

MOBILE AEROPONIC IRRIGATOR UTILIZING ULTRASONIC NOZZLES

BACKGROUND & PRIOR ART

The field of Controlled Environment Agriculture, including greenhouses and indoor farms, utilize various plant irrigation techniques for growing plants in protected environments. The most popular technique is hydroponics, wherein plants are grown in water-based solutions of nutrient salts. One example of such technique is to grow leafy greens in polyester (XPS) or plastic boards (rafts) floating in large pools of nutrient solution in commercial greenhouses. Another technique, which is a hydroponic derivative technique, is called Nutrient Film Technique (NFT), wherein nutrient solution flows over plant roots, often in gutters, and offers a higher degree of control than floating-raft hydroponics. However, NFT also has limitations, including the horizontal plant density cap and high equipment costs. Despite their popularity, various hydroponic and hydroponic-derivative techniques have several limitations, including the horizontal plant density cap, disease spread through the nutrient solution, water waste and others that limit the operator's productivity. It is therefore important to search for new ways to increase greenhouse productivity.

A potential alternative to hydroponic and hydroponic-derivative greenhouse irrigation limitations is aeroponic irrigation. Unlike hydroponic-based approaches wherein plants are floated in, or are exposed to streams of nutrient solution, aeroponic irrigation works by suspending plant roots in air in enclosed environments, and by irrigating the plant roots with aerosolized nutrient solution at a constant rate, at static intervals or at dynamic intervals. From the biological standpoint, most commercial crops respond more favorably to aeroponic irrigation than to hydroponic techniques and produce a higher yield over a shorter crop cycle, thereby increasing facility productivity. Aeroponic irrigation also lowers the possibility of disease formation and spread. Unlike with hydroponics and its derivatives, aeroponically grown plants are exposed to air and can oxygenate more effectively from air than from water. Importantly, air has a much higher amount of oxygen (~21%) compared to limited oxygen solubility in the nutrient solution. Various commercially cultivated plants in different CEA facilities respond most favorably to aerosol droplets that have variable mean diameters between 20 μ m and 100 μ m. Provided that correct droplet diameters and spray intervals are used, the humidity inside the box or chamber wherein the roots hang will fluctuate and positively affect oxygenation and plant growth. Furthermore, when plants grown in hydroponics or NFT absorb the oxygen dissolved in the nutrient solution, the oxygen needs to be artificially replenished in the nutrient solution – this limitation does not exist in aeroponics. Moreover, aeroponically grown plants develop significantly larger root surface area, including due to root hair growth, which creates more active area capable of exchanging water, nutrients and gasses, thereby further boosting plant metabolic rate and yield. Finally, when done precisely, aeroponic irrigation produces the lowest amount of nutrient solution waste, because tiny droplets can be used to precisely coat the root surface with the right amount of liquid, which is then absorbed before the roots are sprayed again. Precision in aeroponics can lead to minimal run-off and thereby reduce or eliminate the need for recirculation, and also importantly, it minimizes the chances of disease formation and transfer.

Beyond the biological benefits, aeroponic irrigation also enables architectural gains. The horizontal plane plant density cap is among the key productivity limitations of hydroponic CEA facilities. While vertical farms can overcome this by stacking layers upon layers of grow-beds with artificial lights, greenhouses rely on natural light as the main source of light and cannot follow this approach. Instead of growing plants on the horizontal plane in hydroponic scenarios, because aerosol can move in three-dimensional space,

aeroponics make it possible to grow plants in aeroponic towers, A-Frames and similar installations that contain more active cultivation area than horizontal hydroponic installations per same floor area. For example, a 2 meter tall vertical aeroponic tower (such as the one disclosed in WO2016/156334, more info available at www.aponix.eu), wherein aerosol is supplied to the top of the aeroponic tower and falls down onto plant roots suspended inside the tower, can take up approximately 0.26m² of ground area and can hold 144 plants, which can be superior to the limited plant density capacity of hydroponic installations in some scenarios. Horizontal density cap for lettuce in hydroponic installations is approximately 24 plants per 1m², therefore, following the lettuce example in an aeroponic tower, the tower offers 6m² worth of cultivation area (144 plants / 24 plants/m²) over ground area that is less than the offered cultivation area.

Other examples of aeroponic systems utilizing architectural benefits were disclosed in CN209788090U, CN214413764U, CN209749389U, CN209950054U and EP3692784A1, however, these systems have the major limitation of the pressure-based irrigation, which renders them unusable in a real-world CEA environment, such as commercial greenhouses, due to limitations discussed in this disclosure below.

Furthermore, aeroponic irrigation can enable irrigation intensity manipulation, which further improves productivity. Hydroponically grown plants, such as the plants floating in nutrient solution pools throughout their lifecycle, are exposed to a constant, high irrigation intensity. Irrigation intensity, in an ideal scenario, is adapted to such factors as the plant's age or the plant's actual photosynthetic rate, which is derived from such environmental factors as lighting and temperature. Aeroponic irrigation enables adaptive irrigation by, for example, manipulating flow rates of dispersed aerosol.

Despite the benefits, aeroponic irrigation is notoriously difficult to implement at commercial scale. Limitations of aeroponic systems have been discussed in U.S. Pat. Nos US.9,474,217, 4,514,930; US 6,807,770; US 8,225,549 and many others. Aerosol production in aeroponic irrigation scenarios is mostly achieved by utilizing fixed-orifice nozzles connected to high-pressure pumps (can be 10 bar and more) via pipes or hoses or tubes or similar. High pressure pumping in aeroponic irrigation is defined as 4 bar and more. The increased pressure forces the nutrient solution through the miniature orifices in nozzles, which break the stream up into droplets between 20µm and 100µm in diameter. Because the nutrient solution contains salts, those salts either precipitate and clog the nozzles internally, or obstruct the orifices externally due to calcification, resulting in wilting crops. Clogging is more prevalent where nutrient solution is recirculated after it has been sprayed, because the re-captured nutrient solution contains plant debris and other solid objects. Furthermore, clogging is more prevalent in locations where water contains higher levels of salts and scale. Once nozzles become clogged, it is difficult to detect the clog before crops start wilting, especially if there are hundreds or thousands of nozzles deployed in the facility. Replacing or cleaning the nozzles requires depressurizing the system, physically removing the nozzle, cleaning it or replacing it with a new or a used cleaned nozzle and re-pressurizing the system, as disclosed in EP2858477B1, which can cause system downtime and further wilting, and requires intensive labor and quick reaction time. If solid objects get into the nutrient solution reservoir, said objects cause clogs in more than one nozzle. Clogging occurs because solid objects can block the tiny orifices, often under 0.2 millimeters in diameter, which are required to achieve the desired droplet variable mean diameters, which are between 20µm and 100µm, and up to 200µm. To reduce the problem of clogging, some systems utilize nozzles with wider orifices, which result in larger droplets of over 100µm in diameter, which results in suboptimal irrigation and oxygenation. Furthermore, the EP2858477B1 discloses a mobile aeroponic system that utilizes a high-pressure pump along with compressed air along with nozzles designed to work with pressurized aqueous solution and pressurized air (1/4J Air Atomizing Nozzles, Spraying Systems Co.,

available at www.spray.com). While it may or may not reduce the instances of clogging and blockage, the extra compressed air will result in a positive pressure problem, wherein air forced into the enclosed root space will increase pressure inside said root space and force aerosol droplets to escape into the CEA facility and will be inhaled by workers in the facility to the detriment of their health and safety.

