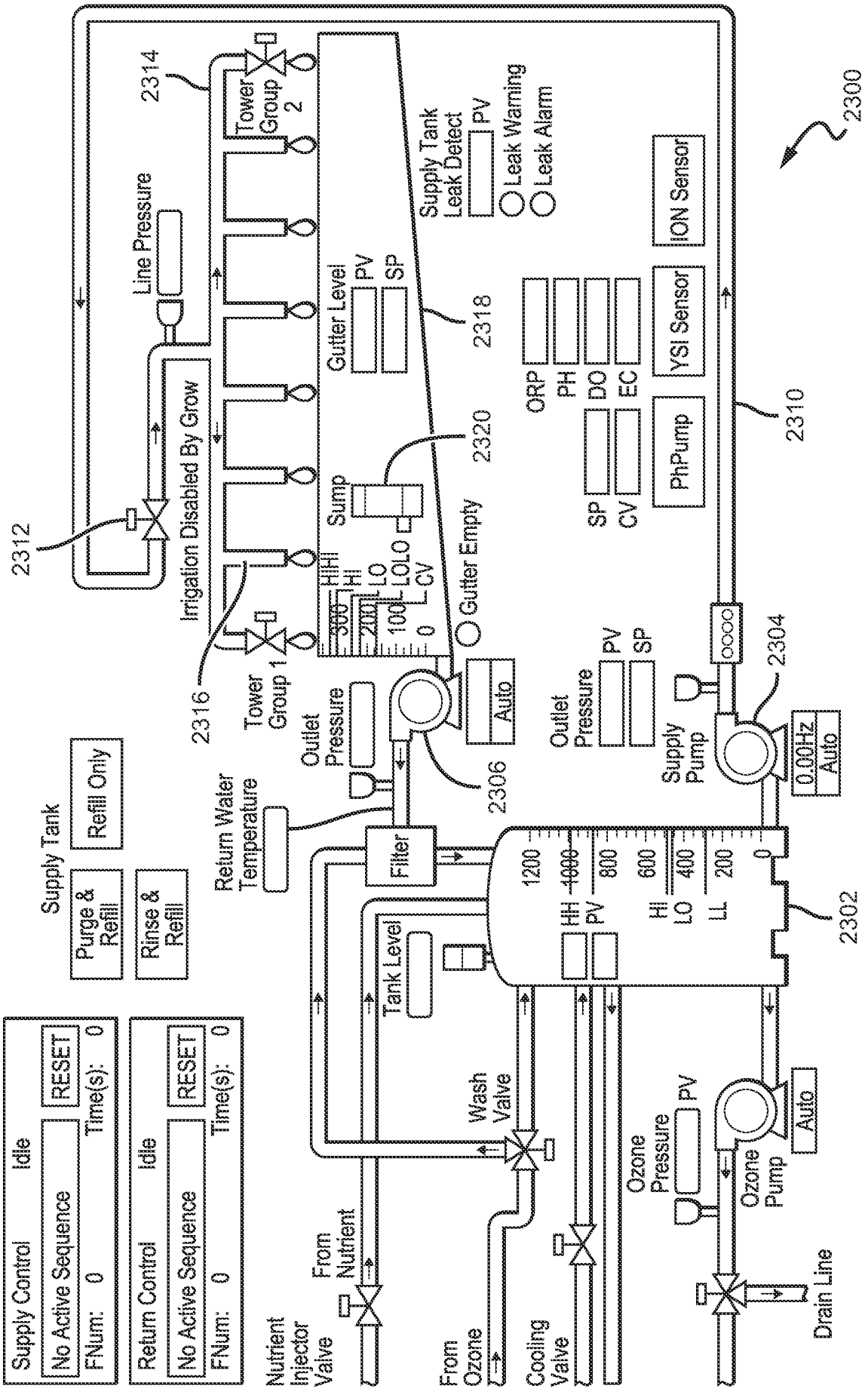

2300
2312
2314
2316
2318
2320
2302
2304
2306
2310
Line Pressure
Irrigation Disabled By Grow
Tower Group 2
Tower Group 1
Gutter Level
PV
SP
Supply Tank Leak Detect
PV
Leak Warning
Leak Alarm
ION Sensor
YSI Sensor
PhPump
ORP
PH
DO
EC
SP
CV
Sump
HiHi
Hi
Lo
LoLo
CV
Gutter Empty
Auto
Outlet Pressure
PV
SP
Supply Pump
0.00Hz
Auto
Return Water Temperature
Filter
Tank Level
Supply Tank
Refill Only
Purge & Refill
Rinse & Refill
Wash Valve
Ozone Pressure
PV
Ozone Pump
Auto
From Nutrient
Nutrient Injector Valve
From Ozone
Cooling Valve
Drain Line
Supply Control Idle
No Active Sequence
RESET
FNum: 0
Time(s): 0
Return Control Idle
No Active Sequence
RESET
FNum: 0
Time(s): 0

