(54) **APPARATUS, SYSTEM AND METHODS FOR IMPROVED VERTICAL FARMING**

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(57) **ABSTRACT**

The present disclosure is directed to improved vertical farming using autonomous systems and methods for growing edible plants, using improved stacking and shelving units configured to allow for gravity-based irrigation, gravity-based loading and unloading, along with a system for autonomous rotation, incorporating novel plant-growing pallets, while being photographed and recorded by camera systems incorporating three dimensional/multispectral cameras, with the images and data recorded automatically sent to a database for processing and for gauging plant health, pest and/or disease issues, and plant life cycle. The present disclosure is also directed to novel harvesting methods, novel modular lighting, novel light intensity management systems, real time vision analysis that allows for the dynamic adjustment and optimization of the plant growing environment, and a novel rack structure system that allows for simplified building and enlarging of vertical farming rack systems.
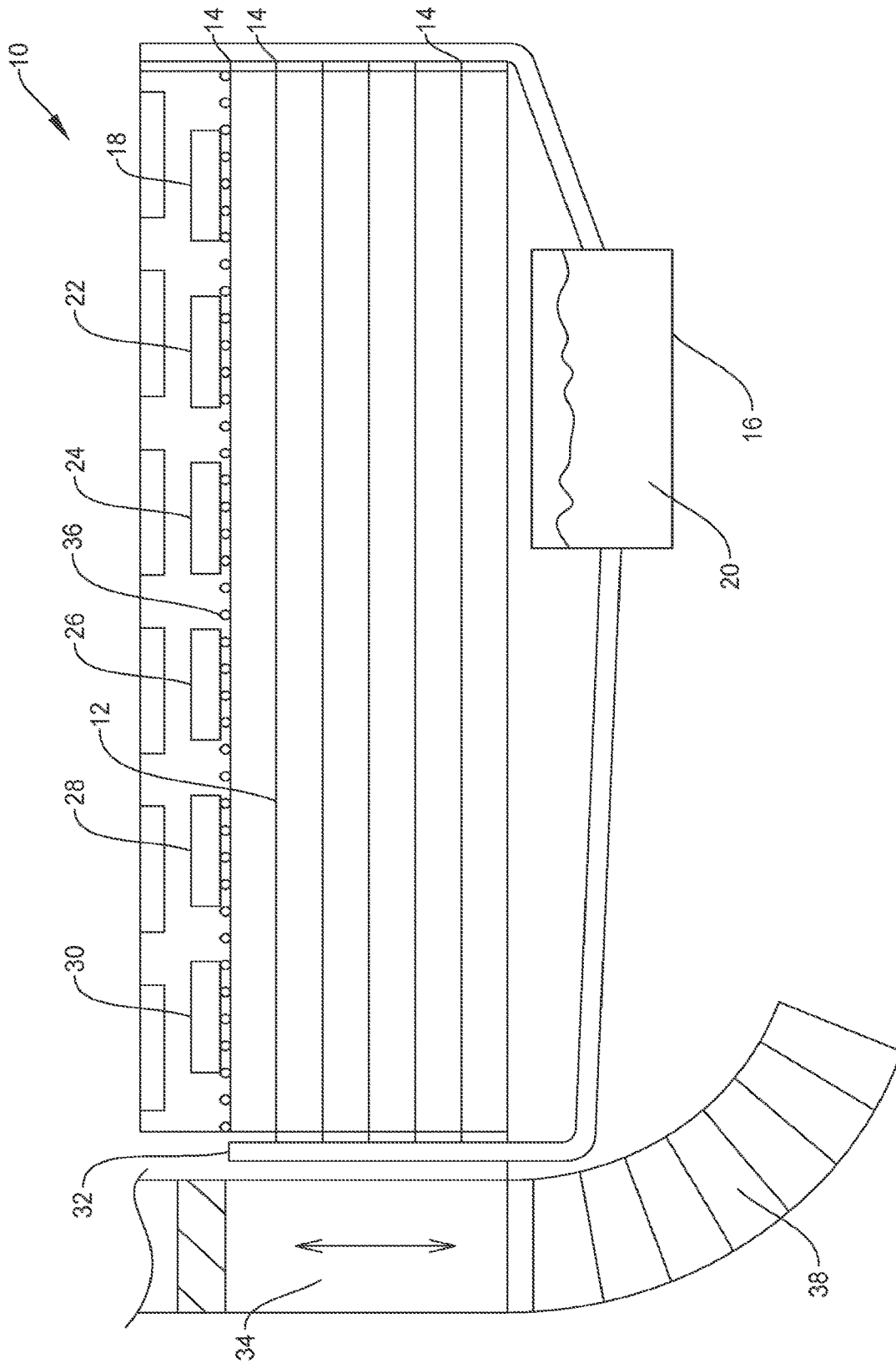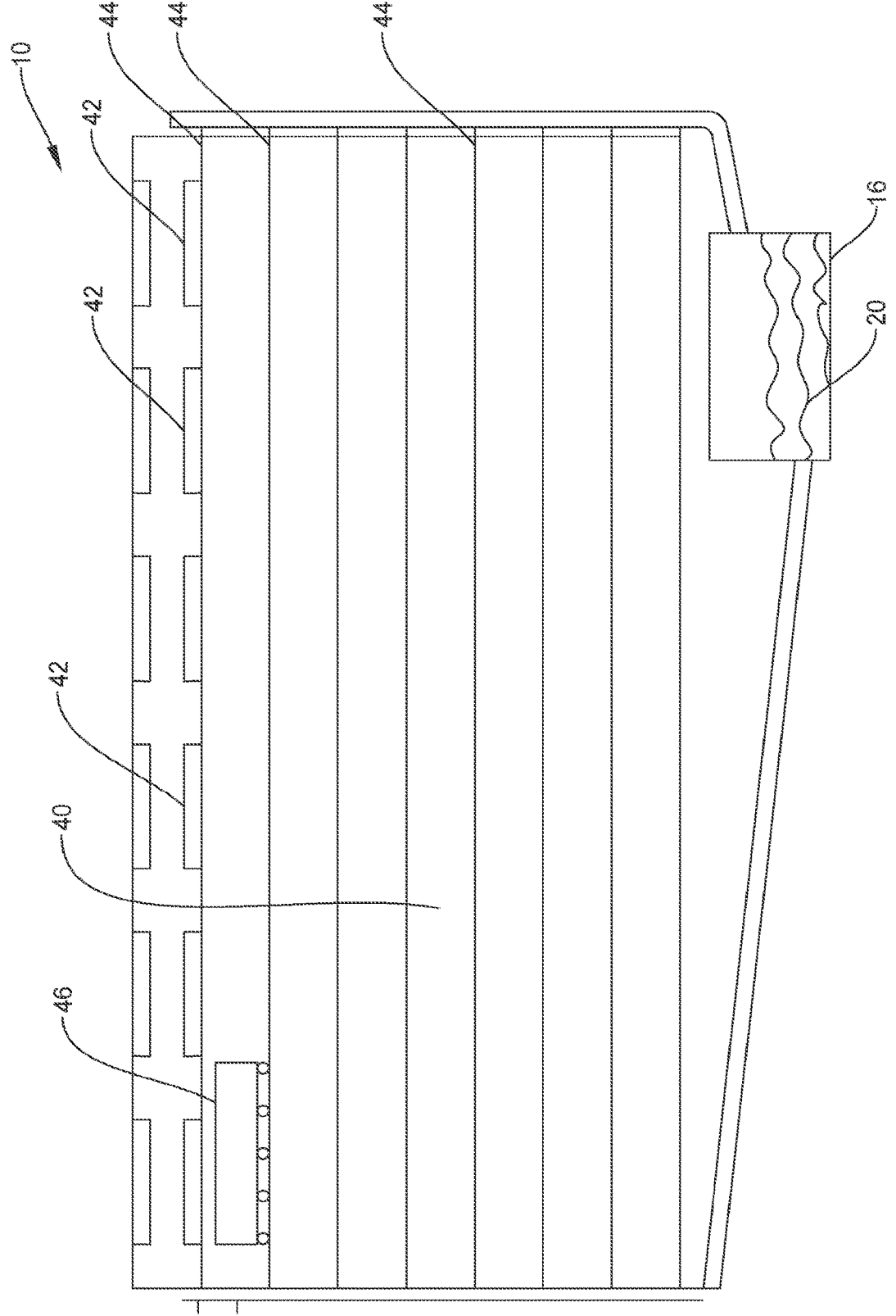
FIG. 1

FIG. 2

FIG. 3

FIG. 4

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FIG. 5A

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FIG. 5C

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FIG. 5B

FIG. 5D

FIG. 5E

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FIG. 5F

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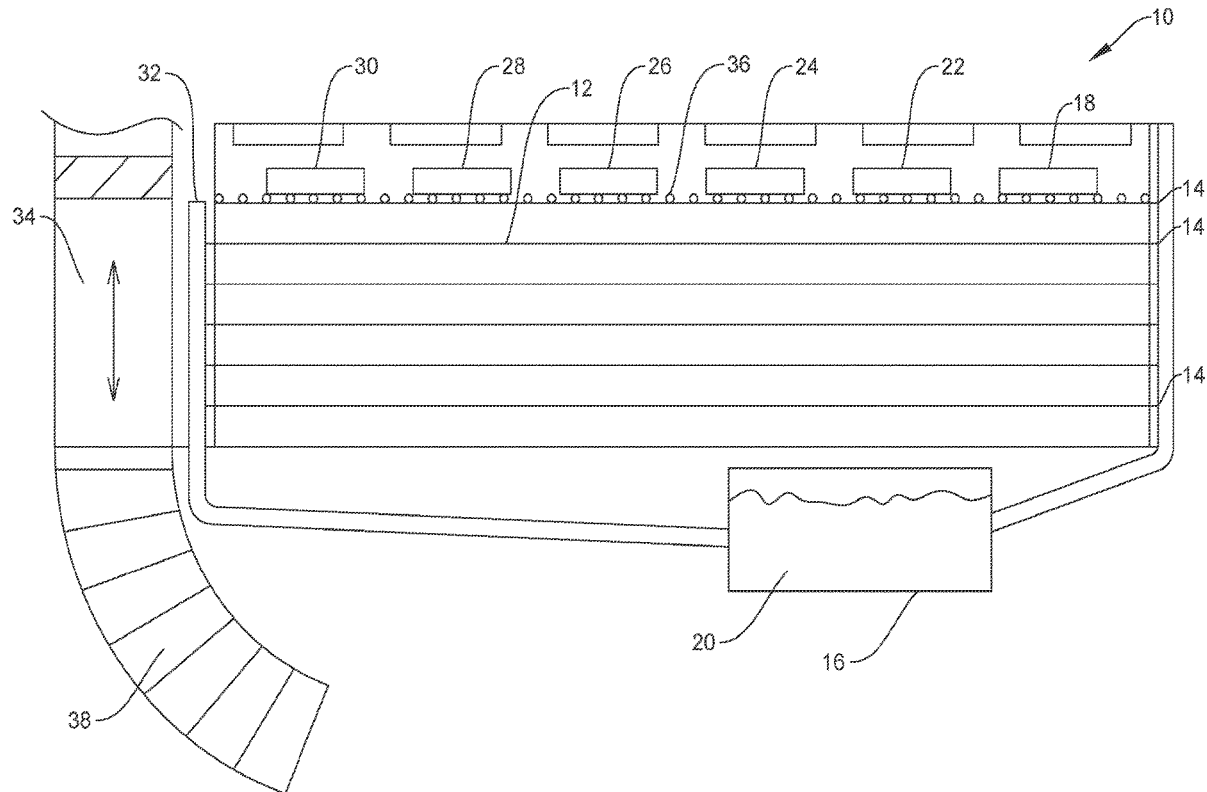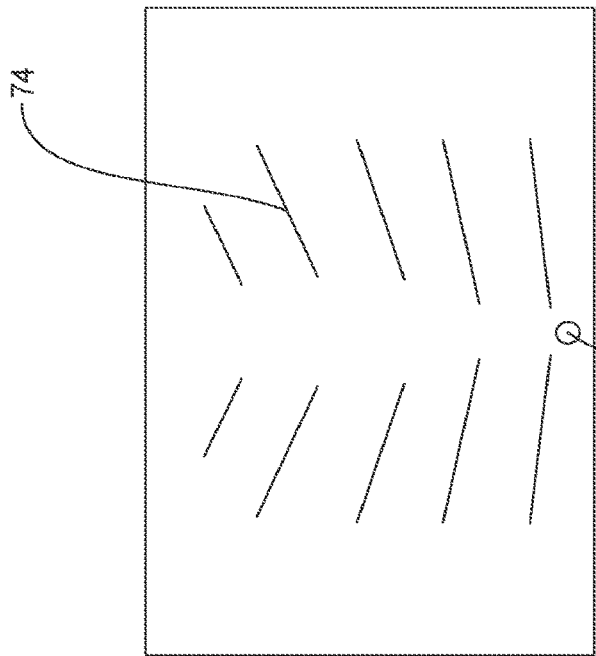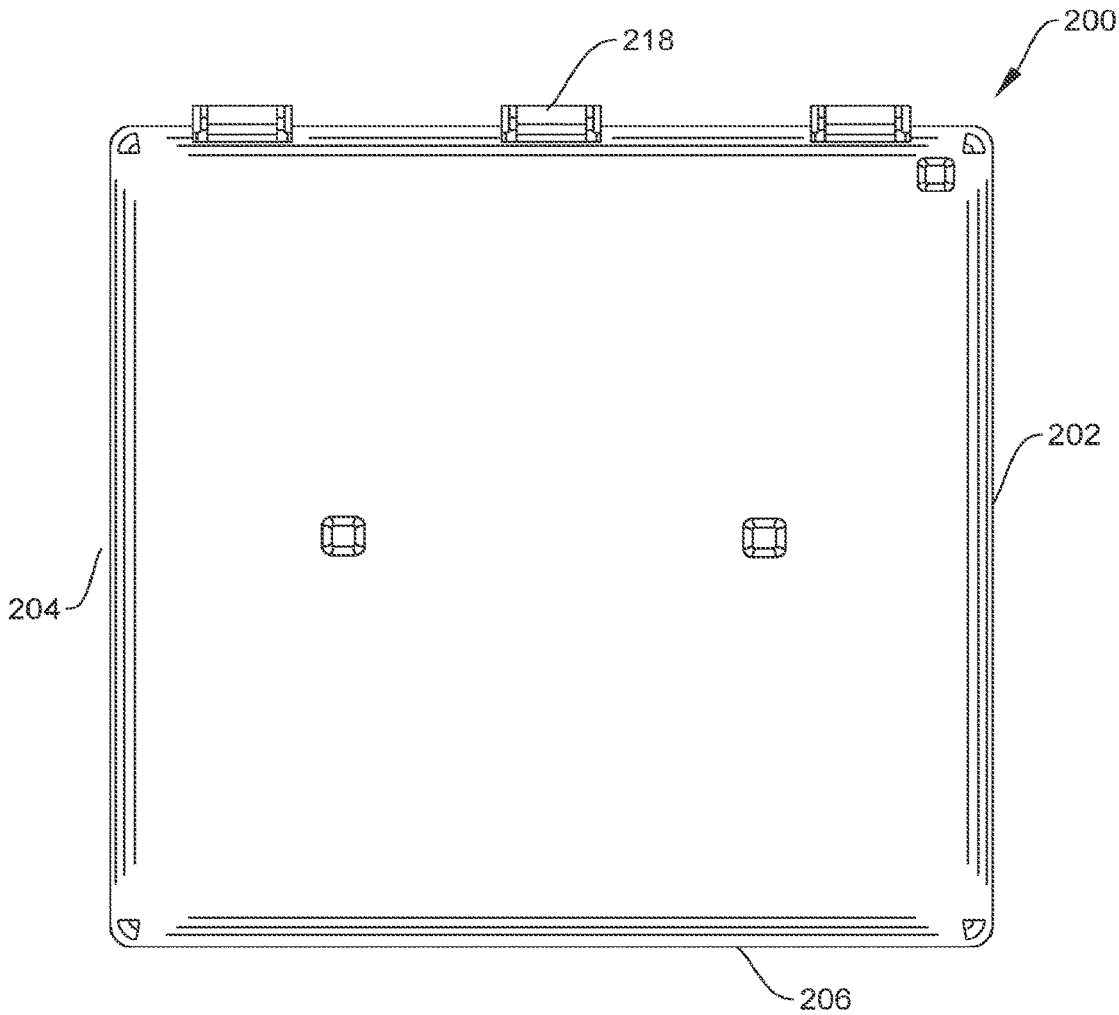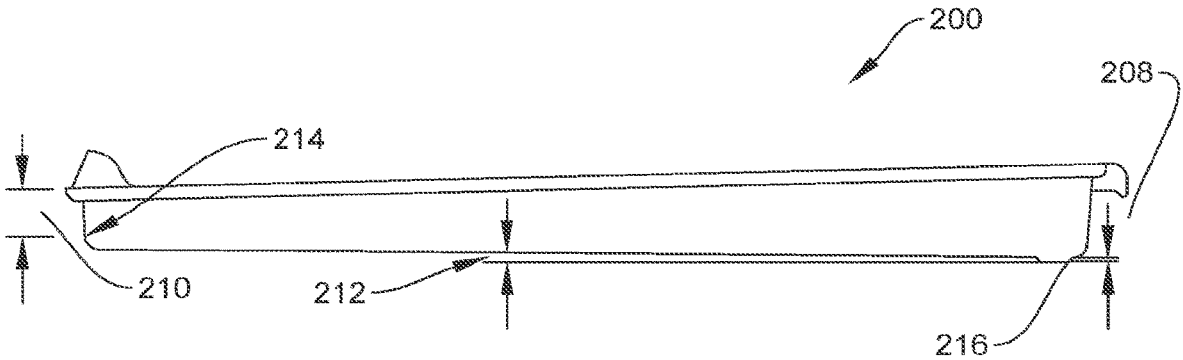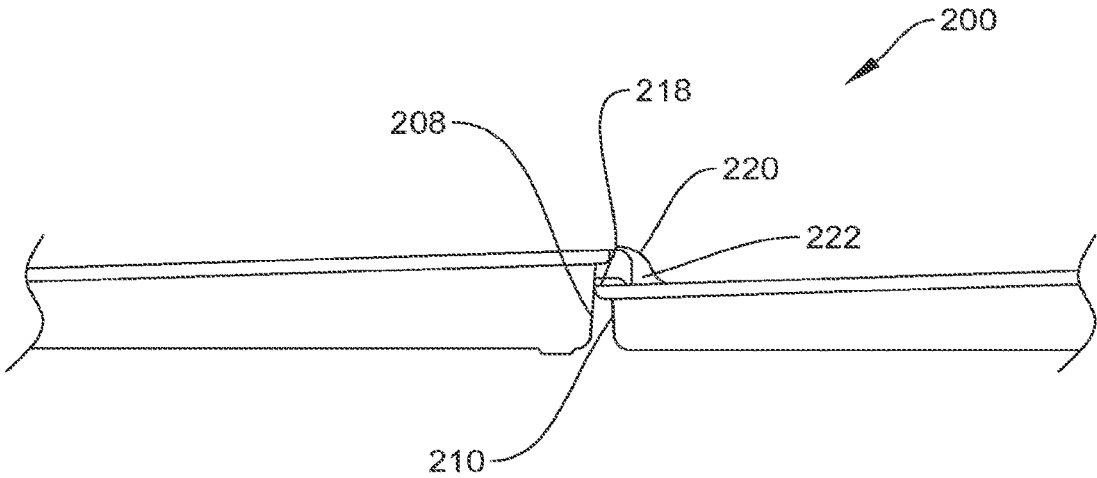
FIG. 5G