Another drawback of previously disclosed systems is constant failures of high-pressure pumps. To address pump failure, for example, US2017/0202163A1 discloses a high-pressure aeroponic irrigation system with a backup system wherein mains water (2 bar pressure) may replace the failed high-pressure pumping system, claiming to provide near-permanent backup irrigation. The disclosure fails to account for a simple fact that mains tap, if seldom used, will collect limescale, and if switched on, will release limescale into the system and cause an immediate and complete clog of all nozzles associated with the pressure line. Operationally, aeroponic irrigation is difficult, because of the high-level of personnel engagement required – pump maintenance, filter replacement, nozzle cleaning and replacements result in high labor costs, which rarely outweigh the benefits.

To overcome pressure-pumping complexities, other methods of aerosol production may be considered as those disclosed in US 2009/200392, WO2018011501A1, CN105499048A, JP H04 265172A, US201717362, JPS61227866A, WO 2017/134472, WO2022/153058. US 2009/200392 discloses an ultrasonic nozzle device wherein ultrasonic vibration is used to vibrate a tip of a nozzle, allowing the creation of aerosol with no additional pressure. A drawback of this system is extremely low flowrate (para 0211, also claim 20) of 0.5g/min to 10g/min with no ability to go upwards due to narrow internal channel chokepoint (para 0200, also fig. 10 ref. 160b). WO2018011501A1 discloses a device for atomizing a solution wherein an ultrasonic nozzle is used for atomization. According to the disclosure (claim 17), the flow rate of atomized liquid is between 5ml/min to 30ml/min, meaning that the highest atomization rate possible is 1.8 liters of solution per hour, which is far below the volume of nutrient solution required in large-scale commercial irrigation. JP H04 265172A discloses an ultrasonic nozzle that electrostatically charges the sprayed particles. Such an apparatus is counter-productive in large-scale commercial agriculture applications due to the high-risk associated with the high-voltage electrostatic charge means, as well as the specialist knowledge required to maintain such equipment that is not available among greenhouse staff, moreover, the apparatus does not disclose a flow-rate of the device. CN105499048A discloses an air-assisted ultrasonic nozzle that requires external airflow to perform the spray function. The liquid flow rate is also not disclosed, but considering the metallic film at the ejection point (fig. 5, ref. 3) is 0.2-0.5 millimeters thick, the liquid inlet channel (fig. 5, ref. 21) is under 1 millimeter in diameter, therefore the possible flow rate is unsuitable for effective irrigation at commercial scale. Moreover, the required airflow will cause positive pressure issues inside the grow-box resulting in worker safety issues. US2017173621 discloses an ultrasonic-rotary nozzle that rotates within its housing to assist with aerosol dispersal. The disclosure does not include information about the flowrate, however, based on the drawings of the submission the flow rate is very low as per other similar disclosures and therefore is unsuitable for commercial-scale irrigation. Moreover, the disclosure necessarily requires a complex casing with several rotating mechanisms, which can cause upkeep and maintenance issues in the high humidity environment, and will result in high maintenance and equipment costs. JPS61227866A discloses an ultrasonic liquid atomizer with replaceable tip heads, however the disclosure does not include the flow-rate capacity. The drawings indicate a very thin internal channel, which restricts liquid flow to a level that is unsuitable for large-scale commercial irrigation. In summary, the existing prior art is useful in scenarios where low liquid flowrates are required, and is not useful in large scale commercial agriculture irrigation in controlled environments such as

greenhouses or indoor farms. Due to flowrate and complexity limitations, no large-scale commercial irrigation platforms can effectively utilize such previously disclosed ultrasonic nozzles without specific modifications.

WO 2017/134472 discloses an A-frame plant cultivation system with a fog generator (fig. 2, ref. 23) at one end of the system, which is connected via pipes or similar infrastructure (fig. 2, ref. 24) to various points of the irrigation chamber in order to distribute aerosol with the assistance of airflow. The inventor discloses that the invention may be implemented by using inkjet printer printheads, specifically "Xaar" printheads, to produce aerosol for irrigation in an A-Frame platform in a CEA scenario. Printheads, however, do not eliminate the issue of clogging as fixed orifice nozzles are selectively activated using ultrasound, and therefore still have the chokepoint problem of solid objects not being able to exit the fixed orifice and therefore causing clogging. Another drawback of this system is that uniform distribution of droplets across different parts of the system is not possible due to droplet coalescence, which is further exacerbated by airflow over longer distances. Furthermore, as different parts of the system wherein roots protrude are not separated, interval control around discharge ports (fig. 7, ref. 36) is practically not possible. The no-pressure aerosol irrigation system used in WO2022/153058 relies on piezoceramic nebulizers (fig. 1, ref. 52) which vibrate the entire body of liquid and create a fine mist, usually in the 1μ - 10μ m range, which is suboptimal for preferred plant root development and growth. Upon closer examination of WO2022/153058 it appears that the system is in fact a hydroponic system where plant roots necessarily reach the liquid in the shuttle (fig. 1, ref. 12) due the distance between the plant displacement board and the liquid reservoir, and the transducers can only provide a secondary irrigation source which may or may not induce the development of new roots around the stem of the plant. An additional drawback of such irrigation system is high energy required to cause the fogging, which results in higher energy costs. Moreover, such transducers produce high levels of excess heat, wherein the excess heat is exchanged with the entire body of liquid, which also raises the temperature of the nutrient solution and results in suboptimal plant development. In addition, this means of fogging alters the pH of the nutrient solution, which causes suboptimal nutrition, stunted growth and requires additional management of the nutrient solution. Finally, such atomizers have high failure rates because membranes of such nebulizers get blocked by sedimentation, nutrient salts and plant debris, causing wilting and resulting in repair costs. CN112753560A discloses an aeroponic A-Frame with stationary 2.4mhz ultrasonic atomizers, which have the same limitations – inability to produce the required droplet diameter range, high energy usage, high failure rate, heating of the nutrient solution, pH changes of the nutrient solution - as described above.