FIG. 23

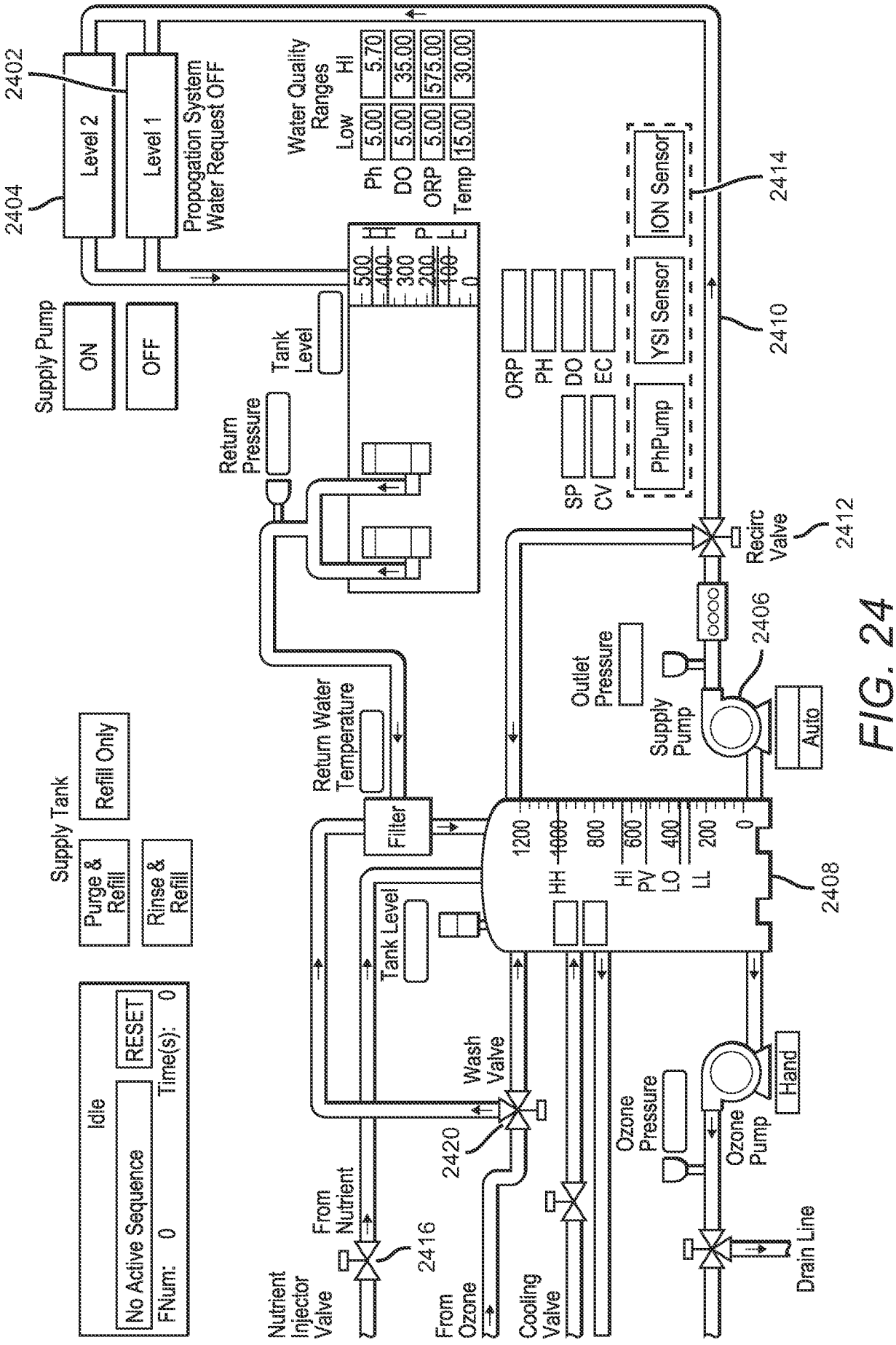

2402
2404
Level 2
Level 1
Propogation System
Water Request OFF
Water Quality
Ranges
Low
HI
Ph
DO
ORP
Temp
5.00
5.00
5.00
15.00
5.70
35.00
575.00
30.00
2414
ION Sensor
YSI Sensor
PhPump
ORP
PH
DO
EC
SP
CV
2410
Supply Pump
ON
OFF
Tank
Level
Return
Pressure
Recirc
Valve
2412
2406
Outlet
Pressure
Supply
Pump
Auto
Return Water
Temperature
Filter
Supply Tank
Refill Only
Purge &
Refill
Rinse &
Refill
1200
1000
800
600
400
200
0
HH
Hi
PV
LO
LL
2408
Tank Level
Idle
No Active Sequence
RESET
FNum: 0
Time(s): 0
Wash
Valve
2420
Ozone
Pressure
Ozone
Pump
Hand
From
Nutrient
2416
Drain Line
Nutrient
Injector
Valve
From
Ozone
Cooling
Valve