FIG. 6B

FIG. 6A

FIG. 6C

FIG. 7A

FIG. 7B

FIG. 7C

FIG. 7D

FIG. 8

FIG. 9

FIG. 10

FIG. 11

FIG. 12

FIG. 13

FIG. 14A
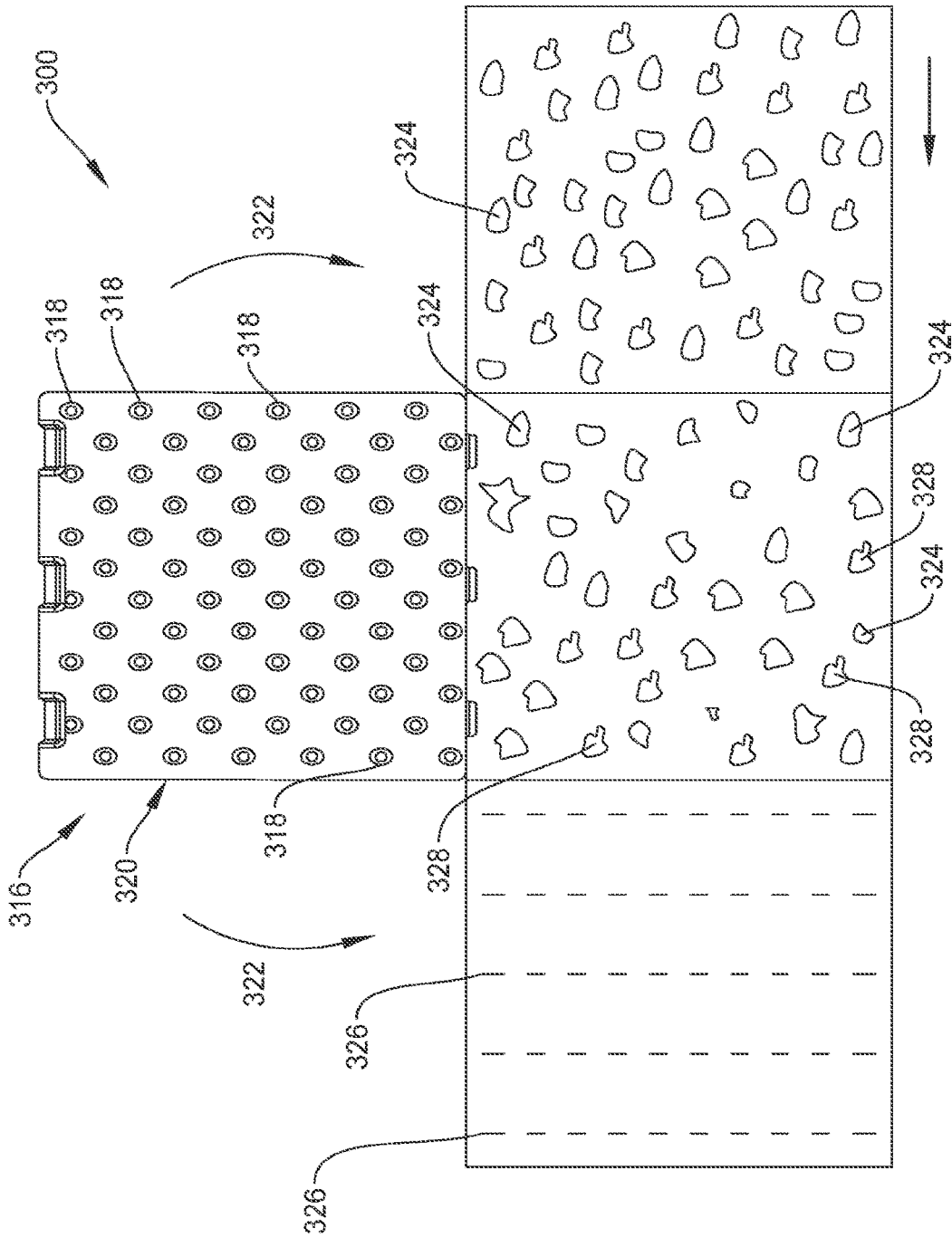
FIG. 14B

APPARATUS, SYSTEM AND METHODS FOR IMPROVED VERTICAL FARMING

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Non-Provisional patent application Ser. No. 15/965,534, filed Apr. 27, 2018, entitled APPARATUS, SYSTEM AND METHODS FOR IMPROVED VERTICAL FARMING, U.S. Provisional Patent Application No. 62/490,822, filed Apr. 27, 2017, entitled APPARATUS, SYSTEMS AND METHODS FOR IMPROVED VERTICAL FARMING, and U.S. Provisional Patent Application No. 62/539,163 filed Jul. 31, 2017, entitled APPARATUS, SYSTEMS AND METHODS FOR IMPROVED VERTICAL FARMING, all of which are hereby incorporated by reference in their entirety as though fully set forth herein.

FIELD OF THE DISCLOSURE

[0002] The present disclosure relates to an apparatus, system and methods for improved vertical farming, including improved farming shelves and racks, efficient transport of grow trays, which utilize a cluster system, novel plant-grow trays or pallets, which allow for combined optimal plant growth and irrigation methods, novel harvesting methods, novel modular lighting, novel light intensity management systems, real time vision analysis that allows for the dynamic adjustment and optimization of the plant growing environment, novel camera mobility systems, and a novel rack structure system that allows for simplified building and enlarging of vertical farming rack systems.