To reduce the overall complexity of static irrigation systems, mobile sprayer systems have been designed to move between two points in a reciprocal manner while spraying plant roots at required intervals. Such systems cannot utilize previously disclosed ultrasonic sprayers due to the highly limited flow rates, because the travelling irrigator must have the ability to produce a high flow rate to irrigate hundreds or thousands of plants. A very large number of such transducers must be used, and the cost and complexity does not outweigh the potential benefits, therefore high-pressure pumping systems are used. These mobile high pressure sprayer systems have several advantages compared to static irrigation systems, such as lower number of nozzles, less pumping infrastructure, and potentially lower equipment cost. Because aeroponic irrigation is mostly done at intervals, for example, tomatoes having been grown with 3 seconds of spray time followed by 10 minutes of rest time (different plants require different intervals in different scenarios), mobile aeroponic sprayers can be configured to move at pre-set speeds to spray each tomato plant for 3

seconds and return 10 minutes later, which may significantly reduce the scale and complexity of infrastructure required. Such systems have been disclosed in US 2017/0202163, WO2019/222827, EP2858477B1, US4965962, CN210610597U, CN213187548U. While some of the complexity associated with static aeroponic irrigation is removed, these novel mobile systems have limitations. One persistent drawback is nozzle clogging. Nozzle obstruction due to calcification may or may not be reduced because nozzles on a mobile sprayer have significantly less rest time and liquid therefore has less time to dry out and create a deposit of salts atop the discharge orifice. Clogging, which happens due to solid objects obstructing the orifices of the nozzles, is not reduced or eliminated due to the underlying limitations of the tiny orifices required to produce the mist in the required droplet diameters. A necessary extension of the clogging problem is the onerous task of depressurizing the system to replace/clean the nozzle and re-pressurizing to inspect whether the problem has been resolved, as disclosed in the EP2858477B1.

An additional drawback with some of the previously disclosed mobile aeroponic irrigation systems is that they are not designed to take advantage of the architectural benefits of three-dimensional aeroponic irrigation. These systems are horizontally oriented and planar, such as the ones disclosed in 2017/0202163 and WO2019/222827, which limits the degree of plant density and ultimately the crop yield that can be achieved per unit measure (e.g., per square meter). Such a horizontally oriented system also creates a relatively large footprint. To overcome the density issue of horizontal systems, EP2858477B1 disclosed an A-frame system wherein a mobile irrigation system is used and wherein plants are placed in angled structures and are irrigated by a mobile pressure-based aeroponic system designed to irrigate angled plant-holding structures. A major limitation of this system is that the moving platform necessarily has a lighting fixture and air system attached to the mobile platform (claim 2, ref 400 and 550) which protrudes outside the A-Frame and takes up extra floor space. Furthermore, the steep angle, the light source-carrying carriage as well as the air duct make the system less useful in greenhouse installations wherein natural sunlight is used, and structures that block sunlight, such as the light and the air duct, are counter-productive. As such, EP2858477B1 is only useful in indoor facilities. Moreover, the system disclosed in EP2858477B1 is designed for cultivating small plants such as leafy greens, and is not compatible with larger commercial crops such as tomatoes, bell peppers, berries and others.

Another drawback with previously disclosed mobile aeroponic irrigation systems is that they lack variable irrigation intensity that allows plants to receive more or less nutrient solution in relation to the plant growth stage or actual photosynthetic rate. Adaptive irrigation in pressure-based systems wherein nozzles are used is not possible because nozzles have fixed orifices, as disclosed in 2017/0202163, WO2019/222827, EP2858477B1, US4965962, WO 2017/134472. Constant irrigation intensity will cause reduced plant productivity due to limited oxygen availability in the rhizosphere. Moreover, the constant irrigation and the resulting limited oxygen availability will cause hypoxia, which will result in stunted plant growth. Further, constant irrigation and the resulting limited oxygen availability will alter produce nutrient composition and taste profile (reference). Constant irrigation intensity may cause a plant response known as "watering stress", which results in bitterness and stunted growth (references). Irrigation intensity adjustment based on actual plant needs adds significant value to the produce. One row of plants in a commercial greenhouse can have younger plants at the beginning of the row and mature plants at the end of the row as per the typical workflow of the commercial greenhouse, therefore the volume of the dispersed aerosolized nutrient solution needs to increase or decrease as the moving irrigator moves between positions. Due to the fixed-orifice nozzles used, wherein an increase of flowrate necessarily results in higher pressure and therefore changes aerosol qualities, such as droplet velocity and droplet

diameter, flowrate manipulation is only possible to a small extent and necessarily has trade-offs in other required aerosol qualities, such as droplet diameter or droplet velocity. If a high-pressure fixed-orifice nozzle receives a significant increase in flowrate, droplet velocity will be so high that the droplet flow damages plant roots. If a high-pressure fixed-orifice nozzle receives a significant decrease in flowrate, the resulting droplets will become larger and suboptimal for irrigation, and also fall short of the intended destination due to increased weight. Fixed-orifice nozzles can potentially be replaced with adjustable-orifice nozzles, however manual adjustments of nozzle orifices on a moving aeroponic sprayer will prove impractical.

Another drawback with previously disclosed mobile aeroponic irrigation systems is that there is runoff to deal with. Due to the nature of static irrigation intensity, the system's spraying capacity will be calibrated to ensure that largest plants in the row will have sufficient irrigation, resulting in any smaller plants receiving more aerosol than is required to precisely coat the root surface of the plant. As a result, the aerosol that is not absorbed during the spray cycle will drip, run off and may be recirculated back to the nutrient solution supply source to be re-used, thereby necessarily requiring additional filtration infrastructure. Alternatively, the runoff nutrient solution may be drained to waste, resulting in water waste and fertilizer waste.

Another drawback with previously disclosed mobile aeroponic irrigation systems is that their operational capacity is necessarily tied to a high-pressure pump or a combination of a high-pressure pump and an air compressor, as seen in 2017/0202163, EP2858477B1 and US4965962. Should one component fail, the failure will impact all nozzles associated to that pressure infrastructure line, resulting in all crops in the cultivation line to either no longer receive irrigation, or to receive irrigation wherein aerosol does not have the required volume, droplet diameter and other required qualities. Previously disclosed systems may have backup pumps, which may or may not alleviate but not eliminate the underlying problem, and necessarily increases system complexity, maintenance costs and equipment costs.

If one mobile pressure-based aeroponic irrigation system is not sufficient for a long line, another one will be required resulting in separate high-pressure infrastructure installation to operate another mobile irrigator. If several rows need to be serviced, the cost and complexity associated to scalability will become problematic for the CEA facility operator.

A drawback of previously disclosed mobile aeroponic irrigation systems, which is non-obvious, is that the systems are designed to provide the entire cultivation platform, such as a frame to displace plants, a carriage engaged with said frame and an irrigation means engaged with said carriage. The non-obvious drawback is that the previously disclosed systems may not be universally used by CEA operators due to non-compatibility with plants or facility. Some plants may have architectural requirements that may not be suitable with the arrangement within the previously disclosed plant cultivation systems. EP2858477B1, for example, utilizes steep cultivation angles (figs. 1, 8, 15) designed to displace small plants with small root architectures (figs. 10b, 10d, 12). If a tomato, a bell pepper, a cannabis or a similar crop were to be displaced in said system, which will develop root systems several times larger than those of the intended crops, the travelling irrigator will destroy the roots and therefore not be suitable for cultivation. US 2017/0202163 discloses a complete system wherein the nozzles on the mobile carriage may be 5 to 60 centimeters from the plant displacement surface, which may not be suitable for such crops as tomatoes which may have a root length of 80 centimeters, or cannabis, which may have a root length of 154 centimeters, or other commercially relevant crops with large root systems. US 4,965,962 discloses a system

that necessarily requires a plant cultivation room shielded from sunlight (claim 1), which is not suitable for greenhouse exploitation.