FIG. 24

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 20/51030

A. CLASSIFICATION OF SUBJECT MATTER

IPC - A01G 9/02, A01G 9/10 (2021.01)

CPC - A01G 9/029, A01G 31/04, H05B 45/10, A01G 9/247

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
See Search History document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
See Search History document

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2018/0014471 A1 (MJNN LLC), 18 January 2018 (18.01.2018), entire document, especially Abstract; para [0016], [0074]-[0075]	1-9, 12-20, and 23-31
Y	US 2009/0216345 A1 (Christfort), 27 August 2009 (27.08.2009), entire document, especially Abstract; para [0005], [0020], [0092]-[0095]	1-9, 12-20, and 23-31
Y	US 5,729,989 A (Sunaga et al.), 24 March 1998 (24.03.1998), entire document, especially Abstract; col 3, ln 10-38	2, 13, 24
Y	US 2014/0083000 A1 (DeMerchant, JR et al.), 27 March 2014 (27.03.2014), entire document, especially Abstract; para [0074]-[0078], [0079]-[0081], [0170]-[0172]	4, 15, 26
Y	US 2010/0218423 A1 (Walhovd), 02 September 2010 (02.09.2010), entire document, especially Abstract; para [0028], [0047], [0052]-[0054], [0076]-[0078]	7-9, 18-20, 29-31
A	WO 2019/074684 A1 (Johnson et al.), 18 April 2019 (18.04.2019), entire document	1-9, 12-20, and 23-31

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"D" document cited by the applicant in the international application
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 January 2021	05 FEB 2021
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Authorized officer Lee Young Telephone No. PCT Helpdesk: 571-272-4300

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 20/51030

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

--- (See Continuation in Supplemental Box) ---

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
claims 1-9, 12-20, and 23-31

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 20/51030

Continuation of:
Box III. Observations where unity of invention is lacking

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be searched, the appropriate additional search fees must be paid.

Group I: claims 1-9, 12-20, and 23-31 are drawn to detecting a fault condition in controlled agricultural environment (CAE), the environmental conditioning equipment for the CAE or the environmental conditioning equipment and changing the operating mode from standard mode to fail-safe mode.

Group II: claims 10, 21 and 32 are drawn to irrigating and then delaying the movement receptacle supports that hold plants until after a first lapse of time that includes drainage of water from the receptacle supports.

Group III: claims 11, 22, and 33 are drawn to determining the recirculated water quality has the received minerals and stopping recirculating the water from the supply tank and direct it towards a propagation area.

The inventions listed as Groups I-III do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons:

Special technical features:

The special technical feature of Group I is detecting a fault condition in controlled agricultural environment (CAE), the environmental conditioning equipment for the CAE or the environmental conditioning equipment and changing the operating mode from standard mode to fail-safe mode, not required by the other groups.

The special technical feature of Group II is irrigating and then delaying the movement receptacle supports that hold plants until after a first lapse of time that includes drainage of water from the receptacle supports, not required by the other groups.

The special technical feature of Group III is determining the recirculated water quality has the received minerals and stopping recirculating the water from the supply tank and direct it towards a propagation area, not required by the other groups.

Shared Features:
Groups I through III share the technical feature of a computer-implemented method/system/one or more non-transitory computer-readable media storing instructions for a controlled agricultural environment (CAE), wherein the CAE includes a plurality of moving receptacle supports for holding plants.However, this shared technical feature does not represent a contribution over WO 2019/074684 A1 to Johnson et al. (hereinafter Johnson) 18 April 2019 (18.04.2019).

Johnson discloses a computer-implemented method/system/one or more non-transitory computer-readable media storing instructions for a controlled agricultural environment (CAE) (pg. 1, ln 23-28; pg. 2, ln 11-17; pg. 4, ln 21-33; pg. 8, ln 12-18), wherein the CAE includes a plurality of moving receptacle supports for holding plants (e.g. a conveyor system such as an overhead monorail or I-beam rail system to move and manage vertical poles holding pots or bags of agricultural plants in a greenhouse or building, stationed in a grow area with natural or artificial light. Through the use of the conveyance, the indoor farm can manage individual poles or groups of poles similarly to how railroad yards shuttle and organize rail cars utilizing switching mechanisms, pg. 1, ln 23-28; pg. 8, ln 12-18).

Thus, unity of invention is lacking under PCT Rule 13.1 because Groups I through III do not share a same or corresponding special technical feature that would provide a unifying contribution over the prior art. None of these special technical features are common to the other groups.