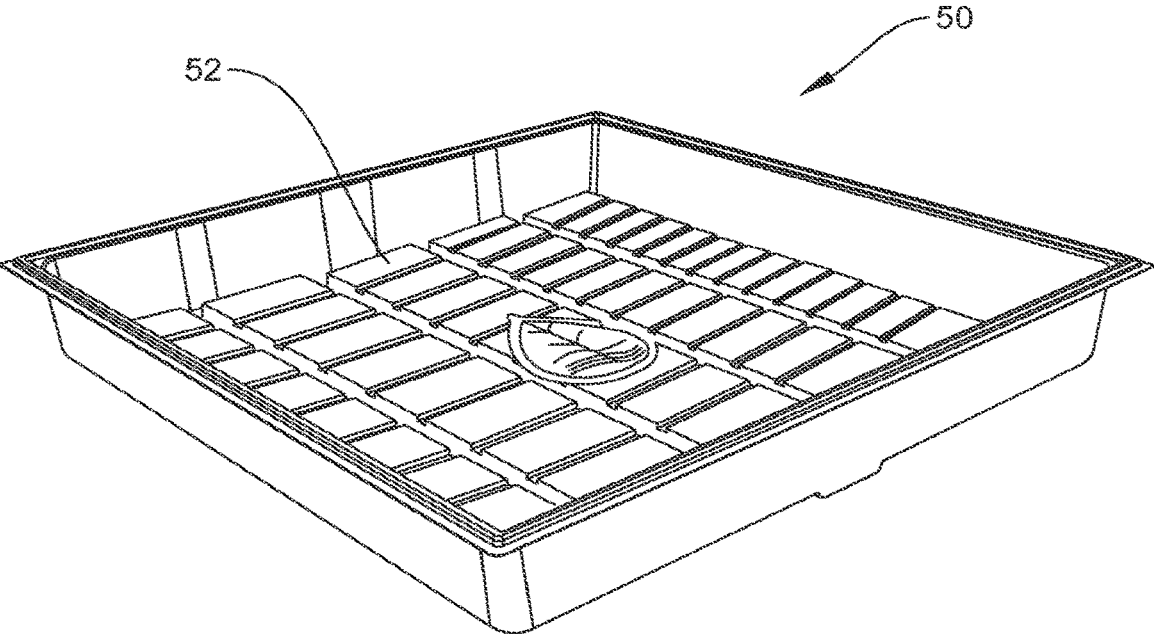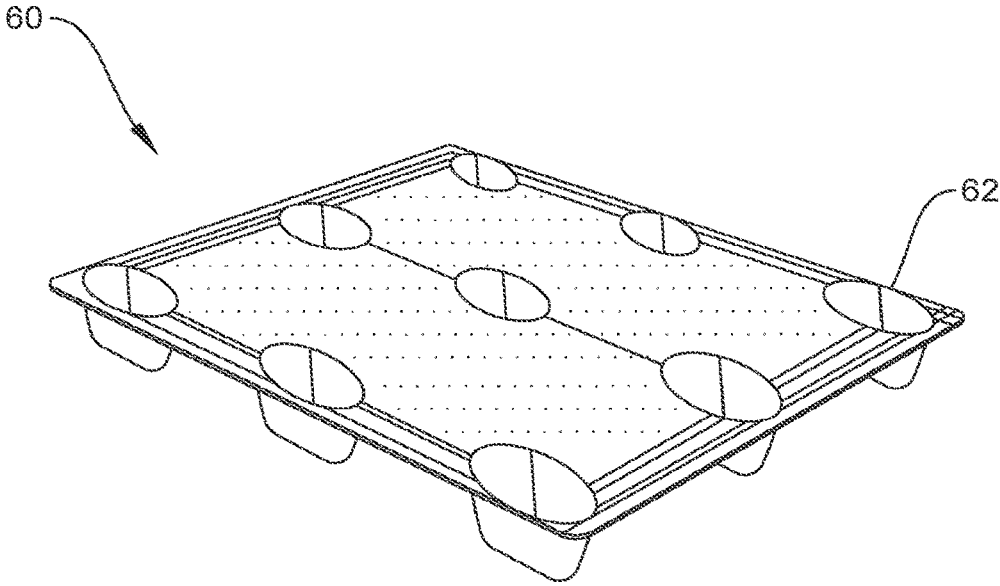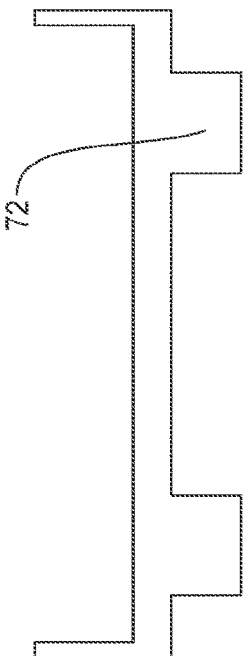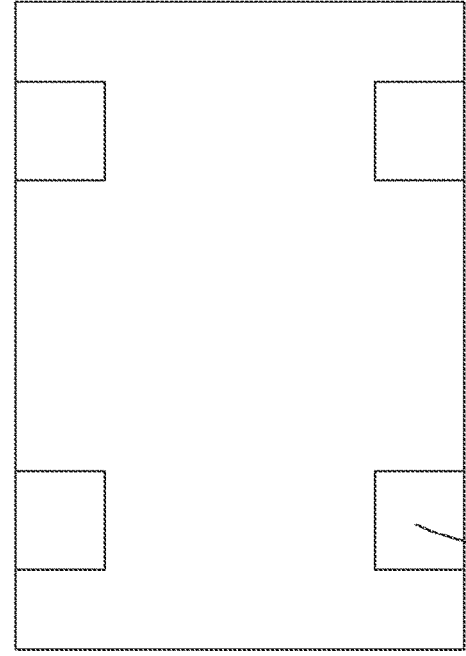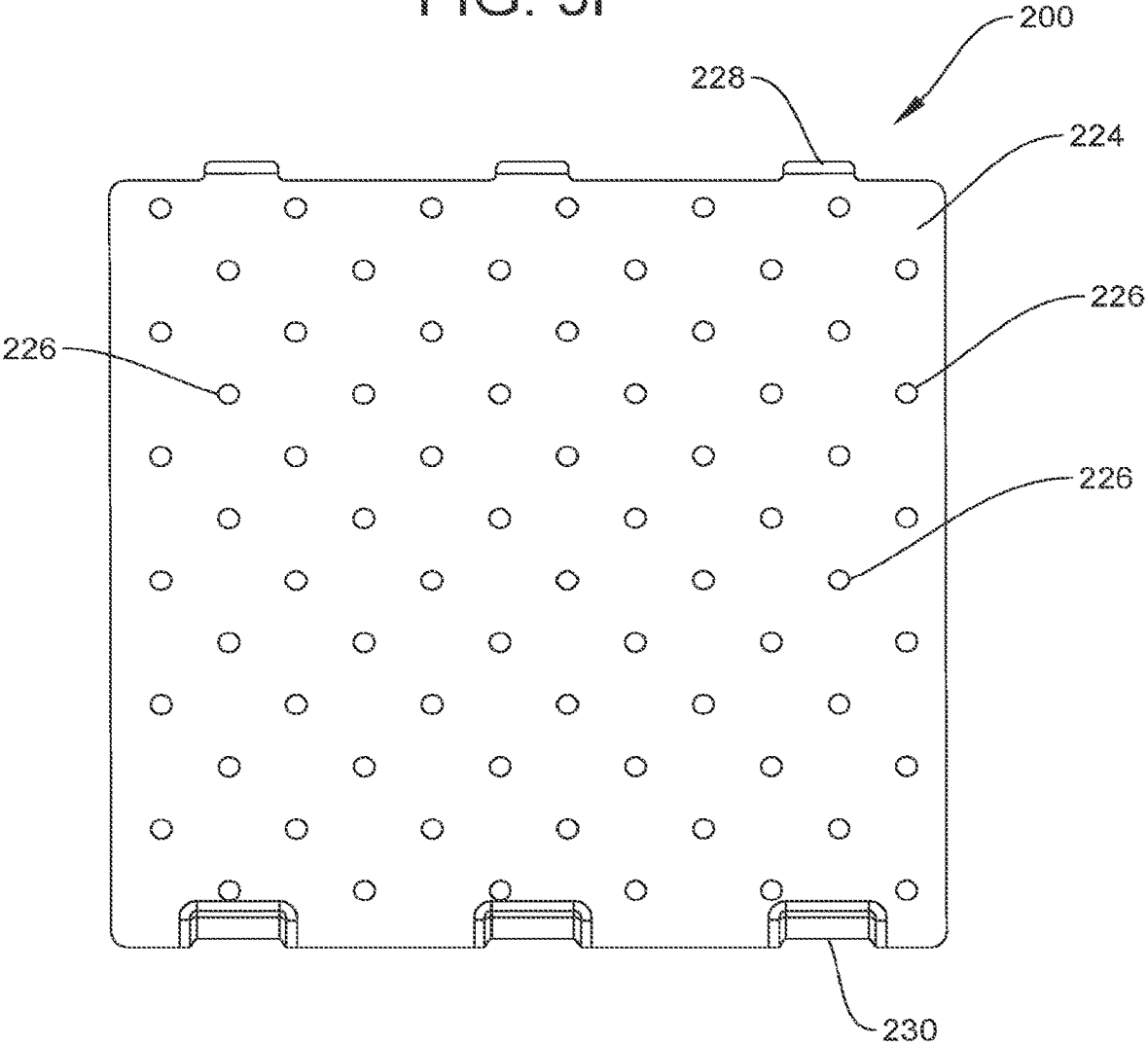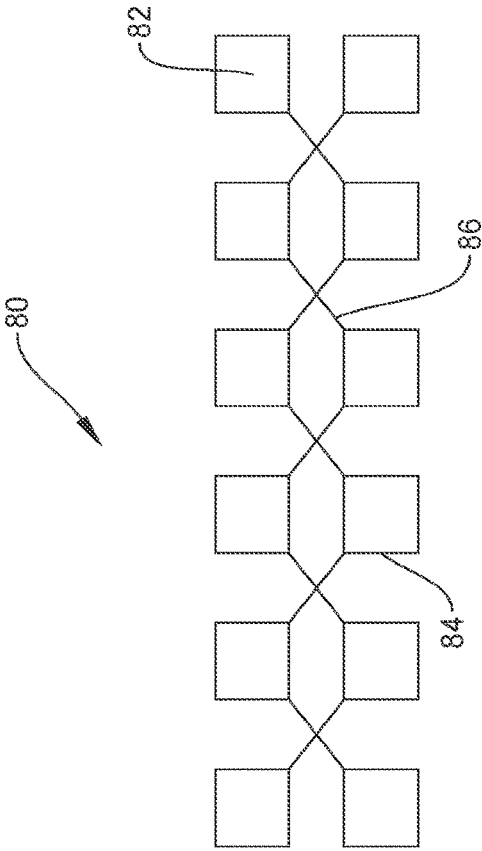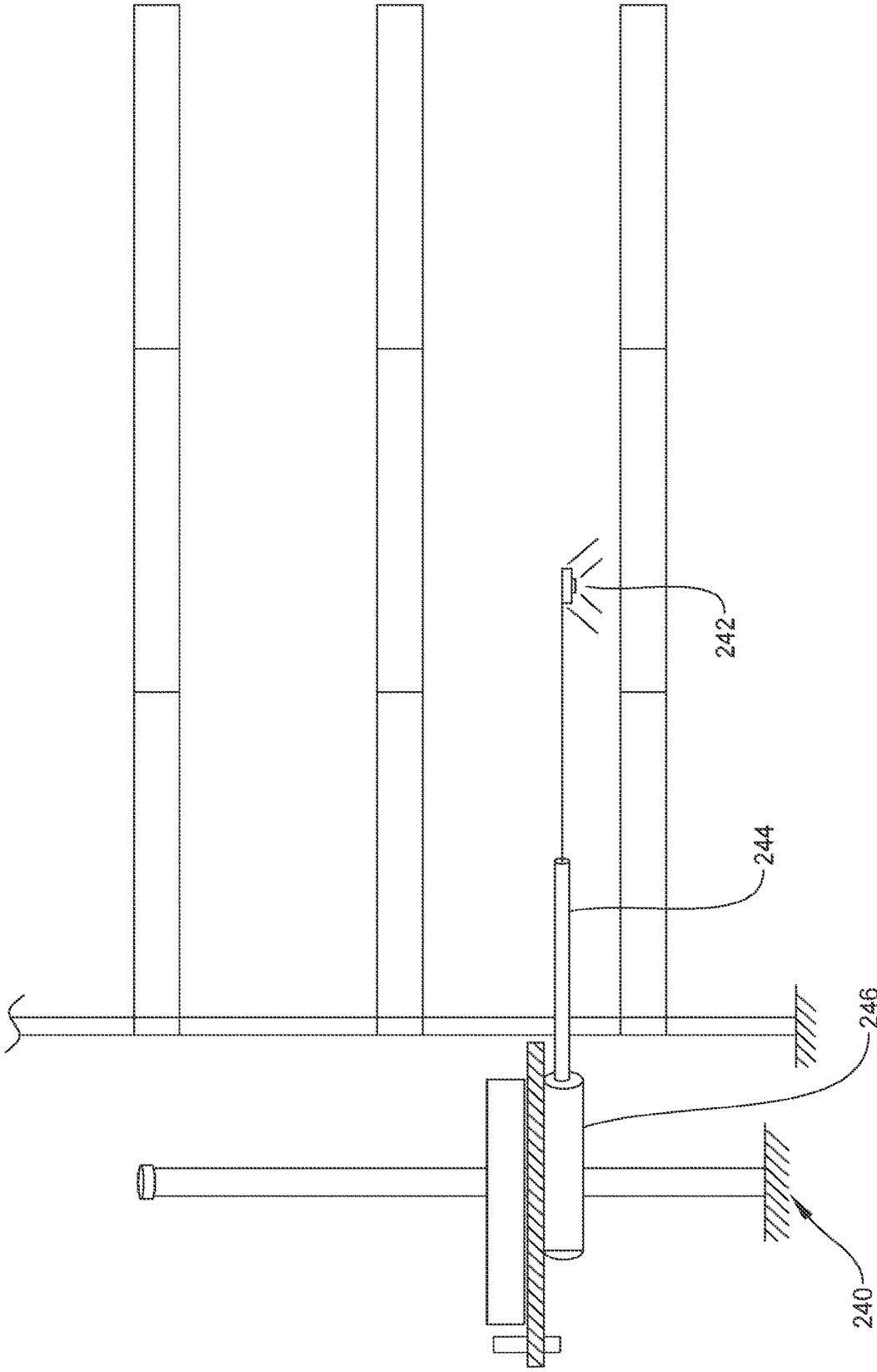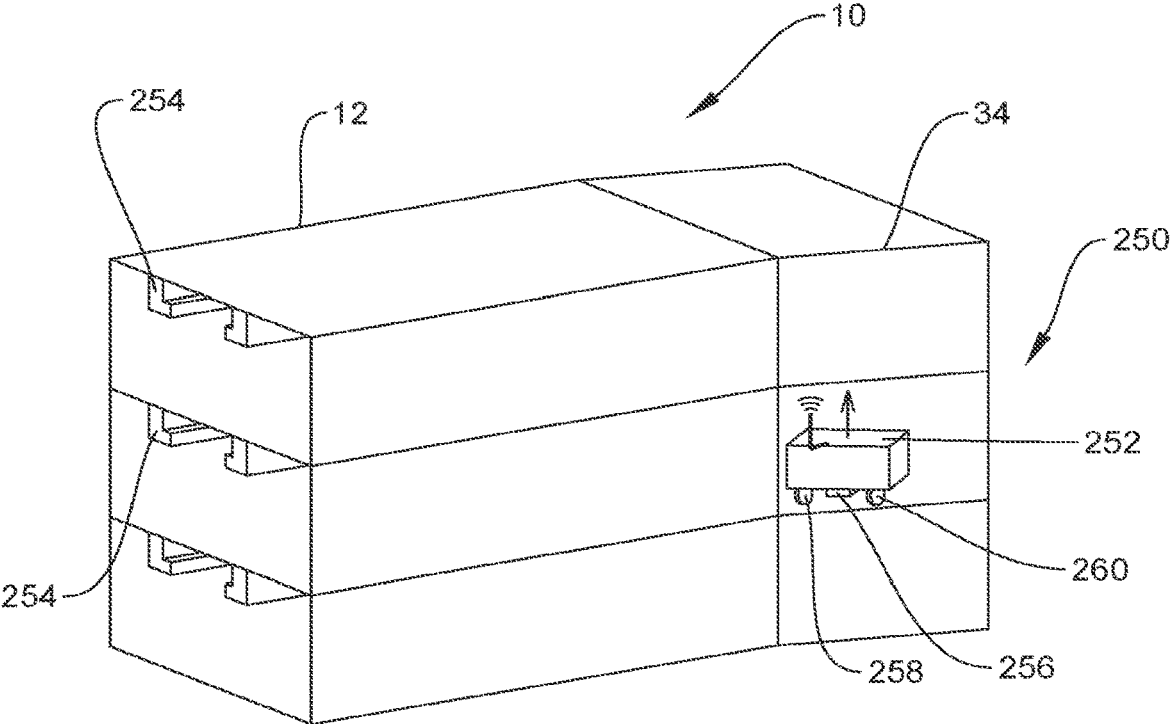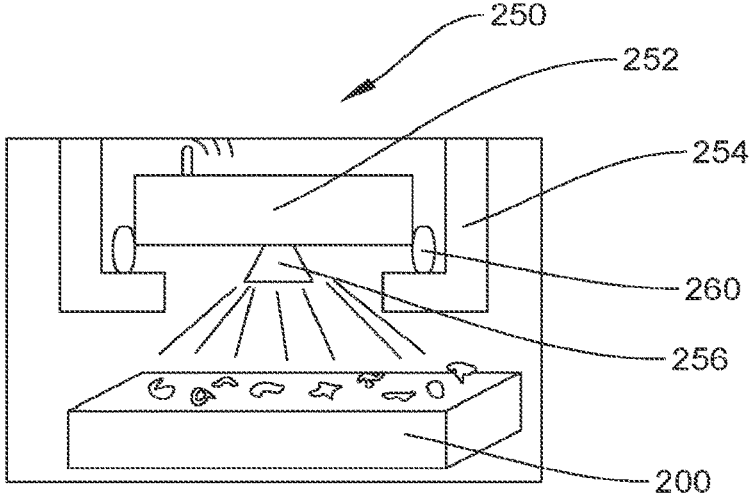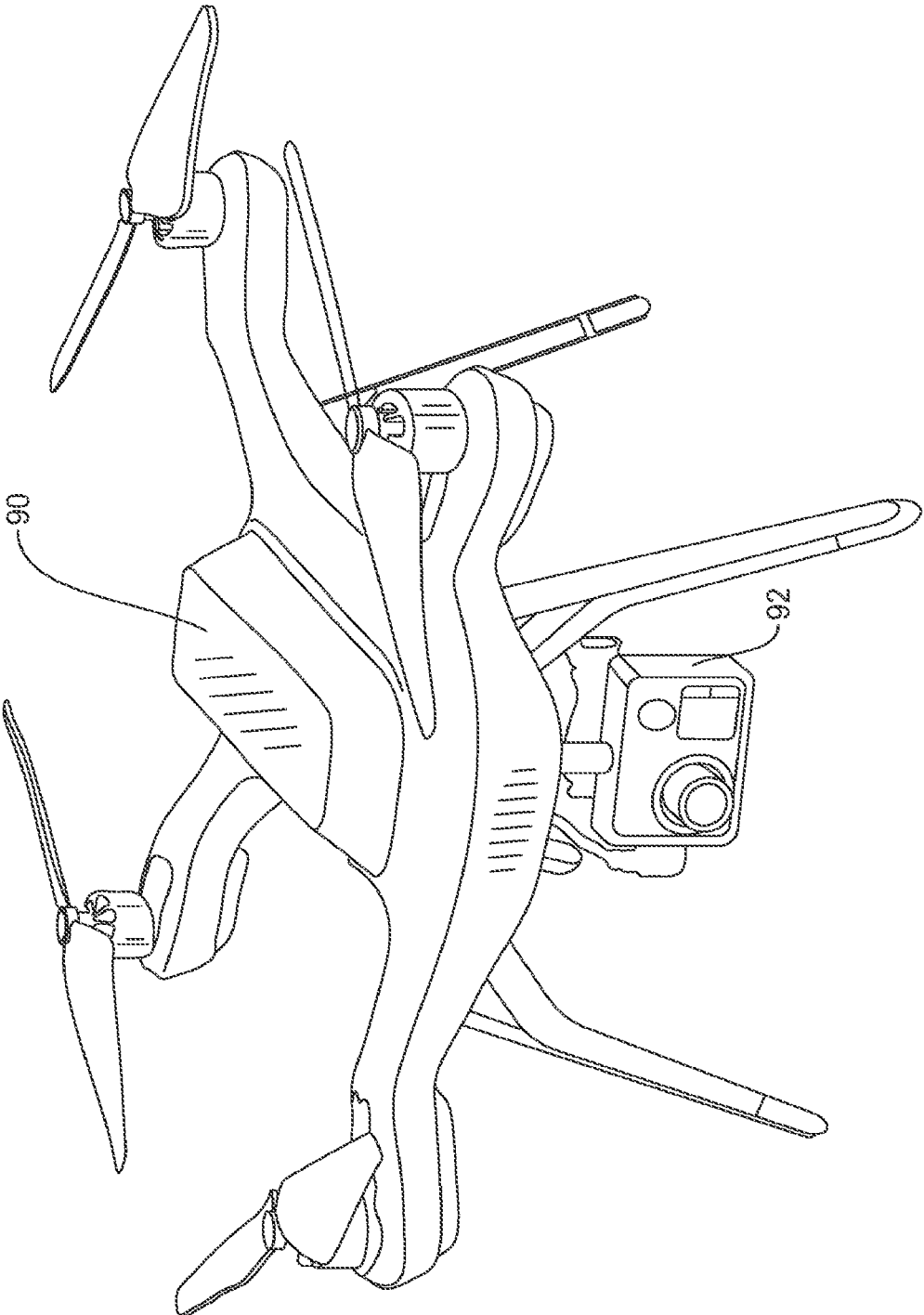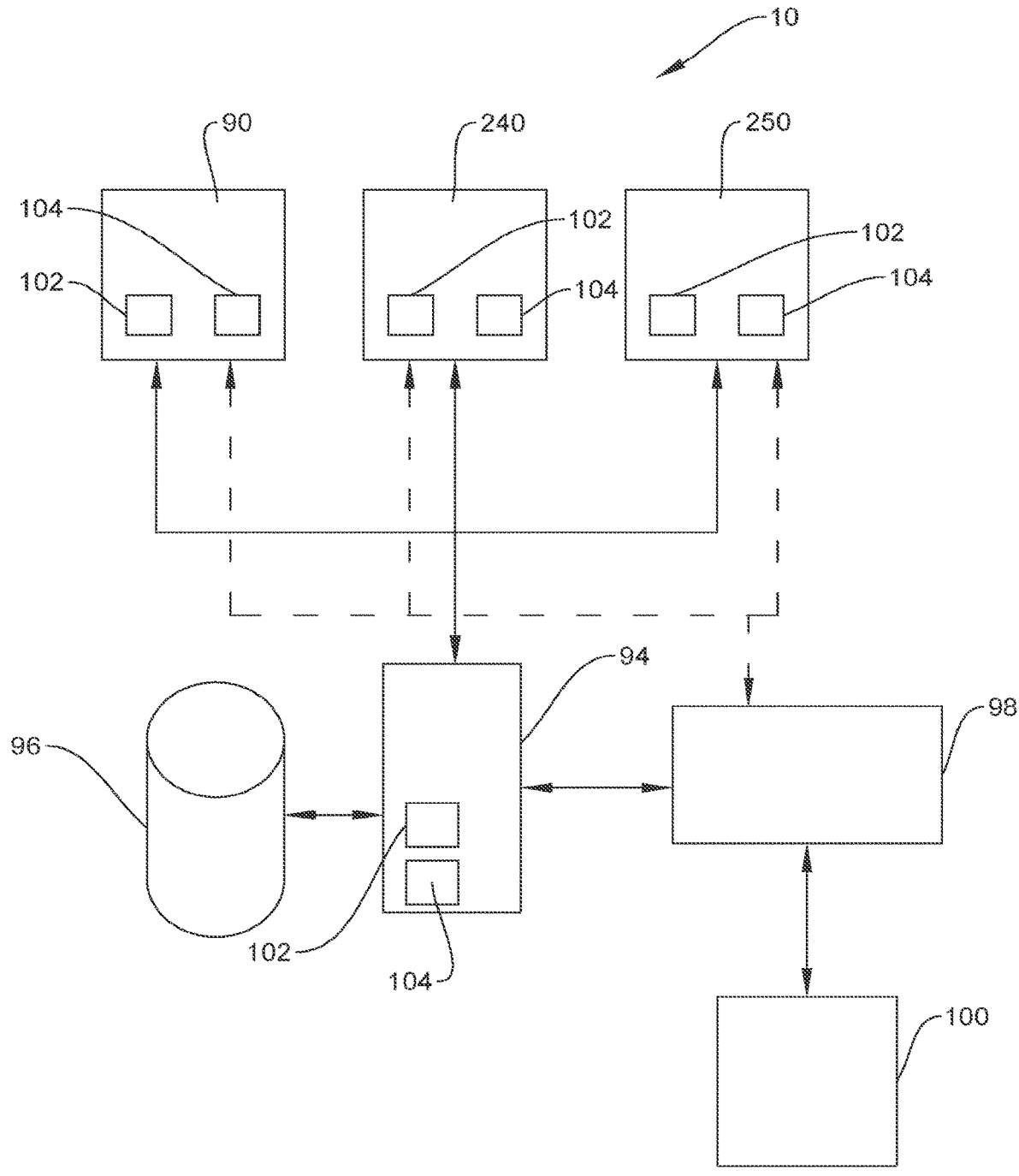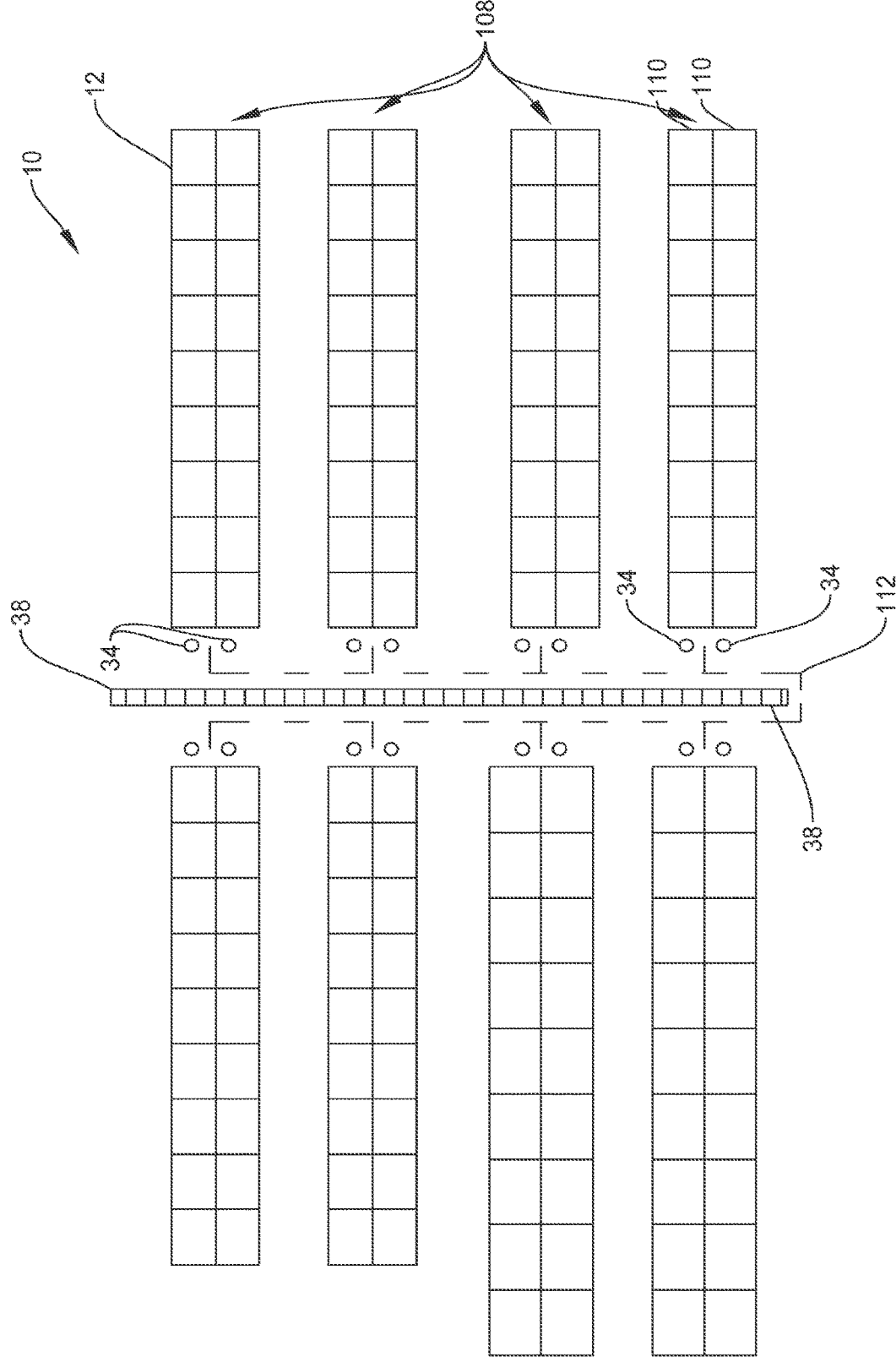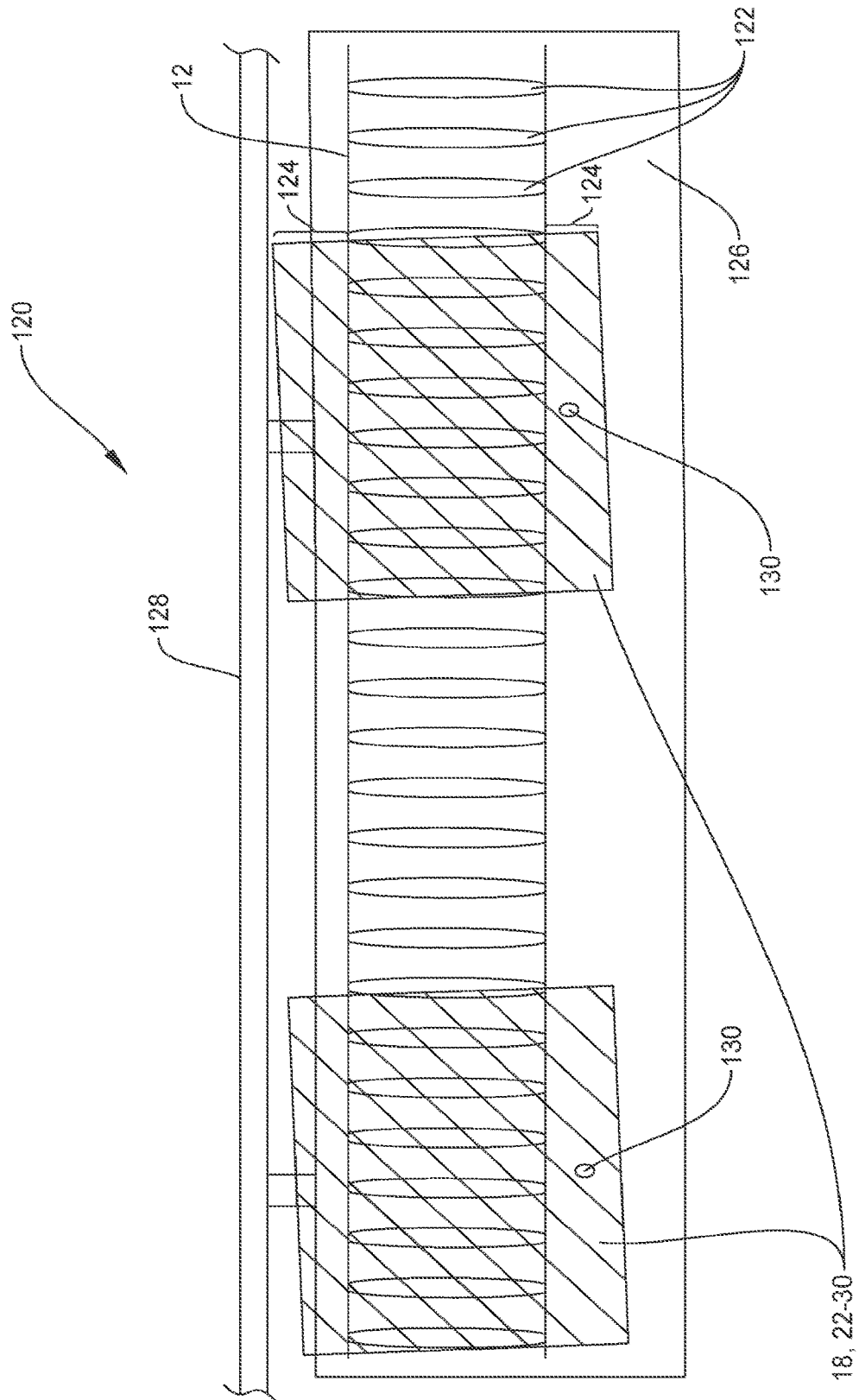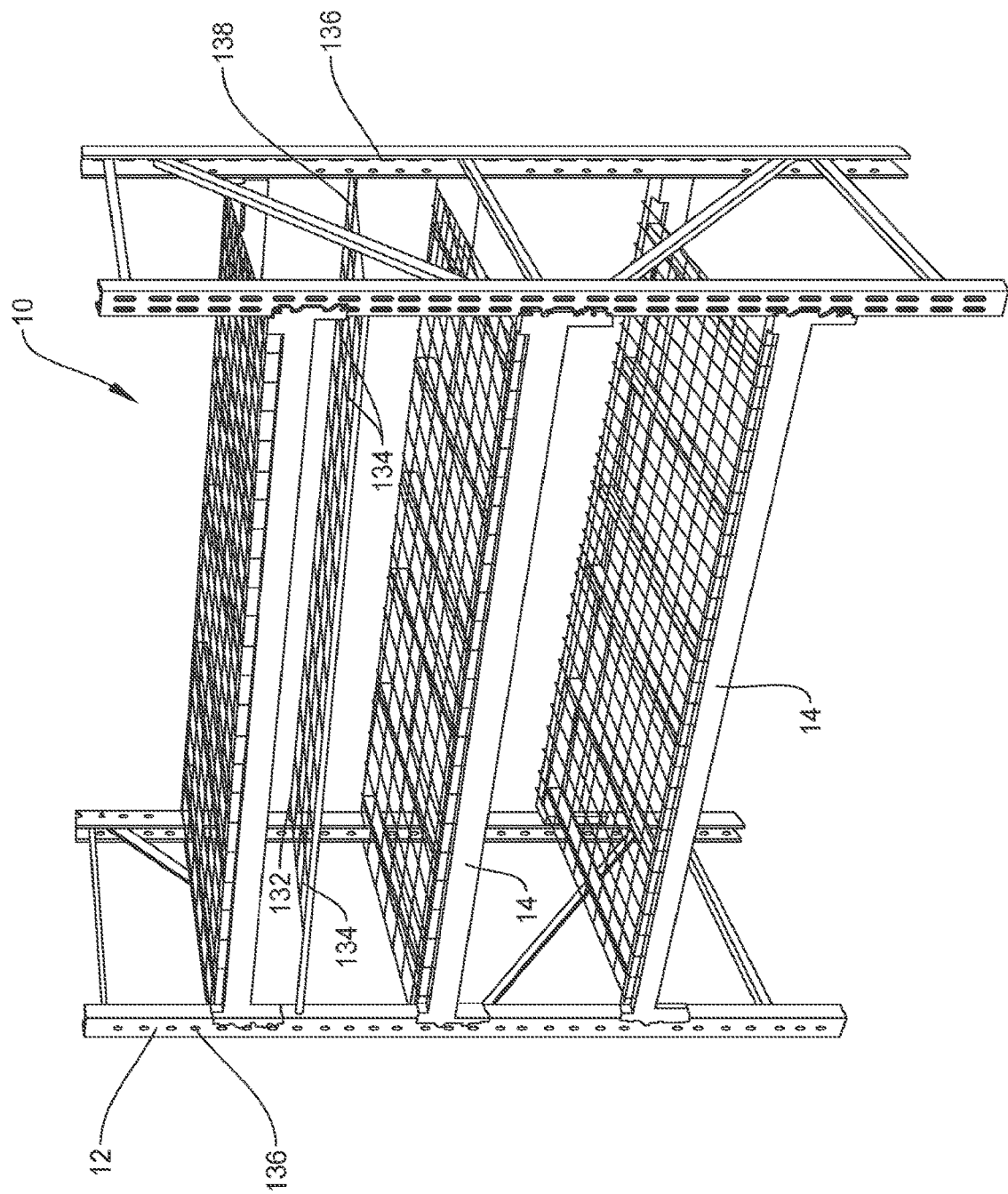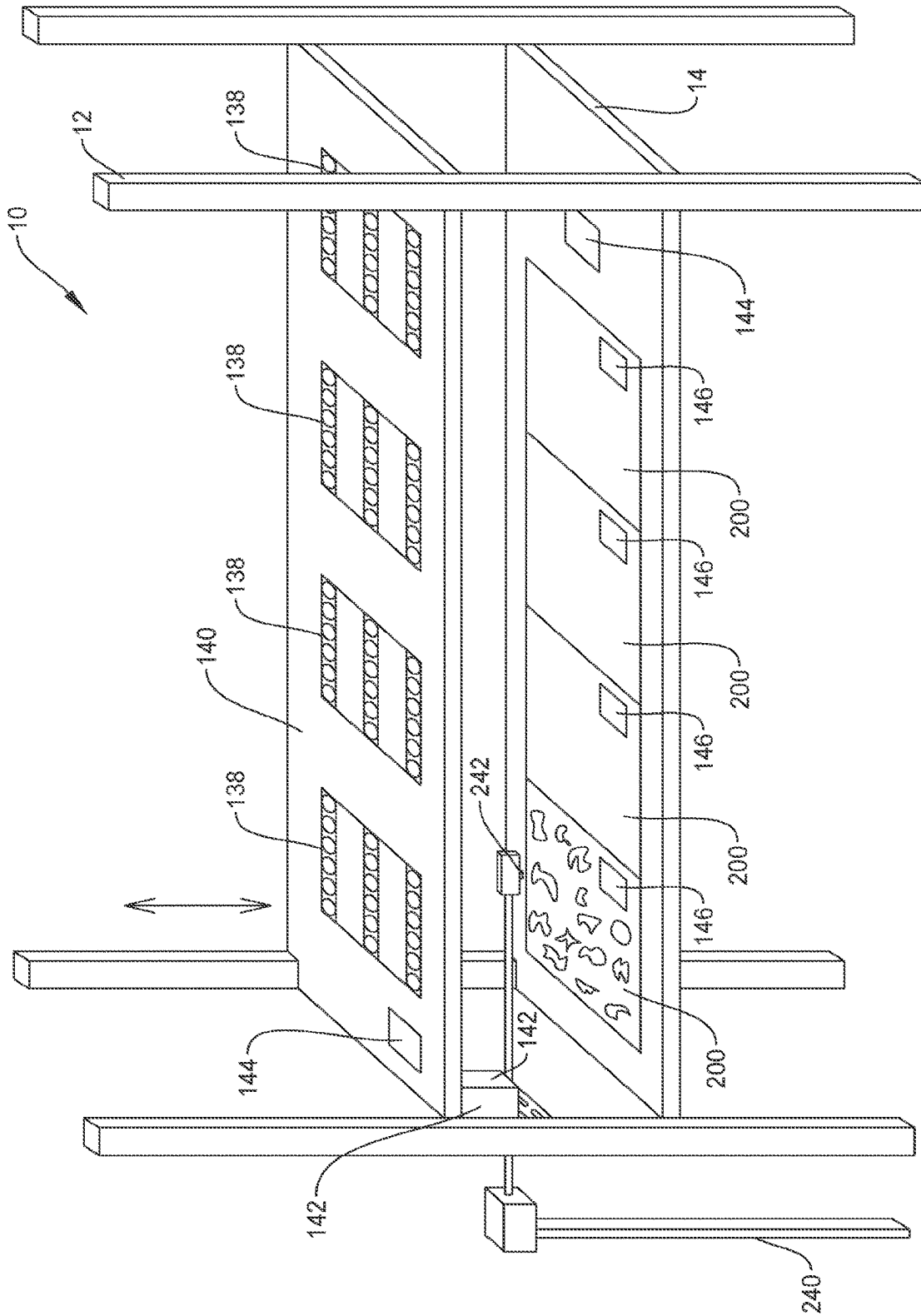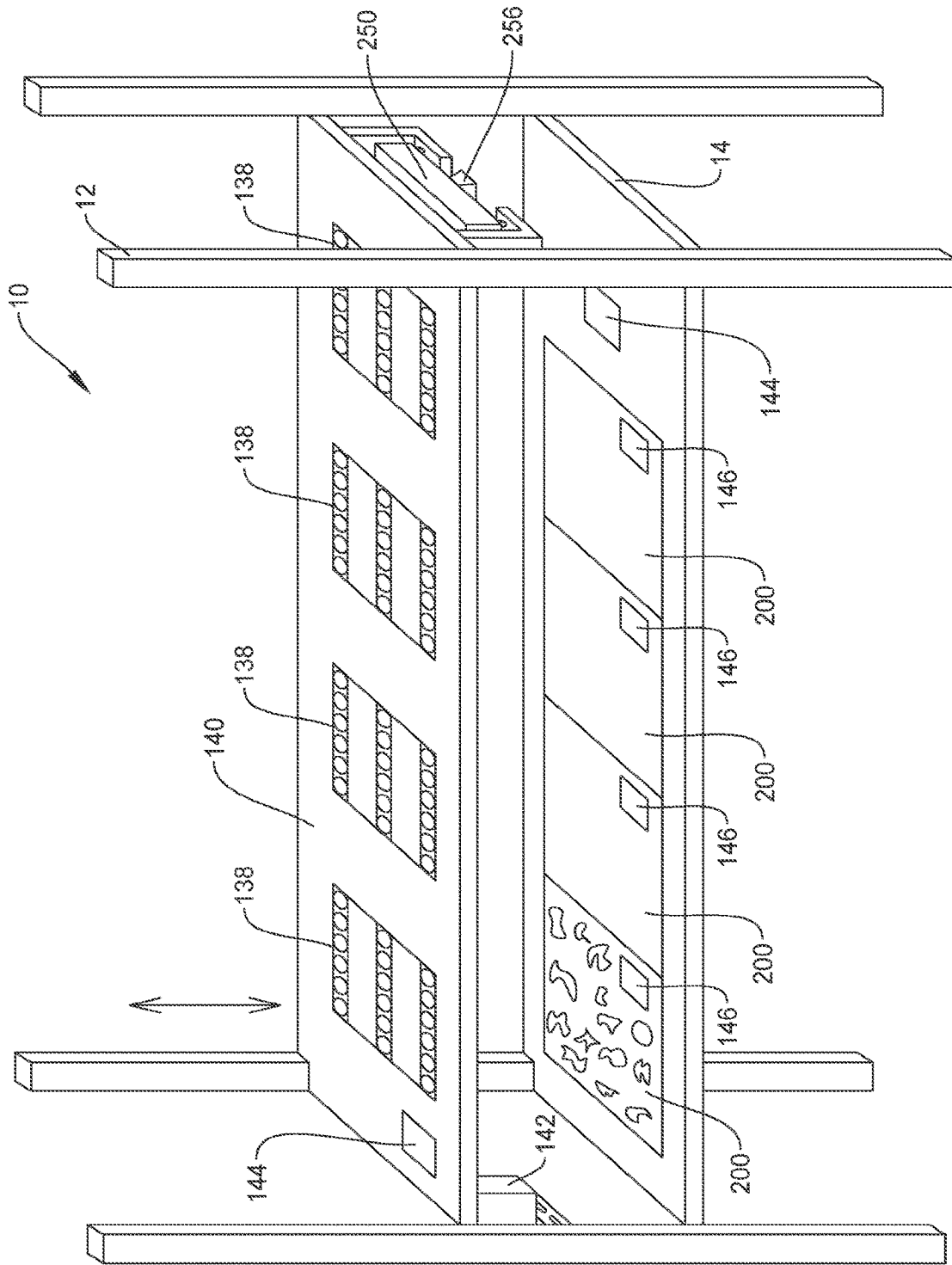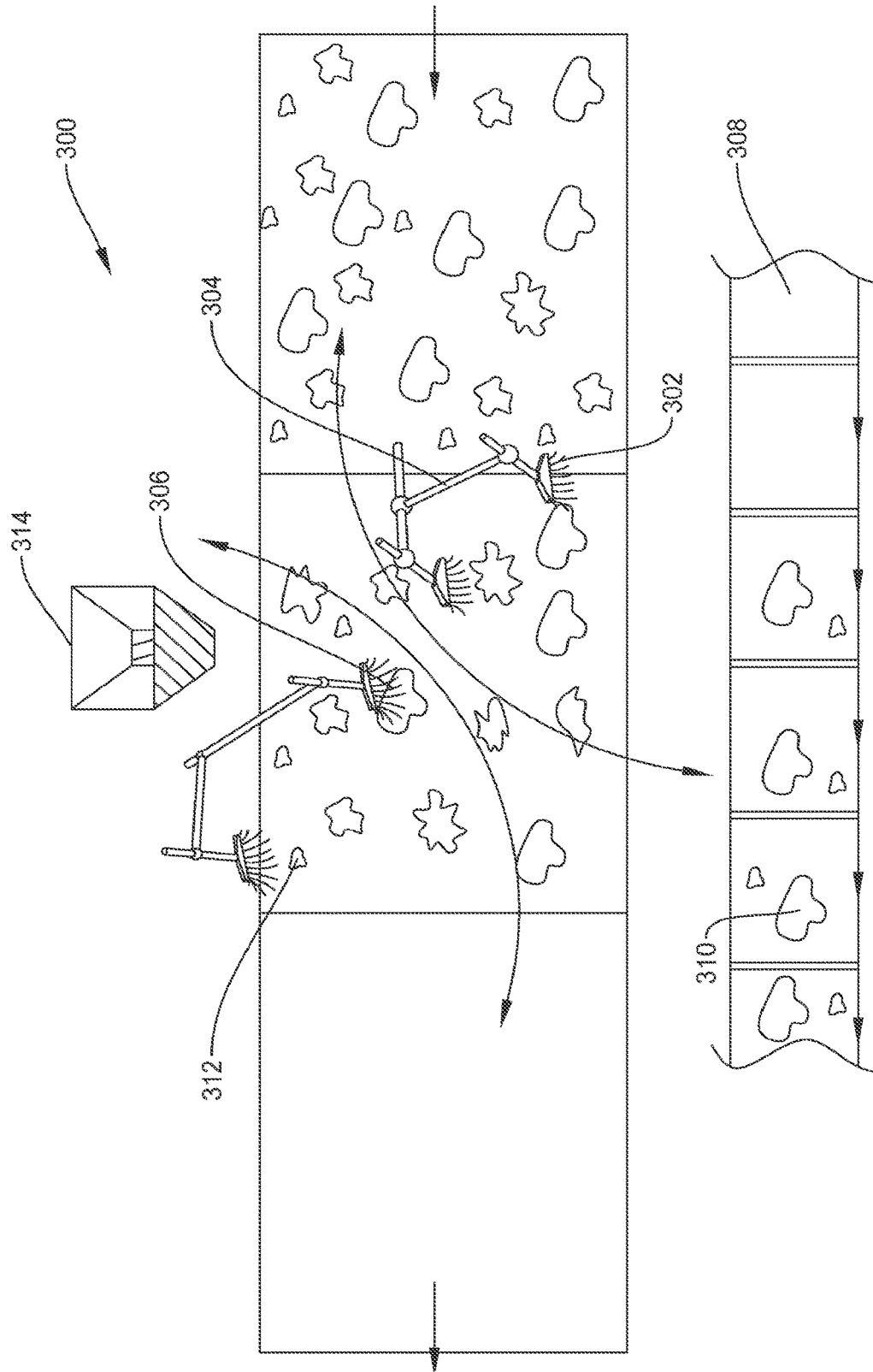[0003] The present disclosure also relates to the improvement of autonomous systems and methods for growing edible plants, using improved scalable stacking and shelving units configured to allow for scaling or increasing the size of the system through additional shelving units. The disclosed shelving units utilize gravity-based irrigation, along with novel water supply and draining, gravity-based loading and unloading of the plant-growing trays and camera system, along with a cluster-based shuttle system for autonomous rotation, incorporating novel plant-growing and germination trays. This system significantly reduces the amount of labor required to tend to a vertical farm.