Another non-obvious drawback with previously disclosed mobile aeroponic irrigation systems is that they necessarily have limited travel distances. Travel distances are a function of droplet diameters and flow rate. Correct droplet diameters, which are between 20 μ m and 100 μ m will induce root morphology changes wherein roots will develop the ability to capture and store droplets, thereby extending irrigation intervals, such as irrigation recipes wherein 1-3 seconds of spray are delivered once every 10-15 minutes. The advantageous recipe may enable the irrigator to travel for over 50 meters or more, thereby irrigating hundreds or thousands of plants, provided that the mobile irrigator delivers sufficient flowrate of between 30 liters per hour and 500 liters per hour, preferably adjustable. If the advantageous result is achieved, the irrigator can travel for more than 100 meters before it needs to return. For example, an A-Frame structure holding 50 lettuce plants over a running meter of the system will hold 5000 plants in a typical 100-meter row. If a mobile irrigator travels for 7 minutes to the end point while spraying, and then travels back for 3 minutes while returning to the starting point, it means that one running meter, or 50 plants, will receive 4.2 seconds of irrigation once every 10 minutes. For this advantageous interval to be sufficient, a droplet diameter of 20 μ m to 100 μ m may be required, preferably 50 μ m, depending on the crop. Assuming that a 50 μ m VMD can be achieved by a typical high pressure aeroponics nozzle, such as the TeeJet XR nozzle, an UDOR Low-Flow Nozzle, a Hypro Ultra Lo-Drift nozzle, AeroJet Aeroponic nozzles, that may atomize 0.5-5 liters per hour at the required droplet diameters. Depending on the environmental variables, such as environmental temperature, environmental humidity, root zone temperature, root zone humidity, plant age, root surface area and others, the 5000 lettuce plants will need 20 liters to 55 liters, or more, of spray per spray cycle. To atomize the 20 to 55 liters of spray using high pressure nozzles, a combined flowrate of the sprayer will need to be between 171 LPH to 471 LPH, resulting in hundreds of high-pressure nozzles required. Previously disclosed ultrasonic nozzles do not provide useful alternatives due to their highly restricted flowrates. By comparison, the apparatus in the present disclosure may comprise one or more ultrasonic nozzles, preferably 10 ultrasonic nozzles capable of producing aerosol at a rate of 1-50 LPH each, resulting in a combined flowrate of up to 500 LPH or more at the required droplet diameter, and therefore resolve all the obvious and non-obvious drawbacks of previous disclosures.

Alternative agricultural machines, such as mobile agrichemical sprayers disclosed in RU2645165C2, CN217771238U, CA3188090A1, WO2023043306A1, CN217308891U, US2012195496A1 are used for field agriculture. Such inventions are designed to spray outdoors, and therefore are not suitable for aeroponic irrigation in CEA applications. While not explicitly stated in the disclosures, such equipment is necessarily restricted in the droplet diameters because applications of agrichemicals by spray means outdoors is often regulated by drift regulations, worker protection standards or spray application exclusion zones in many jurisdictions because small droplets often miss the target application area and drift downwind to neighboring farms, residential areas or protected nature arrangements and negatively affect private or protected ecosystems and health of persons and animals. Equipment designed for outdoor applications therefore is intended and designed for applying droplets over 100 μ m in diameter. Moreover, the scale of outdoor agriculture compared with CEA scenarios is vastly higher, therefore equipment is designed to carry large sprayers, large containers of liquid and intended to cover large areas, which is not suitable for aeroponic irrigation and reciprocal travel in a protected root-zone. Furthermore, such equipment uses pressure sprayers and is not intended to spray nutrient solution at plant roots at relatively short distances.

It is an object of the present invention to overcome the disadvantages of prior art by combining a mobile irrigation system with ultrasonic irrigation means with high flow rates of up to 500 liters per hour.

SUMMARY OF THE INVENTION

The objective of the present invention is to solve the problems of previously disclosed ultrasonic irrigation nozzles means and previously disclosed mobile pressure-based aeroponic irrigation means. The present disclosure solves the problems of ultrasonic irrigation nozzle means, wherein prior art discloses ultrasonic irrigation nozzles with very low flow rates that may be under 2 liters per hour, which are unsuitable for large scale irrigation, wherein irrigation may require up to 50 liters per hour per ultrasonic nozzle, and have other drawbacks. Furthermore, the present invention solves the problems of mobile pressure-based aeroponic irrigation systems, wherein prior art disclosed pressure-based devices prone to clogging, operational failures, limited flowrates, limited application in relation to crop varieties and other issues that prevent universal large-scale irrigation in Controlled Environment Agriculture.

To solve the problems, the present invention provides a mobile ultrasonic aeroponic irrigation apparatus comprising one or more of the following:

1. A modular carriage intended to provide mounting points for any or all the below-mentioned components, wherein the carriage may be triangle-shaped, a rectangle, trapezoid or any other shape suitable to be used as a carriage,
2. An irrigation means, wherein at least one ultrasonic nozzle is used, said nozzle having a wide atomization channel of at least 1 millimeter, and up to 6 millimeters diameter, and an accordingly wide inlet diameter, with a tip that has a surface vibrating at least 10,000 times and up to 3 million times per second, and having an aqueous solution flow-rate of at least 1 liters per hour, and up to 50 liters per hour, further, wherein the ultrasonic nozzle is adapted to engage with a controller and programming, and is adapted to atomize the solution into preferred variable mean diameter droplets between 20 μ m and 200 μ m using ultrasonic oscillation, preferably between 20 μ m to 100 μ m,
3. A means of travel between two points at preferred variable speeds and intervals, comprising at least one mechanism for propelling the sprayer in a direction of travel, which may include wheels for independent travel, wheels for travel on rails, caterpillar tracks, linear motion guides, which enable reciprocal travel between two points inside or under a plant cultivation structure,
4. A means of controlling the apparatus, which may be a programmable controller, to control the irrigation parameters, such as flow-rates and variable mean diameters of droplets of each individual ultrasonic nozzle, increase or decrease travel speeds, to increase or decrease irrigation intensity based on plant's actual irrigation needs or pre-programmed logic, the means to communicate with external systems or persons and inform about operating status, predictive maintenance needs as well as optionally autonomously adapt irrigation strategies based on external data inputs, wherein the means of controlling the apparatus may be engaged with one or more of the electrically operated components of the apparatus, and wherein the means of controlling the apparatus may provide power for one or more of the electrically operated means,
5. A means for power transfer and communication, which may be a wired means for either or both power and communications, or which may be a battery or a supercapacitor for power storage, and wireless means for communications, wherein the means are operatively engaged with the means of controlling the apparatus,

6. A means of transferring an aqueous solution from a solution intake point to one or more ultrasonic nozzles, wherein the means may include a low pressure pump with a flow rate between 1 and 500 liters per hour, and the means for aqueous solution intake may be a port, or an opening or a connection point for solution operatively engaged with the said solution distribution means, and the means of connecting the ultrasonic nozzles or ultrasonic nozzle casings to the solution distribution means may be pipes or hoses or any other means that are appropriate, wherein said solution distribution means are engaged with the means of controlling the apparatus,
7. A means of providing additional airflow, wherein the means may include a centrally mounted fan operatively engaged with ultrasonic nozzle casings, wherein said casings may provide outlet points, or wherein the means of providing additional airflow may be separate fans, wherein additional airflow means may be operatively engaged with the controller.

The adaptation of the ultrasonic nozzle to atomize a volume of liquid to a level that is required in large-scale commercial irrigation by increasing the diameters of flow channels and adapting oscillation, and furthermore the adaptation of said atomizer to operate with such features as self-cleaning, adjustable flow-rate and droplet mean diameter manipulation in the field of ultrasonic engineering, as well as the adaptation of a mobile sprayer to operate independently from pressure-pumping infrastructure in the field of agricultural engineering, and realizing non-obvious synergies of the elimination of clogging, universal applicability to different plants and different aeroponic infrastructure, the elimination of pressure nozzle replacement procedures, elimination of restricted and static flow-rates of both pressure-based and ultrasonic irrigation means in prior art, in combination, constitute significant inventive steps. The invention further provides new, previously unavailable features such as individual ultrasonic nozzle-level configuration of irrigation parameters, unlimited scalability due to plug-and-play capability, enables pre-programmed and autonomous logic implementations surrounding preferred irrigation strategy changes based on live factors, and enables remote upgrades, updates, other improvements, and enables digital irrigation strategies creation, sharing and implementation and any scale.

The body of research surrounding aeroponic irrigation focuses almost exclusively on either one of the factors, such as the effect of the variable mean droplet diameter, or the effect of spray intervals. The research surrounding aeroponic irrigation rarely acknowledges that the process is less to do with either one effect, but rather a combination of factors that in effect aim to precisely coat an organic, ever-changing surface with aerosol so that the aerosol may adhere to the entirety of the available surface, and when done correctly, induces specific root morphology expressions, such as root hair development, which further changes the available surface. Intervals are related to the available surface and the plant's ability to adsorb the coating over a specific period of time, so that there is also sufficient time for oxygenation before re-spraying. Furthermore, as the photosynthetic rate fluctuates during periods, for example day and night, intervals may need to adapt not only to the photosynthetic rate, but also to the root surface that is available at that stage of the plant's cycle. Moreover, droplet diameters may also need to differ during day and night, for example, when larger droplets may be required to wash the roots that may be covered in exudates in order to avoid exudate interaction with nutrient solution ions, which may affect the effectiveness of aerosol adherence to the surface. Therefore, dynamic aeroponic irrigation practices, which are enabled by the disclosed apparatus, wherein irrigation variables may change based on real-time data observations are far superior to static irrigation practices that are available by using pressure-based aeroponic techniques, or those techniques that are available by using ultrasonic nebulizers that vibrate the body of water to produce aerosol.

The field of aeroponics has seen many previous disclosures over the recent years, the vast majority of which have been related to pressure-based aeroponic irrigation systems. Advantageously, some of those systems are designed to move reciprocally in order to eliminate static systems and the drawbacks thereof. Some of the previously disclosed systems rely on ultrasonic nebulizers, such as those that operate by vibrating the entire body of liquid to create droplets in the fine mist range, which are not be beneficial to the plants. Very few previously disclosed inventions have disclosed ultrasonic nozzles suitable to work in aeroponic environments, because the previous disclosures are highly restricted in flow rates and other required qualities, wherein the combination of any previous disclosure with a mobile irrigation platform may require tens or hundreds or more of said nozzles to meet the flow rates required for commercial scale irrigation in controlled environment agriculture. Moreover, all of the previously disclosed mobile aeroponic irrigators are necessarily engaged with a specific cultivation platform as disclosed in the disclosure, which may or may not be suitable to any operator who may already have a cultivation platform in place that may be retrofitted. It is non-obvious that ultrasonic nozzles, adapted to atomize a high volume of liquid, such as up to 50 liters per hour per ultrasonic nozzle, wherein said ultrasonic nozzle is mounted on a reciprocally travelling carriage, wherein the combined apparatus is intended to integrate with an existing aeroponic installation, may solve many or all of the problems of previously disclosed pressure-based mobile irrigators, as well as the problems of previously disclosed ultrasonic nozzles with highly restricted flow rates. Below is a list of non-obvious advantages discovered during the development and testing of the disclosed apparatus.

The disclosed apparatus is a mobile irrigation apparatus that is intended to work with a variety of different irrigation platforms and crops, rather than an entire cultivation system that may or may not work with a variety of systems and crops. Furthermore, the apparatus shape/form is intended to be adjustable to engage with any elongated aeroponic irrigation system of commercial scale, therefore the apparatus may work with existing infrastructure, such as existing A-Frames, rolling benches, tables and other infrastructure and may lower the upfront costs for the facility operator.

The disclosed apparatus advantageously enables different irrigation rates (flow rates) in any of the ultrasonic nozzles operatively engaged with the apparatus, therefore the apparatus enables the cultivation of different crops that have different irrigation needs at the same time.

The disclosed apparatus utilizes uncloggable ultrasonic nozzles and requires no high-pressure pumping or similar high-pressure-based infrastructure to produce aerosol. Furthermore, the spray means of the disclosed apparatus are electronically operated, which enables immediate detection of any failures. Moreover, because no high-pressure or similar pumping infrastructure is required, the disclosed apparatus has no high-risk central point of failure and may adjust the operating capacity of remaining operating ultrasonic nozzles if one or more ultrasonic nozzles fail in order to compensate for the reduced flowrate.

The disclosed apparatus may operate a number of nozzles which may suffer operational failures due to mechanical damage or other reasons. Advantageously, the ultrasonic nozzles use electrical signals to produce aerosol. Beneficially, the ultrasonic nozzle casing is designed to enable very quick removal and insertion of an ultrasonic nozzle. Once inserted, the ultrasonic nozzle is immediately detected by the controller via wires inside the casing of the ultrasonic nozzle, or other means, which are connected to said controller. Because the spray means do not require high pressure to produce aerosol, and because the ultrasonic nozzle can be removed and inserted into its casing very quickly, failed ultrasonic nozzle replacement, or ultrasonic nozzle upgrades, or any other such procedures are very fast and can be

performed in a matter of minutes even by unskilled persons. This aspect of the present disclosure eliminates the drawback of pressure-based systems wherein nozzle replacements require system de-pressurization and re-pressurization.

The disclosed apparatus may operate the spray means at near-constant interval, which reduces the calibration times, energy loss and other losses that occur when such stationary ultrasonic nozzles are used at intervals, which lowers power consumption and increases the lifetime of the components.