[0004] The present disclosure further relates to a system that photographs and records the plant life cycle by 1) high definition cameras located on telescoping poles using one or more gimbals to allow the cameras to record each plant, the telescoping system capable of transport between shelves; 2) a camera vehicle attached to a rail or rail system above the plant-grow trays, capable of independent movement to record each plant; and/or 3) autonomous flying drones, incorporating three dimensional/multispectral cameras, flying preprogrammed routes, thereby reducing or eliminating certain labor costs. Multiple cameras can also be permanently mounted onto the vertical farming system in other strategic places as described herein. The result is to record images and/or video of the growing plants, automatically analyze these images and videos in real-time, thereby understanding exactly what the plant needs for optimal growth, while retaining the database for future plant growth. This will allow the plant itself to become the "sensor," controlling its own environment, thereby continually optimizing its own growing environment and reducing the energy needed to obtain the maximum production. By utilizing these novel methods of camera transport, we can significantly increase the amount of plants that can be monitored autonomously, while significantly decreasing the expense associated with purchasing multiple cameras.

[0005] The present disclosure further relates to cameras, such as 3D cameras, that may be mounted on a gyroscopic stabilizer to obtain clean and precise images and video of the growing plants. The cameras may also comprise additional sensors to obtain information about the vertical farming infrastructure. The cameras may be Wi-Fi enabled, or in other ways wirelessly connected or wired directly to the system for automatically transmitting the recorded images and data to a database in the vertical farming system for processing and for gauging plant health, biotic and abiotic stresses, pest and/or disease issues, and plant life cycle, along with determining the acceptability of the vertical farming system.

[0006] Also, in the present disclosure, lighting bars and/or LED sheets are integrated into a lighting platform, which is dynamically connected to the shelving system that maintains a constant (or near-constant) photosynthetic flux density (PPFD) exposure to plant canopies throughout plant growth stages. The lighting platform is outfitted with infrared sensors, ultrasonic sensors, and/or other sensors, and configured to autonomously be raised and lowered above the grow trays using an integrated motor, driveshaft, cabling, and/or gears. In an embodiment, the motor and gears drive or rotate a shaft to spool or unspool cabling fastened to lighting bars and/or LED sheets via pulley and/or gear systems. Other methods for raising and lowering the lighting platform above the grow trays can be incorporated into the system within the scope of the present disclosure.

[0007] In the present disclosure, the lighting platform supports the integration of individual sensors and/or sensor systems utilizing local processing for data analysis and storage, and wireless communication schema for remote data collection, storage, and analysis, using, for example, machine learning and/or artificial intelligence. Sensors include, but are not limited to, temperature, humidity, distance (e.g., ultrasonic, infrared) and optical (e.g., photodiodes, photoresistors, phototransistors, ultraviolet-cameras, visible spectrum cameras, near-infrared cameras, infrared cameras, thermographic cameras). As described herein, the camera(s) could be mounted to the lighting platform, and when the system desires to capture an image or video, the lighting platform will autonomously raise to an appropriate height to capture as many of the plants in a particular grow tray, or on a shelf, as possible, and then autonomously return to the height most appropriate for optimal plant growth. The motor and/or sensors or sensor systems provide feedback to the vertical farming system as to the distance the lighting bars and/or LED sheets are from the growing plants.

[0008] In the Present disclosure, sensors can also provide information about the plant environment, plant condition, plant life cycle, pest conditions, plant health, etc. A history can be generated, and along with the information from sensors, obtained during the entire life of the plants from seed to harvest, the history can be included in a database of all of the similar or dissimilar plants for optimizing the growth of the plants.

[0009] In addition to creating an optimal plant growing environment, the present disclosure also relates to utilization of the lighting platform representing both labor and energy

savings. Based on the plant canopy's height at any point in the plant's life cycle, the lighting platform autonomously adjusts the lighting fixture height above crops/trays to maintain a constant, optimal position throughout crop growth cycle, thereby eliminating the need for daily, manual adjustments. As described, the lighting platform allows for lighting fixtures to be positioned at a minimum distance from crops/trays (i.e., less than six inches above canopy for lighting platform compared with over twenty four inches for stationary lighting fixtures). By maintaining the lighting fixtures at a minimal height above crops/trays, the system can utilize less powerful (i.e., lower wattage) lighting fixtures (or standard-power lighting fixtures), at lower power consumption rates through dimming schema. By maintaining this minimum light fixture height autonomously, one can produce the required light intensity needed for plants to grow efficiently at significantly less wattage, and therefore significantly less cost. This resolves one of the major expenses in the vertical farm industry: high power consumption. It also enables us to grow crops that are currently thought to be too "energy intensive", such as wheat, at a significantly lower expense.

[0010] The present disclosure further relates to a novel rack structure manufacturing system for vertical farming in which parts and material, such as extruded aluminum or extruded plastic, are used for transporting and transferring irrigation, energy, materials and environments from one place to another. By using predesigned extruded aluminum for example, hollow cavities reduce or eliminate the need for separate conduit, ducts or connections. As such, the rack structure system of the present disclosure can be designed to be originally built, or later enlarged, without the need for designing separate conduit for transporting items necessary for the plant-growing cycle. As the rack system is built or enlarged, each extruded piece connects with the other pieces, using the predesigned hollow cavities to create the necessary conduit, ducts or connections. This will allow the entire shelving system to function as a large, simple appliance, with one input for electricity, one input for water, and one input for air, as well as other built-in mounting points and rails for camera systems. This will significantly reduce the cost and complexity of existing vertical structure designs.

[0011] The present disclosure further relates to a novel harvesting system in which the plants are harvested in their plant-grow trays. Instead of the manual harvesting process, the present disclosure relates to a harvest in place process or system. For example, currently a full head of lettuce is cut at its base to detach it from where it has grown. The leaves are then removed from the head until the core remains, which is then discarded. The process involves many steps, many of which are manual. The present disclosure eliminates a substantial portion of the process by harvesting the plant while in place ("harvest in place"), by knowing exactly where the center of each plant site is located, due to the grow tray lid with predetermined plant spacing, the plant can be cored in the grow tray, reducing a number of the steps and reduce the need to transport product.

[0012] The present disclosure relates to a harvesting press. The harvesting press would be a similar or same size as the grow tray, with corers strategically mounted in a mirror image of the plant sites in the grow tray. The corers could vary in diameter based on the particular crop being harvested and could also spin, to make the coring process simpler. The harvesting press would drop down in a single motion against the grow tray, simultaneously coring all of the plant sites, resulting in the cores remaining in their sites, and the loose leaves separated on the tray. The leaves can then be easily removed for additional processing or packaging.

[0013] The present disclosure further relates to an articulating harvester. The articulating harvester consists of a vision system and robotic arms mounted with corers to individually core each head in a grow tray at high speed. The vision software can also be capable of detecting which heads of lettuce might not pass quality control standards, and opt to skip harvesting that head, leaving it in place to be discarded. This real time quality control at the time of harvest, will greatly reduce the amount of human labor necessary later in the packaging process, and will simultaneously increase the quality of the leaves being packaged.

BACKGROUND OF THE DISCLOSURE

[0014] In the edible plant-growing industry, there is always a need for more efficient and reliable methods of growing edible plants. Since most of the population is located in urban cities and farming historically needs a lot of land, most farming takes place in rural areas. It is estimated that by the year 2050, close to 80% of the world's population will live in urban areas and the total population of the world will increase by 3 billion people. Such an increase in population, with current farming processes, will no doubt require more land to grow the plants. However, there is an increasing need to grow plants closer to the consumer to reduce costs, both monetary and environmental. As such, an increase in plant production efficiencies will be needed to meet these needs and other needs.

[0015] One of the methods being used to obtain these improved efficiencies is through vertical farming. Vertical farming is the practice of producing food in vertically stacked layers, such as in skyscrapers, used warehouses, or shipping containers, quite often in urban areas, closer to a majority of the consumers.

[0016] In general, vertical farming uses indoor farming techniques and controlled-environment agriculture (CEA) technology, where all environmental factors can be controlled to increase production. Unlike traditional farming, indoor vertical farming can produce crops year-round, thereby multiplying the productivity of the farm. These indoor facilities utilize artificial control of light, environmental control, such as humidity, temperature, and gases, among others. Some vertical farms use techniques similar to greenhouses, where natural sunlight can be augmented with artificial lighting and metal reflectors, among other techniques. Further, growing plants and food indoors reduces or eliminates conventional plowing, planting, and harvesting by farm machinery, which can be expensive and harm the environment.

[0017] Further, since the crops are sold much closer to where they are grown, the transportation costs, both monetary and environmental, are reduced. This reduction in transportation time may result in a significant reduction in spoilage, infestation, and energy. Research has shown that, especially in under developed nations, as much as 30% of harvested crops are wasted due to spoilage and infestation.

[0018] Also, the success of crops grown through traditional outdoor farming is always subject to the weather, and issues such as undesirable temperatures or inconsistent

rainfall amounts, along with natural disasters such as tornadoes, flooding, wildfires, and severe drought. On the other hand, vertical indoor plant farming provides an entirely controlled environment, and the success and productivity of the vertical farm becomes almost completely independent of inconsistent weather.

[0019] Further, traditional farming can be a hazardous occupation with particular risks that often take their toll on the health of human laborers, including exposure to infectious diseases, exposure to toxic chemicals commonly used as pesticides and fungicides, and the severe injuries that can occur when using large industrial farming equipment. Vertical farming, because the environment is strictly controlled and predictable, reduces some of these dangers.

[0020] Additionally, vertical farming, used in conjunction with other technologies and socioeconomic practices, could allow cities to expand while remaining largely self-sufficient food wise. This would allow for large urban centers that could grow without destroying considerably larger areas of forest to provide food for their people, while also providing additional employment to these expanding urban centers.

[0021] Although agricultural robots or "agbots" currently exist and can be deployed for agricultural purposes, such as harvesting or weed control, there is currently no apparatus, system or method for enhanced vertical farming that incorporates an improved storage, shelving and growing system, configured to allow efficient gravity-based irrigation on a per level basis, gravity-based loading and unloading, along with a shuttle system incorporating novel plant-growing pallets and germination trays, all under the watch of autonomous or near autonomous (such as on-demand) 3D/multispectral cameras mounted on a gyroscopic stabilizer, to obtain clean images and video of the growing plants. Nor is there a system in which these images and video, along with other information, is automatically sent to a database for processing by a central computer in order to gauge each plant's health, pest and/or disease issues, and plant life cycle; in effect, utilizing the plant itself as the sensor to control its surrounding environment. There is also no system that incorporates these functions and allows for a harvest in place system for processing the growing plants. The present disclosure satisfies these needs.

SUMMARY OF THE DISCLOSURE

[0022] In general, in order to solve the above-mentioned shortcomings in the vertical farming process, the present disclosure utilizes apparatus, system and methods that incorporate an improved storage rack or shelving system used for optimizing the growing process, along with a shuttle system for autonomous rotation of novel plant-growing pallets to optimize growth and significantly reduce labor. The present disclosure further contemplates novel plant-growing pallets and expanding germination trays, along with one or more high definition 3D/multispectral cameras, to photograph and record the growing plants and the plant life cycle. To obtain the optimal pictures and video, the 3D cameras can be mounted on telescoping gimbals, on camera vehicles on rails, or using flying drones, and the recorded images and video are automatically transmitted to a database for processing to gauge plant health, pest and/or disease issues, and other aspects of the plant life cycle.

[0023] The vertical farming system can also check for lighting being evenly distributed, dry spots or wet spots throughout the structure (like puddling on the floor or dry

plant sites). The system essentially utilizes the plant itself as the sensor to autonomously control its surrounding environment. Additionally, the system includes capabilities for harvesting the plants in the grow trays in order to reduce the amount of harvesting steps, to eliminate the need for unnecessary transport/labor, and to simplify the quality control systems.

[0024] As such, it is an object of the present disclosure to provide an improved shelving system or grow structure, configured with each shelf or level at a slight decline to allow for more efficient gravity-based irrigation and gravity-based loading and unloading of trays and pallets. The water from a reservoir is pumped to the uppermost tray of each level, and the grow tray configuration along with the slight decline (approximately 2 degrees) allows the water to run from the first uppermost tray on that level, through the next tray and to each of the rest of the trays on the same level, due to the gravitational force. Alternatively or in combination with, instead of flowing throughout each level, the water can flow through each column. Once the water reaches the last (and lowest) tray on that particular level, it exits the bottom and is drained back to the reservoir to be recirculated to other trays in the vertical farming system. As such, gravity pulls the pallet or grow tray into position so that just one strategically located lift in the load and unload positions, can load and unload an entire cluster of grow trays. This eliminates the need for a shuttle needing to traverse every level.

[0025] It is also an object of the present disclosure to provide an automated lift on the side or end of the structure or shelving unit for both (gravity-based) loading and unloading the trays or plant-growing pallets from the shelves. The present disclosure also contemplates a separate lift (two in total) on both sides of the shelving system, as necessary, and the lift able to travel on a rail along the entire length of the cluster of grow structures. In an embodiment, rollers running the entirety of each level eliminates the need for automation along the whole length of the shelf structure, as the trays or pallets can be loaded and unloaded in a first in/first out order (FIFO), although last in/first out and other loading and unloading protocols are contemplated, depending on the lift system used. In doing so, a single automated lift can load or unload all levels of the structure. The lift ties into a conveyor system that can transport the plant-growing pallets to a number of locations, including facilitating transportation of the trays to the farmer, instead of the other way around. This system will significantly reduce the labor needed on a vertical farm.

[0026] Additionally, it is an object of the present disclosure to provide, either alone or in combination with the gravity-based grow structure, a shuttle system for accessing the particular trays or plant-growing pallets. The grow structure system and shuttle system can be built from standard pallet racking, similar to the pushback grow structure, however, in this instance, all the levels in the shuttle system will be horizontal and the grow trays or pallets will be accessed by shuttles. In the preferred embodiment, one shuttle can service an entire grow rack, as the shuttle can be transported between levels by a lift and move across the length of each level. However, the present disclosure further contemplates that multiple shuttles, one on each level, or even multiple shuttles on each level can be used to effectuate access to each tray or pallet. As described herein, all three

systems, gravity-based, single-shuttle and multi-shuttle can be incorporated separately or in combination with one or two of the other systems.

[0027] In an embodiment the objective of the present disclosure is to use clusters of back-to-back grow racks. In doing so, each cluster consists of two back-to-back grow racks of any length. Each cluster will have one or two lifts, which will be configured to transport a shuttle or the grow tray itself to any level in that cluster, thus enabling the lift to pick any grow tray on any level and then deliver it to a central conveyor belt system, if needed. As such, a shuttle or the grow tray can transport itself from cluster to cluster by way of a ground level rail system that connects to each cluster, and a single shuttle could service every single grow tray position in any cluster on the floor, and deliver that grow tray to the central conveyor system. Additional shuttles can be added to the same infrastructure as the need for through-put increases and the system, as a whole, is scalable.

[0028] It is also an object of the present disclosure that the grow trays or pallets will be accessed (for moving or removing) using a forklift, or arms, conveyors, or any other manner as understood by one having ordinary skill in the art. In the preferred embodiment, each shuttle will accommodate a 4 foot×4 foot grow tray, although many other size trays can be used within the scope of the disclosure.

[0029] It is yet another object of the present disclosure that the grow trays or plant-growing pallets will be configured to grow produce directly inside the pallet, as well as being configured for easy transportation by forklift (or arms, conveyor, etc.) The plant-growing pallets will be engineered for sanitary purposes by reducing areas where water and impurities can congregate. This unitary, one-piece design will help reduce plant disease and other problems with growing plants in such a structure, possibly thermoformed.