The disclosed apparatus utilizes a spray means that enables required droplet diameters of 20μ - 100μ m production at very high flow rates of up to 50 LPH, which enables very long travel distances of the apparatus before having to return to the starting point for the next spray intervals. Considering the daily watering needs of leafy greens varieties throughout their lifecycles, the combination of droplet diameters and the available flow rates, the combination of these advantageous factors may enable a single apparatus with 10 ultrasonic nozzles to travel 70 meters or more before having to return to the starting point. In an A-Frame shaped irrigation platform holding 50 lettuce plants per 1 running meter of said row, a single apparatus may provide sufficient irrigation for up to 6300 kg of gross lettuce yield or more per 70 meter row per year (assuming lettuce target weight of 150 grams and assuming 12 crop cycles per year, and calculated as follows: 70 meter row * 50 plants per one running meter of row * 12 crop cycles * 0.15 kilograms).

The disclosed apparatus can also enable easy installation and scalability due to the plug-and-play capability. As such, starting a new CEA project will be significantly faster compared to pressure-based mobile systems installation. Moreover, in a scenario where the CEA facility operator decides to increase or decrease the operating scale, more than one apparatus can be added or removed without the necessity to install or uninstall high-pressure-pumping infrastructure.

The disclosed apparatus can exert control over functions such as variable mean droplet diameter selection, flowrate, wherein irrigation intervals can be controlled on ultrasonic nozzle-level, meaning that each individual ultrasonic nozzle may operate at different settings. Those settings may be changed remotely or may follow a pre-programmed logic. Furthermore, connectivity to external systems enables control by an external system, such as a system with advanced cognitive capabilities, such as an artificial intelligence system, that may consider data from other greenhouse systems such as temperature systems, weather forecasts, new scientific learnings, and implement new beneficial settings at extraordinary speeds. Furthermore, developers of the disclosed apparatus may provide their clients with software and firmware upgrades, such as those improving energy or water usage, or such as those enabling or improving predictive maintenance of the apparatus, or those related to learnings derived from plant research that enable extra yields and productivity, thereby continuing to increase the operational and technological value of the apparatus past its initial installation. The combination of these factors, which enable smart capabilities solve many of the drawbacks of previously disclosed devices, and enable new, previously unavailable functionality.

BRIEF DESCRIPTION OF DRAWINGS

Figure 1. Mobile aeroponic irrigation apparatus with a triangular carriage.

Figure 2. Various shapes of carriage and non-restrictive implementations of the apparatus.

Figure 3. The apparatus engaged with a triangular cultivation structure.

Figure 4. The apparatus engaged with a rectangular cultivation structure.

Figure 5. Angle adjustability of the top angle of a triangular carriage of the apparatus.

Figure 6. Mobile aeroponic irrigation apparatus with a rectangular carriage, wherein the width is higher than the height.

Figure 7. Mobile aeroponic irrigation apparatus with a rectangular carriage, wherein the height is higher than the width.

Figure 8. Ultrasonic nozzle.

Figure 9. Electronic management unit connectivity with components of the apparatus.

Figure 10. Ultrasonic nozzle inside a casing, wherein front mass is designed to work with replaceable tips.

Figure 11. Ultrasonic nozzle, wherein different spray patterns are displayed.

Figure 12. Cross-section of the ultrasonic nozzle inside a casing.

Figure 13. Casing mounting implementation wherein a ball joint is used.

Figure 14. Two cross sections of ultrasonic nozzles in casings, wherein one casing is designed to engage with an external airflow source, and wherein one casing is engaged with an airflow means wherein the airflow means is a fan.

Figure 15. A potential engagement of the apparatus with a plant cultivation structure, wherein the means of travel is a travel system mounted outside the plant cultivation structure, and wherein the means of travel is engaged with the apparatus.

Figure 16. A potential arrangement wherein more than one apparatus is engaged with the same travel means.

Figure 17A. Front view cross section of the first exemplary embodiment, wherein the embodiment is engaged with a plant cultivation structure.

Figure 17B. Side view cross section of the first exemplary embodiment, wherein the embodiment is engaged with a plant cultivation structure.

Figure 18A. Front view cross section of the second exemplary embodiment, wherein the embodiment is engaged with a plant cultivation structure.

Figure 18B. Side view cross section of the second exemplary embodiment, wherein the embodiment is engaged with a plant cultivation structure.

Figure 19. Front view cross section of the third exemplary embodiment, wherein the embodiment is engaged with a plant cultivation structure.

Figure 20. Top view of the fourth exemplary embodiment, wherein the embodiment is engaged with a plant cultivation structure.

DETAILED DESCRIPTION

THE CARRIAGE

A means for holding any or all the components of the disclosed apparatus is a carriage (Fig 1., ref 1). The carriage (1) is intended for mounting any components, including the irrigation means (8), the mobility means (3), the control and monitoring means (18) and other means. The carriage may be made of lightweight materials that are corrosion-resistant, preferably aluminum or steel. The carriage may also be made of any lightweight, durable inert composites or plastics. The carriage may be in the shape of a triangle (A-Shaped) (Fig 2. 1A) with the top angle between 30° and 80°, a trapezoid (1D), a rectangle (1B, 1C) or any other structure that may align with the plant-suspending surface (Figs. 3, 4). The height or the width of the carriage may be so that it fits inside or under the plant irrigation structure such as a row, an A-Frame, a vertical wall, a grow-table, a gutter system or any other cultivation platform in such a way that enables reciprocal travel between two points while providing sufficient aeroponic irrigation at preferred intervals. The carriage may be such that it provides a distance between the nozzle and the plant-suspending surface of between 10 centimeters to 200 centimeters, preferably 30 centimeters. The carriage may be between 10 centimeters and 300 centimeters in width, preferably 100 centimeters in width. The carriage may be between 20 centimeters and 300 centimeters in height, preferably 100 centimeters in height. The carriage may be between 30 centimeters and 200 centimeters in length, preferably 40 centimeters in length. The carriage may have additional bars mounted on it to provide mounting surfaces for additional components.

Furthermore, the carriage advantageously may include manually adjustable structure angles (Fig 5.). Angles may be adjusted by loosening bolts (6), adjusting the preferred angle and tightening the bolts again (7), or any other appropriate mechanism. Angle adjustment may be beneficial for compatibility with different plants, for example, an A-Shaped mobile aeroponic irrigation system wherein an A-shaped plant-holding platform may be used for cultivating different crops throughout the year. In such an example, baby leaf lettuce may be grown for one or more cycles, and large head lettuce may be grown for one or more cycles, but not at the same time. The same A-shaped apparatus system can perform the task of irrigation, however adjustments of the top carriage angle may be required (Fig 5., refs. 6, 7) when switching to a different crop, because baby leaf lettuce develop smaller roots compared to head lettuce. The apparatus may therefore have a different top angle in order to provide more distance between the boards or other structures wherein the plants are displaced and the mobile carriage itself in order to avoid any root damage as the carriage travels. Furthermore, advantageously, adjustments of all angles may be made to accommodate two varieties of crops on two different sides of the A-shaped cultivation platform at the same time in a scenario wherein root architectures are different.

It is further advantageous to adjust the various angles and therefore the size and shape of the carriage of the apparatus in other scenarios, such as tomato cultivation. Over their crop cycle, tomatoes develop very long roots. It is therefore advantageous to irrigate tomatoes from the bottom rather than the side in regard to the plant displacement board or structure early in the crop cycle when roots are shorter (fig. 6), and in later stages when roots are longer it may be beneficial to irrigate the roots from the side (fig. 7) rather than the bottom avoid root damage. Advantageously, the ability to adjust the size and shape of carriage of the apparatus may eliminate the need to make adjustments to the plant cultivation platform or cultivation structure throughout crop cycles, or when switching between crops.

IRRIGATION MEANS

The irrigation means may be one or more ultrasonic aerogenic nozzles (Fig. 8, ref. 8) adapted to provide a flowrate, which is several times higher than previous disclosures, and has also been adapted to engage with the on-board means to control the device to provide beneficial features of flowrate management, individual nozzle settings adjustment, self-cleaning and other as listed below. The nozzle may be made of titanium parts or other appropriate materials. According to the present invention, the ultrasonic nozzle comprises a wide atomization channel of at least 1 millimeter in diameter (9) that has a tip (10) with a vibrating surface of 10,000 times to 3 million times per second and atomizes solution flow into droplets and prevents sedimentation, and a wide solution inlet of at least 1 millimeter in diameter (11). The internal channel (12) diameter of the nozzle may be between 1 millimeter and 6 millimeters. The flow rates of solution for atomization in the nozzle may be between 1 liter per hour to 50 liters per hour. These features in combination allow to eliminate any possibility of clogging arising from undissolved agrichemical solution particles or plant debris during agrichemical solution recycling, as well as external sedimentation or calcification-caused obstruction/blocking due to the intense vibration. Furthermore, the nozzle inlet is capable of transferring a variable flow of solution, and atomizing said variable solution flow, resulting in variable irrigation intensity, thereby resolving the drawbacks of previous disclosures wherein solution flows are highly restricted. The vibration and ultrasonic waves provide droplets with initial inertia for aerosol travel without additional airflow. The nozzle comprises a back mass (13), two or more piezoceramic units (14) with electrodes (15), a front mass with a tip (16), and a bolt to bind components together (17). Solution flow in the present invention is atomized into droplets of 20 to 200 μ m, preferably into droplets of 20 μ m to 100 μ m in variable mean diameter. The nozzle is connected to a controller means (fig. 9, ref. 18) via physical connectors (19) that are also connected to the electrodes (Fig. 8, ref. 15) which may be placed between nozzle parts including front mass (16), back mass (13) and piezoceramic units (14). The controller means (Fig. 9, ref. 18) controls the operating parameters of each nozzle connected to said controller. The nozzle (Fig. 8, ref. 8) may have a front mass (Fig. 10, ref. 16A) that is designed to work with replaceable tips (17A, 17B) that may be detached from the front mass (16A) (Fig. 10). Different shapes of tips (Fig. 11, ref. 17A, 17B) can be used to help manage aerosol dispersal shape, dispersal distance, droplet diameter and other operationally relevant parameters. Advantageously, because the nozzles may be operated near-constantly, ultrasonic calibration, which may take place between the time when a cold nozzle (Fig. 1, ref. 8) is switched on and the time the nozzle reaches its operating temperature, may be highly reduced or eliminated compared to static nozzles operating at intervals. Moreover, temperature-related expansion and contraction of the front mass (Fig. 8, ref. 16), back mass (13) of the nozzle (Fig. 1, ref. 8) may create increased degradation of the piezoceramic units (Fig. 8, ref. 14), which may shorten their useful lifetime, therefore, a mobile system operating the nozzles at near-constant rate may be superior to a static ultrasonic system operating the nozzles at intervals in that respect.

NOZZLES MOUNTING MEANS

Nozzles may be mounted on the carriage (Fig. 1, ref. 1) using casings (20) designed to be attached onto the carriage to maintain a fixed position, and to provide a stable waterproof housing for the nozzle (8). The casing provides a secure and waterproof connection between nozzle electrodes and wires connected to the controller means (18). The casing (20) provides a tight connection between the nozzle inlet (Fig. 12, ref. 11) and the solution supply means (Figs. 2 & 6, ref. 23). The fixed mounting position and the stable housing for the nozzle may be joined by a joint, such as a ball joint (fig. 13, ref. 24), a Stewart platform or another mechanism that provides tilting and aiming ability. Fixed nozzle (8) position may be adjusted in any direction on the carriage (Fig. 1, ref. 1) by releasing the tension of a bolt (fig. 12, 25) or another mechanism that is built-in to provide the stable mounting position on the carriage (Fig. 1, ref. 1), then moving the casing (20) to a desired position on the carriage (1) and increasing the tension again to maintain a fixed position of the nozzle casing (20). Advantageously, the joints in between the fixed position latch and the stable nozzle holder may be tilted to any direction by at least 30 degrees from the central point (fig. 13). The tilt may be done manually, or may be motor-assisted by the use of a Stewart platform. Beneficially, motor-actuated tilting of the nozzle (8) may be done while the carriage (Fig. 1, ref. 1) is moving between two points in order to adjust to the plants if, for example, younger plants are displaced in the beginning of the row and older plants are displaced in the end of the row. The holders include O-rings (fig. 12, ref. 22) to seal electrical connections between the electrodes (15) on the nozzle (8) and the electrodes (26) in the nozzle stable housing (20), and between the solution inlet (11) and electrodes (15, 26). Beneficially, in case of nozzle (8) failure, the housing (20) enables easy replacement of the nozzle (8) even while the apparatus is in operation, which also advantageously solves the drawback of pressure-based systems of having to stop the operation, depressurize any lines, replace/clean the nozzles and repressurize the lines to check if the issue has been resolved.

In case the nozzle (Fig. 8, ref. 8) creates excess heat, constant high solution flow, such as the nutrient solution flowing at the high flowrate, such as 1-50 liters per hour per nozzle (8) internal channel (12) in the front mass (16), which is possible due to the wide internal channels (12) of the nozzle (8), provides cooling effect due to temperature exchange with the solution. Because the nutrient solution is often cooled in CEA scenarios to be several degrees lower than the ambient facility temperature, it may provide a significant cooling effect. In a scenario where additional cooling is required, the nozzles (8) may have extra channels in or around the front mass, such as inlets being drilled from the bottom of the nozzle front mass to the top of the nozzle front mass, to provide more surface area for heat transfer to the solution. Advantageously, as the solution flow is nebulized into tiny droplets, the droplets effectively exchange their temperatures with the environment due to the increased surface area of the solution as they travel between the nozzle and the plant root surface, therefore not causing any heat stress to the plant root. Furthermore, the nozzles may advantageously be cooled by air flow, such as direct air flow delivered by the air flow system (Fig. 1, ref. 27) that may be advantageously mounted on the carriage (1) and which may also be engaged to provide directional air from the nozzle casing outlets (fig. 14, ref. 30) flow to affect aerosol flow dynamics including speed, travel distance and others, thereby creating the benefits of cooling and aerosol management with the same means. Furthermore, directional air flow may be achieved by a centrally mounted fan (Fig. 1, ref. 27) wherein airflow is directed to the nozzles via tubes or similar means and may be engaged with nozzle casings (20), wherein said casings may be configured to provide inlet (Fig. 14, ref. 29) and outlet points (30) for said additional airflow. Moreover, separate fans (31) may be mounted on nozzle casing (31), or any other way that is beneficial. It is an important advantage to utilize the air

inside the root zone without the introduction of air from outside the root zone. When air is introduced into the root zone from outside the root zone, it may carry pathogens, and importantly, it may cause positive pressure inside the root zone, which may in turn force aerosol to escape the root zone and result in worker inhalation of nutrient solution or any other chemicals used in the system.