[0030] Additionally, it is another object of the present disclosure that each grow tray can be configured with a cover with multiple holes that will allow the plant to grow through the holes and the top of the cover will be reflective to optimize the amount of light that is provided to the plants. As such, the configuration will reflect light from the source to the underside of the plants that might not receive as much light. This will increase the effectiveness of the light source. The grow tray configuration also includes inlet and outlet ports or holes to allow water to cascade from one tray's outlet port to the adjacent tray's inlet port. This configuration allows for complete irrigation by filling the highest tray with water and letting the water move (through gravity) from one tray to the next until it reached the lowest tray, where the water can be removed and recirculated as necessary. This tray design eliminates the need for a water supply line to every grow tray, increases the levels of dissolved oxygen in the water to enhance plant growth, and eliminates the need for bell siphons.

[0031] Another aspect of the present invention includes expanding germination trays comprising a tray similar to the currently used trays, to propagate seeds in, but configured with joints and hinges to expand to the proper spacing necessary for mature plants to grow properly and without the normal shock the plants receive upon replanting. The present disclosure, describes a system with only a few plant sites, but a typical plant-grow tray may have anywhere from 10-150 plant sites.

[0032] It is yet another object of the present disclosure that the grow trays or plant-growing pallets will be configured

such that the inside of the tray or pallet may have ridges to assist in directing the water to all internal areas in the grow tray, so that each plant site will be exposed to and receive water. The plant-growing pallets will also contain strategically located holes to allow for proper draining, as described above, and for emptying into the adjacent grow tray. The floor of the grow tray may be slightly inclined, preferably 1 to 5 degrees, to assist and allow water to flow from one side of the tray to the other, and may further include a bell siphon, or similar device, which will be located over the drain hole to allow the grow tray to fill to a certain water level before draining out.

[0033] Another object of the present disclosure is a novel water supply and draining system. In an alternative embodiment not using the adjacent tray draining system, any number of grow trays can sit on top of a level of rollers, with the grow trays jutting out slightly on either end of the rollers. Under the rollers, and spanning the entire length of the level, and having a width larger than the tray itself, is a trough style drain. The purpose of this trough drain is so that the water supply can feed directly into the grow tray and then drain out of the opposite end of the grow tray into the trough drain. If a pallet is absent from its position, i.e., it has been unloaded, the water supply will still feed directly into the trough drain and recirculate back into the systems nutrient reservoir. The trough will be wider than the rollers so that any water being supplied or drained does not make any contact with the rollers.

[0034] Additionally, the rollers will be positioned at an angle towards the drain, so that supplied water will be pulled by gravity towards the grow tray's drain hole. The rollers will also be angled towards the grow rack's lift, keeping in line with the gravity pulled system. By having these two angles or slants, the water is forced by gravity towards the drain, while the grow tray is forced by gravity towards its unloading location.

[0035] Another object of the present disclosure is to provide a novel lighting system. Depending on the particular crop, the distance from the light source to the plant canopy can improve the growth of the plant. Historically, vertical farmers would need to build an entire grow rack to the particular distance specification for the crop being contemplated, and would mount the LED bars directly to a unistrut, or another fixed location, in the pallet racking. Once the grow rack is built, it is difficult to adjust the distance of the light to the plant canopy without disassembling the entire rack. Instead, in an embodiment, the LED lighting bars are configured to be moved for different heights for different crops. A wire level can hook directly into the pallet racking holes, and the LED lighting bars would be attached. In this manner, if the lighting bars needed to be adjusted to change the distance from the LED lights to the plant canopy, the wire level is unhooked and moved to the desired height, without disassembling the entire section thereby allowing farmers to adjust the distance of the light to the plant canopy on demand, either manually or automatically (the wire level could be attached to rods and gears to be moved automatically based on the plant's maturity)

[0036] It is yet another object of the present disclosure to provide an automated lighting system in which lighting bars are integrated into a lighting platform. The lighting platform is connected to the shelving system, but can be raised and lowered independently above the grow trays and plants using a motor, precise enough to provide feedback to the

vertical farming system about the distance the lighting bars are from the growing plants throughout the life of each plant. A history is generated, and incorporated with information from sensors in the grow trays or integrated into the vertical farming system itself, to be included in a database of all of the similar plants for optimizing the growth of the plants. Lighting platforms in the same system can be controlled separately so that each tray/pallet receives the optimal light spacing and light intensity for the cultivar that is growing in it. This allows multiple crops to be grown in the same structure, each in their own optimized environment.

[0037] It is yet another object of the present disclosure, in addition to creating an optimal plant-growing environment in which the plant is the main sensor and provides feedback to the system to optimize growing performance, to utilize the automated lighting platform to reduce both labor and energy costs and thus generate labor and energy cost savings. As described above, based on the plant canopy's height at any point in the plant's life cycle, the lighting platform is configured to autonomously adjust the lighting fixture height above the crops to maintain a constant, optimal position throughout crop growth cycle, thereby eliminating the need for daily, manual adjustments. These continuous adjustments allow the lighting fixtures to be positioned at a minimum distance from the crops throughout the growth cycle. Maintaining the lighting fixtures at a minimal height above crops allows for the utilization of less powerful (i.e., lower wattage) lighting fixtures (or standard-power lighting fixtures at lower power consumption rates through dimming schema). Additionally and as described herein, the novel tray design may include reflective covers to reflect the lighting to the underside of the plant thereby increasing the effectiveness of the lighting element and reducing the need for more power. Maintaining this minimum light fixture height (along with the reflective cover) autonomously produces the required light intensity needed for plants to grow efficiently at a reduced, and sometimes greatly reduced wattage, therefore reducing the cost. This resolves one of the major expenses in the vertical farm industry: high power consumption.

[0038] It is yet another object of the present disclosure to provide a camera system for taking photographs and video of the growing plants at each stage of development. As described herein, these cameras can be incorporated into the vertical farming system in a number of ways, including through either one or more of high definition cameras located on telescoping poles; using a camera vehicle that houses one or more cameras and is attached to a rail or rail system; and autonomous flying drones, flying preprogrammed routes. Each of these systems will greatly reduce or eliminate certain labor costs such as monitoring the plants for disease and care purposes. One or more cameras can also be permanently mounted onto the vertical farming system in strategic places.

[0039] The system can incorporate high definition cameras to record the life cycle of the plants. These types of cameras provide high-resolution images and video of the growing plants. Cameras can utilize physical filters (e.g., low-pass, high-pass, band-pass) to highlight vegetation (or the absence of) within an image. Additionally, digital image filtering and manipulation (i.e. digital image analysis; digital image processing; computer vision) facilitate the real-time identification of individual plants (or tray canopies) in order to track and quantify plant growth, plant growth rate and

biotic and abiotic stress. Digital image processing may include one or more of the following techniques: thresholding (static and variable), erosion, dilation, color space manipulation, image channel manipulation and pixel value normalization and transformation schema. Digital filters and digital image manipulation improve and expedite contour detection, contour centers calculations, image histogram analysis, comparisons, and correlation between pixel (i.e. digital) representation and actual crop canopy area (i.e. physical units). Real-time quantification of plant canopy areas (and temporal changes in plant canopy areas) are used to autonomously adjust light intensity and/or photoperiod to maintain optimum light quantity throughout the growth cycle; as well as to compare growth rates with established crop models (i.e. historical data) to gauge plant health and vigor. Early detection of plant stress (and elimination/alleviation of it) is fundamental to the consistent production of high value crops. Therefore, in addition to autonomously modifying environmental conditions (e.g. light intensity, photoperiod, air speed, air temperature, water temperature, humidity) upon detection and identification of a plant/crop abnormality, the system also transmits and logs an alert to operators. Each of these systems will greatly reduce or eliminate certain labor costs such as monitoring the plants for disease and care purpose.

[0040] It is yet another object of the present disclosure to provide autonomous flying smart drones that land on charging mats or bases, when not in use for charging purposes, and follow a preprogrammed flight pattern (usually at night, but can be scheduled or on demand) to obtain images and video (and possibly infrared images, among others) of the growing plants and the grow structure (i.e., system) itself. These recorded images and video, along with other information, such as temperature and humidity at particular times and locations, is automatically sent to a computer database for processing in order to gauge the health of the system as a whole along with each plant's health, pest and/or disease issues, and plant life cycle. The system can also check for lighting being evenly distributed, dry spots or wet spots throughout the structure (like puddling on the floor or dry plant sites). This system will therefore allow itself to automatically "flag" any potential issues for a human to review.

[0041] It is yet another object of the present disclosure to provide a novel rack structure manufacturing system in which the rack is made up of predesigned structure, such as extruded aluminum or extruded plastic, and uses hollow cavities for transporting water, electricity, cool and warm air and humidity from one location on the rack structure to one or more locations on the rack structure, without the need for separate conduit, ducts or connections. The rack structure system of the present disclosure can be designed to be originally built, or later enlarged, without the need for designing (or redesigning) separate conduit for transporting items necessary for the plant-growing cycle. As the rack system is built, or later enlarged, each rack system component connects with the other components, using the predesigned hollow cavities to create the necessary conduit, ducts or connections. This will allow the entire grow structure to function as large, simple appliance, with one input for electricity, one input for water, and one input for air, as well as other built-in mounting points and rails for camera systems. This will significantly reduce the cost and complexity of existing vertical structure designs.

[0042] It is yet another object of the present disclosure to provide a novel harvesting system, either a harvesting press or an articulating harvester, in which the plants are harvested in their plant grow trays. Instead of the manual harvesting process, the present disclosure relates to a harvest in place process or system. The harvesting press uses multiple corers strategically mounted in a mirror image of the plant sites in the grow tray. The corers could vary in diameter based on the particular crop being harvested and might also spin, to make the coring process simpler. The harvesting press would drop down in a single motion against the grow tray, simultaneously coring all of the plant sites, resulting in the cores remaining in their sites, and the loose leaves separated on the tray. The leaves can then be removed in a number of different ways for additional processing or packaging. The articulating harvester, on the other hand, consists of a vision system and robotic arms mounted with corers to individually core each head in a grow tray at high speed, removing the leaves for processing and/or packaging. As described herein, the vision software can also be capable of detecting which heads of lettuce might not pass quality control, and opt to skip harvesting that particular head, leaving it in place to be discarded, and potentially reducing the amount of human labor necessary at a later time in the packaging process, while increasing the quality of the leaves being packaged.

[0043] These and other aspects, features, and advantages of the present disclosure will become more readily apparent from the attached drawings and the detailed description of the preferred embodiments, which follow.

DRAWINGS

[0044] The preferred embodiments of the disclosure will be described in conjunction with the appended drawings provided to illustrate and not to the limit the disclosure, where like designations denote like elements, and in which:

[0045] FIG. 1 illustrates an improved vertical farming system comprising a pushback grow structure in accordance with one embodiment of the present disclosure;

[0046] FIG. 2 illustrates an improved vertical farming system comprising a shuttle structure in accordance with one embodiment of the present disclosure;

[0047] FIG. 3 illustrates a prior art plant grow tray used in vertical farming systems and methods;

[0048] FIG. 4 illustrates a prior art plastic pallet used transportation and storage of boxes and the like;

[0049] FIGS. 5A-5C illustrate an improved plant grow tray for vertical farming systems in accordance with one embodiment of the present disclosure;

[0050] FIGS. 5D-5G illustrate an improved plant grow tray for vertical farming systems in accordance with one embodiment of the present disclosure;

[0051] FIGS. 6A-6C illustrate an improved expanding plant germination tray and cutting apparatus for vertical farming systems in accordance with one embodiment of the present disclosure;

[0052] FIGS. 7A-7D illustrate camera systems used for accessing inaccessible locations and taking images and video of objects at those locations;

[0053] FIG. 8 is a block diagram view of an exemplary embodiment of a vertical farming system utilizing autonomous flying drones.

[0054] FIG. 9 illustrates an improved vertical farming system comprising a clustered grow rack and inter-cluster shuttle system in accordance with one embodiment of the present disclosure;

[0055] FIG. 10 illustrates an improved vertical farming system comprising a novel water supply, drain system and rollers for grow racks in accordance with one embodiment of the present disclosure;

[0056] FIG. 11 illustrates an improved vertical farming system comprising a novel modular lighting system in accordance with one embodiment of the present disclosure; and

[0057] FIGS. 12 and 13 illustrate improved vertical farming systems comprising an alternative novel modular lighting system in accordance with one embodiment of the present disclosure.

[0058] FIGS. 14A-14B illustrate improved vertical farming systems comprising an automatic harvesting systems in accordance with one embodiment of the present disclosure.

DETAILED DESCRIPTION

[0059] Referring to the drawings, wherein like reference numerals refer to the same or similar features in the various views, the present disclosure pertains to an improved vertical farming system for autonomously growing edible plants, using improved stacking, storage and shelving units are configured to allow for easy access and gravity-based irrigation and feeding, alone or in combination with an improved shuttle system for autonomous rotation of the growing plants throughout the improved vertical farming system.

[0060] The innovative vertical farming system further comprises novel grow trays or plant-growing pallets, and incorporates camera systems, including telescoping arms, camera vehicles and autonomous smart drones, fly preprogrammed routes; all with 3D and multispectral cameras (and other recording instruments) to photograph and record the growing plants and obtain vertical farming metrics, as necessary. The images and other data recorded being automatically sent to a database for processing and for gauging plant health, pest and/or disease issues, and plant life cycle. The system can also check for lighting being, evenly distributed; dry spots or wet spots throughout the structure (like puddling on the floor or dry plant sites).

[0061] The innovative vertical farming system also comprises autonomous or nearly autonomous harvesting systems for harvesting plants in the grow trays. The harvesting systems disclosed include articulating harvesters that can autonomously determine the location or center of the plant to be harvested and use telescoping arms to move the harvester into the proper location before harvesting the plant. Alternatively, a harvest press uses a device sized similar to the grow tray for harvesting all of the plants in the tray at once in a single motion. The harvested material can be packaged for consumption or other use, and the remaining cores (in tray) can be discarded or further processed.

[0062] FIG. 1 shows an improved vertical farming system 10 comprising a shelving system or pushback grow structure 12, configured with multiple shelves or levels 14, each shelf or level 14 at a slight decline to allow for more efficient gravity-based irrigation and gravity-based loading and unloading. In the preferred embodiment, the shelf 14 decline angle is between 1 and 5 degrees and preferably 2 degrees, however, other angles can be used for the same purpose. The

pushback grow structure **12** can be any length from a few feet to a thousand feet long, and based on the description herein, the only limitation on the height of the structure **12** is the height of the building (not shown).

[0063] In practice, water or a nutrient solution **20** (for ease of reference, we will refer to water, but the present disclosure contemplates any solution that can be transported throughout the system) from a reservoir **16** is pumped to the uppermost tray of each level (here shown as **18** in the upper level), and the slight 1 to 5-degree decline allows the water **20** to run from the first uppermost tray **18** on that level **14**, through the rest of the trays **22-30** (as examples) on the same level **14**, due to the gravitational force, or down each column as described above. Once the water reaches the last (and lowest) tray **30** on that particular level **14**, it exits the bottom **32** and is drained back to the reservoir **16** to be recirculated to other trays on the pushback grow structure **12**.

[0064] FIG. 1 also shows an automated lift structure or lift **34** on the side of the pushback grow structure or shelving unit **12** for both loading and unloading the trays or plant-growing pallets **18** and **22-30** from the shelves **14**. Rollers **36** running the entirety of each level **14** reduce the need for automation along the whole length of the shelf structure **12**, as it is a "push back" loading system and the trays or pallets **18** and **22-30** can be loaded and unloaded, with a gravitational assistance, in a first in/first out order (although other loading and unloading protocols are contemplated). In doing so, a single automated lift **34**, which can traverse between the different levels **14**, can load and unload all levels **14** of the structure **12**. The lift **34** ties into a conveyor system **38** that can transport the grow trays or plant-growing pallets **18** and **22-30**. In the preferred embodiment, gravity pulls the pallet or grow tray **18** and **22-30** into position so that just one or two lifts **34** can load and unload an entire level **14**.

[0065] The preferred embodiment comprises two lifts **34** per shelving system **12**, regardless of the number of shelves **14**. This eliminates the need for a separate lift structure **34** on every level. As one grow tray **18** is removed form a shelf **14**, gravity and the slant or decline of the shelf **14** moves the next grow tray **18** into the location left vacant by the removed grow tray **18**. Additionally, after removal of a grow tray **30** on a shelf **14**, the remaining grow trays **18 22-28** on that shelf **14** move over one place due to gravity and the rollers **36**.

[0066] FIG. 2 shows an improved vertical farming system **10** comprising a shuttle system **40** for accessing the particular trays or plant-growing pallets **42**. The shuttle system **40**, which is used for autonomous rotation of the crops, can be used either alone or in combination with the pushback grow structure **12**. Although shuttle systems **40** with multi-level scalability currently exist, such as the one distributed by Invata Intralogistics, the novel system may comprise, at a minimum, combining the pushback grow structure **12** with a multi-level shuttle system to improve the plant growth process. As such, the vertical farming system **10** can see improvements incorporating an irrigation system using the reservoir **16** with slightly sloped levels **14** (FIG. 1), alongside the shuttle system **40**.

[0067] Likewise, the pushback grow structure **12** and the shuttle system **40** can be built from standard pallet racking materials and designs. However, if the shuttle system is used without the grow structure **12**, all the levels **44** will be horizontal (no slope) and the plant-growing pallets **42** will be accessed by shuttles **46**. In the preferred embodiment, one

shuttle **46** can access an entire grow rack level **44**. If the shuttle **46** is transported between levels **44** by a lift (not shown), it can then move across the length of each level **44**. The present disclosure contemplates that multiple shuttles **46**, one on each level **44**, or even multiple shuttles **46** on each level **44** can be used to access to each tray or pallet **42**.

[0068] The present disclosure further comprises a shuttle system **40** in which the plant-growing pallets **42** will be accessed (for moving or removing) by the shuttle **46** using a forklift, or arms, or any other manner as understood by one having ordinary skill in the art (not shown). In an embodiment, each shuttle will be able to access and move or remove a 4 foot×4 foot plant-growing pallet **42**, although other size trays **42** can be used to obtain the same results. In practice, the shuttle **46** will be moved into a proper location to access the pallet **42**. A forklift or arms will grasp the pallet **42**, either from underneath or from the side, and remove the pallet **42** from the location. Once the shuttle **46** has secured the pallet **42**, the system will instruct the shuttle **46** as to where that particular pallet **42** must be moved to (or removed) from the level **44** for further processing. Similar to the pushback grow structure **12**, the shuttle system **40** can be used in conjunction with a conveyor system **38**, as shown in FIG. 1.

[0069] FIGS. 3, 4 and 5A through 5C show various grow trays **18** and/or plant-growing pallets **42**. FIG. 3 shows a prior art plant grow tray **50**, such as that distributed by Botanicare. The tray is 4 feet by 4 feet and made from thick ABS plastic, with a smooth plastic surface and large drain channels **52**.

[0070] FIG. 4 shows a prior art Economy Plastic Pallet **60**, but not for growing plants. The plastic pallet is distributed by Uline Industries and is configured to stack on top of one another for easy storage when not in use. The pallet **60** has nine legs **62** and provides access for a forklift from all four sides. The **9** legs **62** provide additional support and the pallets **60** are either 48 inches by 40 inches, or 48 inches by 42 inches.

[0071] FIGS. 5A through 5C show the present disclosure of a grow trays or plant-growing pallets **70** configured to grow produce directly inside the pallet **70**. Similar to the 9-legged pallet **60**, the plant-growing pallet **70** provides a stable tray for placing on the pushback grow structure **12** or the shuttle system **40**. The plant-growing pallet **70** is configured for easy access and transportation by a forklift, robotic arms, etc. and the plant-growing pallet **70** can be configured for 4, 9 or any other number of legs (to hold the plants, or to hold a tray that is holding the plants). The grow tray **70** may also have a smooth bottom with no legs, and be slanted on the bottom to better accommodate the slanting or declining shelf **14** or to facilitate the transport of water **20** for better irrigation purposes.

[0072] FIG. 5A shows a side view of the plant-growing pallet **70**, showing two of the four legs **72**. The lift **34** can access the plant-growing pallet **70** from any one of four directions. FIG. 5B shows a top view of the plant-growing pallet **70** with the four legs **72**. FIG. 5C shows a top view of the floor of the plant-growing pallet **70**, with ridges **74** and a drain hole **76**. The tray may be sloped (again 1 to 5 degrees) to allow the water to move to the drain hole **76**. A bell siphon or similar device may be used to ensure that water levels do not overflow from the grow trays.

[0073] The plant-growing pallets will be engineered for sanitary purposes by reducing areas where water and impurities can congregate. This unitary, one-piece design will

help reduce plant disease and other problems with growing plants in such a structure, possibly manufactured through a thermoform process.

[0074] FIGS. 5D through 5G show the preferred embodiment grow trays or plant-growing pallets 200 configured to grow produce directly inside the grow tray 200. The disclosure may reference grow tray 70 or grow tray 200, although each of the novel grow trays disclosed herein can be used in the improved vertical farming system 10 disclosed herein, and can be used interchangeably with other grow trays or plant-growing pallets disclosed herein and referred to as 18, 22-30, 42, 70, 80, 200.

[0075] Similar to the description above, FIGS. 5D and 5E show a top view and side view of the grow tray 200 respectively, with the bottom of the grow tray 202 shown, where the water and nutrients will be placed to water and feed the plants. In the preferred embodiment, the grow tray is 48.80 inches long 204 by 48.69 inches wide 206, and is tapered with a 4.7 inch height at the tall end 208, and a 2.47 inch height at the short end 210, providing for a 2 degree slant 212 from one side 214 to the other 216.

[0076] At the tall end 208 of the grow tray 200, there are one or more ports 218 to allow water to cascade from one tray 200 to the adjacent tray 200 on the shelf. In FIG. 5D there are three ports 218. Thus, due to the angle of the vertical farming system shelves, when the grow trays 200 are placed next to each other on the shelf, water can be poured into the highest tray 200 and once it reaches the port 218 level 220 of the grow tray 200, water will cascade out through the port 218 and into the adjacent tray 200. In the example shown in FIG. 5D, each of the three ports 218 tapers from 5.44 inches to 5.00 inches to direct the water into the next tray 200.

[0077] FIG. 5F shows two grow trays 200 adjacent each other, such that the tall end 208 of one tray 200 is above the short end 210 of the adjacent tray 200. In this configuration, water 222 can be seen exiting the port 218 and entering the short end 210 of the adjacent tray 200. This will be repeated when each tray fills with water 20 to the level of the port 218 and pours into the adjacent tray 200.

[0078] FIG. 5G shows a cover 224 for the novel grow tray 200. The cover 224 has multiple holes 226 for growing the plants (through the holes 226). In the example shown in FIG. 5G, there are 72 different holes 226 for growing plants, although more or less plants can be grown depending on the configuration, which may be due to the type of plant.

[0079] The grow tray cover 224 also contains port cover portions 228 for covering the ports 218 and reducing spillage. The grow tray cover 224 also contains cover indents 230 where the ports 218 from the adjacent tray 200 will connect to make sure the overflow water 20 from the adjacent tray 200 is properly received. When the last tray 200 on the shelf fills with water, the overflow will pour into a gutter or reservoir 16, where it can be either disposed of or reused. This system and the novel grow tray 200 allows for irrigating multiple trays and many plants merely by pouring water into the highest tray 200 at the height of the shelf 14, and collecting the water 20 as it pours out of the ports 218 of the lowest tray 200 at the short end 210 of that tray 200.

[0080] FIGS. 6A through 6C show the present disclosure and the related novel expanding seed germination tray 80 of the vertical farming system 10, configured to grow produce directly inside each cell section 82 of the germination tray 80

for a longer period of time, without the need to replant the seeds into a different cell section 82 for additional room. The expanding germination tray 80 is meant to reduce the amount of "shock" that a plant's root system goes through every time the root system is moved or replanted. The germination tray 80 can also be used in combination or conjunction with the grow tray 200 design disclosed herein.

[0081] Typically, a Rockwool tray is inserted into a propagation tray where the seeds will germinate. Other types include cocoa coir, and other grow media. Then, the Rockwool tray is separated into parts and transplanted into a Styrofoam raft, which has more appropriate spacing for mature plants.

[0082] FIGS. 6A and 6B of the present disclosure show an expanding germination tray 80 comprising a tray similar to the currently used trays (FIG. 6A), to propagate seeds in, but configured with joints 84 and hinges 86 to expand (FIG. 6B) to the proper spacing necessary for mature plants to grow properly and without the normal shock the plants receive upon replanting.

[0083] Additionally, FIG. 6C shows an expanding germination tray cutting die apparatus 88 for creating the novel expanding germination tray 80. As understood by one having ordinary skill in the art, the cutting die apparatus 88 is a near identical size to the expanding tray 80, but utilizes razor edges to assist in cutting the Rockwool expanding trays 80 into parts before expanding. Further, the cutting die apparatus 88 may be used to just cut the Rockwool into sections so that the tray easily expands.

[0084] The improved vertical farming system 10 further comprises a camera system or systems to photograph, take video, record and monitor the plants during the entire plant life cycle. FIGS. 7A through 7D show the different types of camera systems in accordance with the present disclosure. Since farms, including vertical farms, rely on either human beings or multiple cameras to monitor crops, the novel solution described herein allows the use of a single camera to monitor and analyze many plants on different levels and even in different areas of the vertical farming system.

[0085] FIG. 7A shows a telescoping camera system 240 in which the camera 242 is located at the end of a telescoping arm 244, and utilizes a gimbal system 246 to move the camera to the desired location. The lifts 34 described herein that load and unload grow pallets 200 from the shelving system or grow structure system 12, already are configured to traverse each shelf or level 14, including moving from one group of shelves 14 to another. The camera system 240 utilizes those existing lifts 34 in the monitoring and recording system by moving the camera system 240 from shelf 14 to different shelf 14. Programming the lifts 34 to traverse every load and unload position (while not actually loading or unloading a grow pallet 200) and extending the telescoping arm 244 into the shelf 14 and above the plant canopy, the camera 242 can then record and analyze each and every plant on the particular level 14. In doing so, the information recorded can flag any potential issues.

[0086] By travelling to every load and/or unload position, remaining on the lift 34, and inserting the telescoping arm 244 into each level, one lift 34 and one camera 240 can monitor, photograph and/or video every grow tray 200 position on the level 14. Since the telescoping arm 244 can be used from both sides of the shelf (load and unload), the telescoping arm 244 need only travel half of the length of the shelf or level 14, which in turn can minimize cost and

maximize the speed of vision analysis. This camera system **240** and the accompanying vision analysis software allows the vertical farming system **10** to analyze the maximum number of plants with a minimum number of cameras **242**, saving a significant amount of cost, and also greatly simplifying the system.

[0087] FIGS. 7B and 7C show a different type of camera system, the autonomous vehicle camera system **250** in which an autonomous vehicle **252** can be loaded and unloaded onto rails **254** above the grow trays **200** to travel the distance of the shelf **14** and take pictures or video using an in-vehicle camera **256**. The vehicle **252** can travel by the use of one or more powered wheels **258** along with passive wheels **260** in multiple configurations, to move along the rail **254** (above or below). Additionally, the system **250** can be designed to use a single rail **254** and the vehicle **252** can hang from the rail **254**, in an example.

[0088] Further, similar to the telescoping camera system **240**, the vehicle camera system **250** can use the existing lift system **34**, but the autonomous vehicle **252** can instead be loaded and unloaded onto each rail **254**. As such, the vehicle camera system **250** can be loaded onto the rail **254** of one level, where it will travel above the shelf **14**, and take photographs and video, and then be loaded back onto the lift **34**, where it will be raised or lowered to another level **14**, and loaded onto the rail **254** of that level, for more recording and monitoring. The vehicle camera system **250** can be wirelessly connected to the vertical farming system **10** so that any information obtained can be transmitted to the database **96** (FIG. **8**) in real time.

[0089] FIG. 7D shows yet another example of recording and monitoring the plant life cycle, using an autonomous flying smart drone **90** for flying preprogrammed routes at preset times or on demand. The flying smart drone **90** incorporate one or more cameras **92**, such as a 3D or multispectral camera. As described herein, these types of cameras provide high-resolution images and video of the growing plants and can also be incorporated into the camera system **240** and/or vehicle camera system **250** disclosed herein. For stability purposes, the cameras are mounted on a gyroscopic stabilizer, however, it is contemplated that the flying smart drone **90** will be able to photograph every plant in the vertical farming system **10** environment.

[0090] The autonomous flying smart drones **90** are also programmed to land on and connect to their charging mats or bases (not shown), and follow a preprogrammed flight pattern (usually at night) to obtain images and video (and possibly infrared images, among others) of the growing plants. These recorded images and video, along with other information from all of the camera systems disclosed, such as temperature and humidity at particular times and locations, is automatically sent to a computer database **96** for processing in order to gauge the health of the system **10** as a whole, along with each plant's health, pest and/or disease issues, and plant life cycle. The system **10** can also check for lighting being evenly distributed, dry spots or wet spots throughout structure (like puddling on the floor or dry plant sites)

[0091] FIG. **8** is an exemplary block diagram of the vertical farming system **10** utilizing a drone **90** or camera system **240** or vehicle camera system **250** along with a computer system to control the cameras, access the images and videos captured by the camera systems **90, 240, 250**, and determining the health of the vertical farming system **10** as

a whole, along with each plant's health, including any pest and/or disease, and each plant's life cycle.

[0092] As such, the present disclosure further comprises custom software and a graphical user interface (GUI) that allows the system to autonomously or near-autonomously control one or more of the camera systems **90, 240, 250**. The autonomous or manual control allows for the capture of images and video of some or all of the growing plants using a camera or cameras **92, 242, 256**. Along those lines, the present invention contemplates the ability to electronically transmit plant-growing data to the computer system of the vertical farming system **10** for automatic or manual plant health determination.

[0093] As a non-limiting example of a processor system, FIG. **8** is a block diagram view of an exemplary vertical farming system **10** for growing plants. The vertical farming system **10** may include a plurality of camera systems **90, 240, 250** (three such combinations are represented in FIG. **8**), a vertical farming support server **94** (which may be referred to herein as a vertical farming platform server **94**), a vertical farming database **96**, a vertical farming application programming interface ("API") **98**, and a system user access **100**, whereby vertical farming system users and others, such as distributors, consumers, restaurant owners, end users, programmers, etc., can access the vertical farming system **10** data for monitoring the growing plants, and upgrading the software, as necessary, among other reasons. The vertical farming system user access **100** can be a single site or multiple sites depending on the needs of the system **10**. In the preferred embodiment, multiple sites are contemplated.

[0094] The present disclosure will be described with reference to embodiments in which the vertical farming system **10** utilize a vehicle camera system **250** autonomously, although all of the different camera systems **90, 240, 250** are contemplated. The vertical farming system users access the data through the system user access **100**, connected to the vertical farming API **98**. It should be understood, however, that the present disclosure is not limited to the preferred embodiment detailed herein; rather, the system, methods and functionality illustrated and described herein may be effected in other ways as understood by one having ordinary skill in the art.

[0095] For example, a restaurant owner may use one application program ("app") on a smart phone to access certain information about the vertical farming system **10**, while a programmer may use an app to upgrade the software, and a system user may use an app to manually control an autonomous vehicle **252** to capture information about a particular plant or set of plants. Accordingly, the vertical farming system users may access the vertical farming API **98** through the vertical farming support server **94** or through the system user access **100**.

[0096] Each of the camera systems **90, 240, 250** may be configured to be controlled autonomously with an onboard program, which may include a travel program, a docking and charging program and hardware and software to capture plant images and video and transmit the information to the vertical farming support server **94**. Additionally, the vertical farming system **10** may include control of the different camera systems **90, 240, 250** autonomously or manually through the vertical farming support server **94** or through the system user access **100**.

[0097] The vertical farming system **10** (which may be referred to herein simply as "the system **10**") may include

and provide a graphical user interface (GUI) having a number of features described above and below. Portions, or all, of the GUI may be provided by the vertical farming support server **94**, in an embodiment. Accordingly, in an embodiment, the vertical farming support server **94** may be configured to perform one or more operations, methods, etc. described herein that enable various control, calculations and determinations for the system **10**.

[0098] The vertical farming support server **94** may be configured to perform a number of functions to assist vertical farming system users in their decisions. For example, the vertical farming support server **94** may be configured to provide a daily or nightly control of the camera system **90, 240, 250** to capture the plant images and video, along with reading sensors in the vertical farming infrastructure or located on the camera systems **90, 240, 250** to determine if the vertical farming system **10** is operating within certain parameters. The vertical farming support server **94** can be configured to contact vertical farming users if the measurements exceed the acceptable range. These routines, programs and protocols may be obtained from the vertical farming support server **94**, in an embodiment, from the vertical farming API **98** and/or from the system user access **100**.

[0099] The vertical farming support server **94** may be further configured to store data in and retrieve data from the vertical farming database **96**. Data stored in the vertical farming database **96** may include camera system **90, 240, 250** controls and docking programs in general, rotation of crop programs, specific plant health information, range of acceptable temperatures and humidity, plant health programs, etc., and similar information related to plant health determinations that may be performed through the vertical farming system **10**.

[0100] The vertical farming database **96** may be or may include one or more data repositories including, but not limited to, one or more databases and database types as well as data storage that may not necessarily be colloquially referred to as a "database." The vertical farming database **96** may be configured to store the information described herein, and programs that may be performed through the vertical farming system **10**, along with similar information related to the needs of the vertical farming system **10**.

[0101] The vertical farming support server **94** may be in electronic communication with the camera systems **90, 240, 250** and with the vertical farming system users to obtain and deliver updated information, programs and routines, and other information, in an embodiment. In embodiments, the vertical farming support server **94** may be owned, controlled or operated by the vertical farming system user, a separate vertical farming facility, or some other entity. Furthermore, the vertical farming support server **94** may be a single server, or multiple servers acting in a redundant or additive capacity.

[0102] In embodiments, the camera systems **90, 240, 250** may be configured to perform one or more of the functions described herein with reference to the vertical farming support server **94** and/or the vertical farming system **10** or facility. Accordingly, the camera systems **90, 240, 250** may be in direct electronic communication with the vertical farming support server **94**, the vertical farming database **96**, the vertical farming API, and/or the system user access **100**.

[0103] The camera systems **90, 240, 250** may include a processor **102** and a memory **104**, and the vertical farming

support server **94** may include a processor **102** and a memory **104**. The processor **102** may be any appropriate processing device (and may be the same or different in each location). The memory **104** may be any volatile or non-volatile computer-readable memory (and may be the same or different in each location). The memory **104** may be configured to store instructions that embody one or more steps, methods, processes, and functions of the camera systems **90, 240, 250** and/or the vertical farming support server **94** described herein. The processor **102** may be configured to execute those instructions to perform one or more of the same steps, methods, processes, and functions. One or more of the camera systems **90, 240, 250** and/or the vertical farming support server **94** may be or may include a personal computer or mobile device (e.g., tablet, smartphone), in an embodiment.

[0104] Instead of, or in addition to, a processor **102**, and memory **104**, the vertical farming support server **94** and/or one or more of the camera systems **90, 240, 250** may include a programmable logic device (PLD), application-specific integrated circuit (ASIC), or other suitable processing device (not shown).

[0105] The programs and information described herein may be provided, in an embodiment, by both the camera systems **90, 240, 250** and the vertical farming support server **94**. That is, some elements or features of the system **10** may be installed on the camera systems **90, 240, 250**, and other elements or features of the platform may be provided by the vertical farming support server **94** (e.g., on a software-as-a-service (SaaS) basis). For example, the camera systems **90, 240, 250** may provide (i.e., may have installed) a program that includes a graphical user interface of the vertical farming system **10**, and the vertical farming support server **94** may provide much of the underlying data, programs and protocol. However, storage and retrieval of data displayed in the vertical farming system **10**, calculations performed by or under the vertical farming system **10**, and services provided through the vertical farming system **10** may be performed by one or both of the camera systems **90, 240, 250** and the vertical farming support server **94**.

[0106] FIG. **9** shows an improved vertical farming system **10** (from a different top down viewpoint) comprising a shelving system **12**, configured with multiple shelves or levels **14** (see FIG. **1**), and comprising a cluster **108** configuration of back-to-back grow racks **110**. In doing so, each cluster **108** consists of two back-to-back grow racks **110** of any length. Each cluster **108** will have one or two lift structures **34**, which will be configured to transport a shuttle **46** (see FIG. **2**) to any level in that cluster **108**, thus enabling the shuttle **46** to pick any grow tray **200** on any level **14** and then deliver it to a central conveyor belt system **38**. As such, a shuttle **46** can transport itself from cluster **108** to cluster **108** by way of a ground level rail system **112** that connects to each cluster **108**, and a single shuttle **46** could service every single grow tray **200** position in any cluster **108** on the floor, and deliver that grow tray **200** to the central conveyor system **38**. Additional shuttles **46** can be added to the same infrastructure, as the need for throughput increases and the system, as a whole, is scalable.

[0107] In an alternative embodiment, the same cluster **108** configuration can be utilized without the need for shuttles **46**. Based on the slant of the shelf **14** and the lift **34**, each grow tray **200** can be accessed and placed onto the ground level rail system **112** without the need for a shuttle, thereby

reducing the cost of the overall vertical farming system **10**. Additionally, a hybrid system can be utilized in which the grow trays **200** are used without a shuttle **46**, while on the shelving system **12** and once removed for processing by the lift **34**, each grow tray **200** is placed onto a shuttle for transport on the ground level rail system **112**.

[0108] FIG. **10** shows an improved vertical farming system **10** (from a top down viewpoint) comprising a shelving system **12**, configured with multiple shelves or levels **14** (see FIG. **1**) and comprising a novel water and draining system **120**. In a preferred embodiment, two grow trays **200** can sit on top of a level of rollers **122**, jutting out slightly on either end of the rollers **124**. Under the rollers **122**, and spanning the entire length of the level **14**, and having a width larger than the grow tray **200** itself, is a trough style drain **126**. The purpose of this trough drain **126** is so that the water supply **128** can feed directly into the grow tray **200** and then drain **130** out of the opposite end of the grow tray **200** into the trough drain **126**. If a pallet or grow tray **200** is absent from its position, i.e., it has been unloaded, the water supply **128** will still feed directly into the trough drain **126** and recirculate back into the systems nutrient reservoir **16** (see FIG. **1**). The trough **126** will be wider **124** than the rollers **122** so that any water **20** (see FIG. **1**) being supplied or drained does not make any contact with the rollers **122**.

[0109] Additionally, the rollers **122** will be positioned at an angle towards the drain **130**, so that supplied water **20** will be pulled by gravity towards the grow tray's drain hole **130**. The rollers **122** will also be angled towards the grow rack's lift **34**, keeping in line with the gravity pulled pushback system. By having these two angles or slants, the water **20** is forced by gravity towards the drain **130**, while the grow tray **200** is forced by gravity towards its unloading location on the conveyor belt structure **38**.

[0110] FIG. **11** shows an improved vertical farming system **10** (from a perspective viewpoint) comprising a shelving system **12**, configured with multiple shelves or levels **14** (see FIG. **1**) and comprising a novel modular lighting system **132**. The disclosure comprises a wire level **134** that can hook directly into the pallet racking holes **136**. Attached to that wire level **134**, are LED lighting bars **138** (two of them).

[0111] To the extent it is determined by the system **10** that the distance from the LED lights **138** to the plant canopy grow trays **200** needs to be adjusted, it can be accomplished without disassembling the entire shelving system **12**. To move the LED lights **138**, the entire wire level **134** is unhooked, and moved the desired distance from the plant canopy, completely avoiding the uninstallation and reinstallation of the shelving system **12** and/or LED light bars **138**. The process could further be automated by attaching the wire level **134** to a series of rods and gears (not shown) or motors and having the system **10** detect through sensors and the database **96** when the LED light bars **138** need to be moved and how far to adjust them.

[0112] FIGS. **12** and **13** show different perspective views of an alternative embodiment to the novel modular lighting system **132** in FIG. **11**. This embodiment includes a motor and feedback for automating the raising and lowering of the lighting bars **138**. In FIGS. **12** and **13**, the LED lighting bars **138** are integrated into a lighting platform **140**, which is connected to the shelving system **12**, but can be raised and lowered above the grow trays **200** using a motor **142**, such as a stepper motor, for example. Stepper motors are highly

reliable, work in almost any environment, and provide precise positioning for starting, stopping and reversing.

[0113] The motor **142** provides feedback to the vertical farming system **10** as to the distance the lighting bars **138** are from the grow tray **200** and, in effect, the growing plants. As such, a history can be generated of the distance of the lighting bars **138** from a particular grow tray **200** and the plants in that grow tray **200** during the entire life of the plants from seed to harvest. That history can be included in the database **96** of all of the similar plants for optimizing the growth of the plants.

[0114] Additionally, sensors **144**, such as temperature and humidity sensors can be placed in or incorporated into the grow trays **200** or elsewhere to determine additional information for the database and for ultimately obtaining the optimal temperature and humidity for growing plants. The sensors **144** can also be incorporated into the shelving system **12** of the vertical farming system **10** so that at any particular time, the system **10** knows where a particular grow tray **200** is located and the conditions surrounding that grow tray **200** during the plant life cycle. Either way, the information obtained from the sensors **144** can be used in conjunction with (or in addition to) the distance of the lighting bars **138** at any particular time or for the entire life of the plant to further optimize growing conditions.

[0115] As such, the changing distance of the overhead lighting bar **138**, in association with the existing database **96** of the vertical farming system **10** creates a Dynamic Light Zoom (DLZ), which can be (computer) controlled to maintain constant Photosynthetic Photon Flux Density (PPFD) exposure throughout the plant growth stages (i.e., seedling, vegetative, reproduction). Plant PPFD values are autonomously and automatically adjusted and/or maintained in real-time through sensor **144** data analysis, such as proprietary algorithms (including machine learning and artificial intelligence) and the raising and lowering of the lighting platform **140** containing the lighting bars **138**. As described, sensors **144** include, but are not limited to, distance sensors (e.g., ultrasonic, infrared) and optical sensors (e.g., photodiodes, phototransistors, ultraviolet-cameras, visible Spectrum cameras, near-infrared cameras, infrared cameras, thermographic cameras). The motor and/or sensors (or sensor systems) can be configured to provide feedback to the vertical farming system as to the distance the lighting bars and/or LED sheets are from the growing plants.

[0116] Additionally, and as disclosed herein, the system cameras **92**, **242**, **256**, which can be incorporated into the camera systems **90**, **240**, **250**, could also be mounted to the lighting platforms **140** (or other areas on the vertical farming system **10**). When the system desires to capture an image (or a video, such as time lapse video), the lighting platform **140** can autonomously raise to an appropriate height to capture as many of the plants as possible, and then autonomously return to the height most appropriate for optimal plant growth. The cameras described herein, mounted to the DLZ can be instead of or in addition to the cameras **92**, **242**, **256**, disclosed herein, with the DLZ mounted cameras have at least all the same functionality.

[0117] The lighting bars or lighting fixtures **138**, which can be proprietary and/or commercially available, are mounted to the lighting platform **140** that can be mechanically raised and/or lowered, automatically or manually. Regardless of the type of raising and lowering of the lighting

platform **140**, the system will keep track of the distance and the temperature/humidity (or any other metrics being monitored by the sensors **144**).

[0118] The PPFD maintained by the DLZ is user defined and will be revised over time, depending on the feedback of the growing environment. Lighting bars **138** can be maintained at a specified height above the grow trays **200**, and thus the growing plant canopy, and the lighting bars **138** can be adjusted autonomously to a height above the growing plant canopy to maintain a specified PPFD, or a combination of a specified height above the growing plant canopy and a specified PPFD exposure to the growing plant canopy.

[0119] In accordance with the present disclosure, a novel manufacturing system for vertical farming is contemplated in which the parts and materials used to build and enlarge the rack system **12** are configured to allow for ease of building and enlarging without the need for separate conduit, ductwork or electrical connections. The rack system **12** design allows for the transfer or transport of supplies and resources necessary for plant growth without separate connecting designs. The rack structure manufacturing system utilizes predesigned and preformed materials, such as extruded aluminum or extruded plastic, comprising hollow cavities, for transporting and transferring irrigation, energy, materials and environments from one place to another without the need for separate conduit, ducts or connections.

[0120] As a non-limiting example, the rack structure system **12** of the present disclosure can be designed to be originally built, or later enlarged, without the need for designing separate conduit for irrigation. The rack structure system **12** is designed and extruded to include hollow cavities for transferring water from a single input location on the rack structure **12** to an area where it can be diverted to the grow trays for irrigation purposes. Further, the same rack system **12** can be designed with additional hollow cavities to allow for irrigation draining once the water has matriculated through each of the grow trays **200** on a level **14** or in a cluster **108**. With this system, once the rack structure **12** is built (without separate water conduit or hoses), the water supply can be connected to the water input, and the exiting water can be connected to the drain and the rack structure system **12** will automatically transport water to each location for irrigation, redistribution or removal, regardless if the rack system **12** is four levels high or eight levels high, and if the rack structure **12** has clusters of 300 plants per level (5 grow trays at 60 plants per grow tray), or **1440** plants per level (20 grow trays at 72 plants per grow tray).

[0121] The same design can be used to transport or force cooling or heating air and/or humidity to the plants. The additional hollow cavities in the rack structure **12** allow for cooling or warming air from an HVAC system to enter the rack at a single location and be transported to various exit points to cool, heat or humidify the growing plants based on the needs that the system has determined, ostensibly from sensing the plants. The various exit locations can be vented automatically so that the system can determine what each plant needs and control the system accordingly. Again, as the rack system **12** is built or enlarged, the hollow cavities will be automatically connected for ease of design and build purposes.

[0122] The rack structure **12** can also be designed to allow electricity and other necessary energy to be connected at a single point and be delivered to various points on the rack system for use in lighting, sensors, cameras, and other needs.

As the rack system **12** is built or enlarged, each extruded piece connects with the other pieces to create the necessary conduit, ducts or connections. This will allow the entire grow structure **12** to function as a large, simple appliance, with one input for electricity, one input for water, and one input for air, as well as other built-in mounting points and rails for camera systems. This will significantly reduce the cost and complexity of existing vertical structure designs.

[0123] Additionally, as described above, the environmental database **96** can incorporate information obtained by stationary cameras and/or camera systems **90**, **240**, **250** throughout the vertical farming system **10**. Further, each grow tray **200** may include a pallet identification **146**, such as a barcode, RFID tag or QR code, as understood by one having ordinary skill in the art, allowing the vertical farming system **10** to automatically keep track of a particular grow tray **200** or even a particular plant. As such, a particular grow tray **200** can be monitored for input (water and fertilizer), information or metrics throughout the plant growth stages (temperature and humidity) and at harvest (time and yield), with the information being stored in the database **96** and used to optimize future growing environments.

[0124] The present disclosure also comprises an autonomous or near-autonomous harvesting system **300**. As described above, when harvesting heads of lettuce for example, the full head must be manually cut at its base to detach it from the ground or from the grow media. Next, the leaves are manually cut from or removed from the head of lettuce for packaging, until only the core of the head remains, which will be discarded. As such, the process involves many steps, and often, multiple individuals. The autonomous harvesting system **300** eliminates a substantial portion of this manual process by harvesting in place. This is possible since based on the improved vertical farming system **10**, the location of the center of each plant site is known for certain. Accordingly, the plant can be harvested in the same grow tray, in a one-step process.

[0125] FIGS. **14** A and **14**B show the harvesting systems **300** of the present disclosure in which the plant is harvested autonomously in the grow tray to reduce harvesting steps and time. FIG. **14**A shows an articulating harvester **300** in accordance with the present disclosure. The articulating harvester consists of a base **302** to hold the articulating harvester **300** in place, and articulated robot arm **304**, which can be programmed to move in multiple axes so that each plant on a particular grow tray can be accessed, and a corer **306** at the end of the robot arm **304**. The corer **306** can core or harvest each plant in the grow tray **200** one at a time to separate the leaves from the head of lettuce (for example) at high speed.

[0126] The leaves can then be removed for additional processing or packaging, either by tipping the grow tray **200** with a pneumatic arm or piston (not shown), causing all of the loose leaves to fall onto a conveyor belt or basket **308**, resulting in only the wanted leaves **310** being harvested, with no waste or unwanted plant matter commingled with the leaves **310**. The remaining cores **312** can be placed into a hopper **314** for further processing or discarding.

[0127] The articulating harvester also consists of a vision system and software capable of detecting which heads of lettuce might not pass quality control standards, and then skip the harvesting of that particular head, leaving it in place to be discarded with the other cores. This real time quality control at the time of harvest, will greatly reduce the amount

of human labor necessary at a later time, in the packaging process, and will simultaneously increase the quality of the leaves being packaged.

[0128] FIG. 14B shows a harvesting system **300** comprising a harvesting press **316** in accordance with the present disclosure. The harvesting press **316** would be similar to or the same size as, a grow tray **200**, with multiple corers **318** strategically mounted in a mirror image press **320** of the plant sites in the grow tray **200**. The corers **318** could vary in diameter based on the particular plant or crop being harvested, and might be configured to spin, to make the coring process simpler. The harvesting press **316** would drop down in a single motion **322** against the grow tray **200**, simultaneously coring all of the plant sites **324**, resulting in the cores **326** remaining in their sites, and the loose leaves **328** separated on the tray. Again, the leaves **328** can then be removed for additional processing or packaging, either by tipping the tray with a pneumatic arm or piston (not shown), causing all of the loose leaves to fall onto a conveyor belt or basket (see FIG. **14**A), resulting in only the wanted leaves **328** being harvested, with no waste or unwanted plant matter commingled with the leaves **328**. The remaining cores **326** can be placed into a hopper (see FIG. **14**A) for further processing or discarding.

[0129] These "harvest in place" harvesting systems **300** allow for the harvesting of multiple lettuce heads in exactly the same place that they grew during their life cycle, eliminating any unnecessary steps and monumentally increasing throughput and efficiency in the harvesting process.

[0130] It will be understood that the embodiments of the present disclosure, which have been described, are illustrative of some of the applications of the principles of the present disclosure. Although numerous embodiments of this disclosure have been described above with a certain degree of particularity, those skilled in the art could make numerous alterations to the disclosed embodiments without departing from the spirit or scope of this disclosure.

[0131] All directional references (e.g., upper, lower, upward, downward, left, right, leftward, rightward, top, bottom, above, below, vertical, horizontal, clockwise, and counterclockwise) are only used for identification purposes to aid the reader's understanding of the present disclosure, and do not create limitations, particularly as to the position, orientation, or use of the disclosed system and methods.

[0132] Additionally, joinder references (e.g., attached, coupled, connected, and the like) are to be construed broadly and may include intermediate members between a connection of elements and relative movement between elements. As such, joinder references do not necessarily infer that two elements are directly connected and in fixed relation to each other. It is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative only and not limiting. Changes in detail or structure may be made without departing from the spirit of the disclosed apparatus, system and methods as disclosed herein.

1. A vertical farming system for optimizing a plant growing process, comprising:

a shelving system, said shelving system comprising a plurality of shelves, each of said plurality of shelves having a first end and a second end with said first end being located higher than said second end, each of said plurality of shelves configured to accept and secure at least one grow tray, said plurality of shelves comprising a plurality of rollers, said plurality of rollers capable of rotating and configured such that a grow tray placed on said rollers will be transported from said first end to said second end using gravitational force;

a lift, said lift positioned at the said second end of said plurality of shelves, said lift configured to remove said grow tray from a first of said plurality of shelves and moving said grow tray to a second of said plurality of shelves;

said grow tray comprising at least one port, said port located and configured on said grow tray such that when said grow tray fills with water to a port level, the water will cascade out of the grow tray and into an adjacent grow tray, wherein when multiple grow trays are placed adjacent to each other on one of said plurality of shelves, such that each grow tray is higher than the adjacent grow tray, pouring enough water into the highest grow tray will fill all of the grow trays, thereby optimizing a plant growing process.

2. The vertical farming system for optimizing a plant growing process in claim **1**, further comprising one or more rails and a camera system, said one or more rails located above each of said plurality of shelves, said camera system comprising a camera and a set of wheels, said camera system configured to use said set of wheels to move along said one or more rails above each of said plurality of shelves, said camera system configured to use said camera to take a plurality of pictures of said grow tray on said plurality of shelves.

3. The vertical farming system for optimizing a plant growing process in claim **2**, wherein said lift is further configured to move said camera system from said first of said plurality of shelves to said second of said plurality of shelves.

4. The vertical farming system for optimizing a plant growing process in claim **2** wherein said set of wheel comprises four wheels and two of said four wheels are powered.

5. The vertical farming system for optimizing a plant growing process in claim **2** wherein said camera system is configured to wirelessly transmit said plurality of pictures to a database on said vertical farming system.

6. The vertical farming system for optimizing a plant growing process in claim **5** wherein said vertical farming system comprises an application programming interface that uses the photographs to optimize said plant growing process.

7. The vertical farming system for optimizing a plant growing process in claim **6** wherein said vertical farming system comprises a user interface that accesses the application programming interface to optimize said plant growing process.

8. The vertical farming system for optimizing a plant growing process in claim **7** wherein said user interface can be accessed by third party vendors to determine conditions of a plant in said grow tray.

9. The vertical farming system for optimizing a plant growing process in claim **8** wherein said third party vendor is the owner of a restaurant.

10. The vertical farming system for optimizing a plant growing process in claim **1** wherein said shelving system

comprises preformed materials containing hollowed cavities for irrigation of said grow trays, thereby obviating the need for separate conduit.

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