MOBILITY AND CONNECTIVITY

The apparatus is designed to move between two points. The apparatus may move in a reciprocal manner at preferred intervals and preferred speed. The apparatus may move in an endless loop (fig. 20). The travel speed and travel intervals may be adjustable. The mobility means of the apparatus may be self-propelled through the use of a motor (fig. 9, ref. 32), such as a stepper motor or a servo motor, with or without a gearing system, or may be engaged with a belt (fig. 3, ref. 33), a wire or a cable, or a combination of these or any other means to propel the apparatus at adjustable speed towards any direction on its intended travel path, or to stop the apparatus and maintain said apparatus in place. The travel speed of the apparatus may be between 0.1 meter per second and 10 meters per second. Optionally, a stepper motor or a servo motor may provide for a means to calculate the exact position of the apparatus through the use of an encoder. The disclosed apparatus may travel by engaging with the ground through wheels (34), which may be rubber, plastic or metal wheels with rubber tires, or any other combination of appropriate materials. Said wheels (34) or may be engaged with a rail (35), which may be a guided rail, or a number of rails, wherein the wheels may be metal or plastic or rubber wheels designed to engage with said rails. Wheels may or may not be flanged. Wherein the apparatus is self-propelled, the wheels may be operatively engaged with a motor through gears or other means. The apparatus may also use a caterpillar (fig. 4, ref. 36) system to engage with the ground.

A travel path start-point and end-point detection devices, which may be induction sensors, may be engaged with the apparatus, and may be configured to engage with start-point and end-point markers, which may be any markers appropriate for engagement with said detection devices, and which may be displaced and preferred start point and end point of the preferred travel path. The apparatus may also be pulled or pushed by an external system (fig. 15, ref. 37), such as a system with ropes, wires or cables, a belt, or a combination thereof, and pulleys designed to move the mobile system. Such wires or cables or other physical mobility connectors may be also used to transfer the power, communications and the nutrient solution to the disclosed apparatus. Moreover, linear bearings may be used wherein faster travel speeds may be required, which is especially beneficial for longer distances such as those that may be required in commercial greenhouses. In an arrangement where several rows require irrigation, several mobile irrigation units may be engaged with a combined mobility system (Fig. 16), wherein a boom (38) may be engaged with the apparatus to provide mobility, solution and power, and wherein the mobility means may comprise a motor engaged with a rail so as to provide mobility (39), and wherein the boom may comprise wheels (34), and said wheels may engage with rails (35), or any other appropriate travel means.

Wherein the apparatus is self-propelled, an external power source (fig. 17B, ref. 53) may be used to power the apparatus, and wherein said external power source may be engaged with the by a power cable (ref. 51), which may be engaged with a self-reeling drum (49) fitted on the apparatus. Alternatively, a battery fitted to the carriage inside a waterproof casing may be used to power the propellant system, wherein the battery may be the main power source, further, wherein the battery may be a backup power source. Alternatively, supercapacitors may be used, which are beneficial due to their fast charging time.

CONTROL AND MONITORING

A means of controlling and monitoring apparatus, such as an electronic management unit (EMU) (Fig. 9, ref. 18), which may be a programmable controller, may be attached to the carriage (1), or may be mounted outside a cultivation platform and connected to the moving apparatus through cables or wires. The EMU may be inside a waterproof casing. The EMU may be connected to at least one component of the apparatus via wires or other physical connectors (19). The EMU may be programmable to control at least one or more of the following, including travel speeds, irrigation intervals, solution flow rates, air flow rates, droplet diameters or other operating variables (Fig. 11). Advantageously, the EMU may detect failures of any individual nozzles and inform the required systems or persons about said failure through wired or wireless communications. The EMU may contain ultrasonic drivers to power associated nozzles. The EMU may adjust the atomization rate of at least one nozzle by adjusting power, oscillation, solution flow to the nozzle or other relevant operating parameters. Moreover, highly beneficially, in case of a single nozzle failure, the EMU may be programmed to change the aerosol flow rate of other nozzles operating on the apparatus in order to compensate for the loss of flow rate from the failed nozzle. In addition, the EMU may also adjust nozzle direction by controlling the motor-assisted aiming system and airflow to ensure plants do not wilt until the operator has replaced the affected nozzle. Advantageously, any number of contingencies and predictive maintenance scenarios can be programmed into the EMU, thereby resolving the drawbacks of system maintenance, fixed orifice nozzle-clogging and related wilting, adjustable flow rate and other disadvantages of previously disclosed systems.

The EMU may optionally be used for real-time scanning of nozzle (Fig. 1, ref. 8) acoustic profile to detect new tip shapes (17A, 17B) and autonomously adjust the resonance frequency based on the changed acoustic profile enabling autonomous optimal solution atomization with different tip shapes without manual firmware and software reconfiguration. The EMU may scan in real-time nozzle resonance frequency and phase shift, which may enable performance tracking, physical degradation tracking and data flows collection required for predictive maintenance and self-cleaning. The EMU may have a wired and/or wireless connectivity to on-site or remote physical or digital control or management tools. The EMU may have a pre-built contingency management logic for operating in low energy mode in power grid failure scenarios when running on backup power infrastructure). Wherein the EMU is engaged with a primary power source, and wherein a secondary power source is made available by, for example, greenhouse infrastructure or a battery fitted to the apparatus, and wherein the EMU detects an interruption of the primary power supply, the EMU may switch to backup power. Moreover, the EMU may be programmed to implement at least one contingency logic to reduce power usage, for example, by disabling optional or ancillary functions, spacing out spray intervals, reducing flow rate, or implementing any such logic that is appropriate or required. This is especially important in indoor farms or greenhouses utilizing aerosol irrigation, wherein the interruption to power and the resulting interruption to irrigation will rapidly cause wilting and death of plants. The disclosed apparatus does not require high pressure infrastructure and may autonomously change dispersal intervals to keep the plants alive by working with limited backup power infrastructure.

The real-time scanning of nozzle resonance frequency and phase shift enables autocalibration and optimal operating performance of nozzles, therefore manufactured nozzles may not need to be precisely tuned. This is important because the scanning of the nozzle enables the utilization of nozzle parts manufactured by different suppliers who may use different manufacturing techniques and quality standards. Furthermore, the nozzle's performance depends on the ability to precisely reach peak vibration at tip (Fig.

8, ref. 10) – in real world scenarios this may be impacted by wear, operator damage or any other mechanical changes to the nozzle front mass (Fig. 10, refs. 16, 16A) or tip (fig. 8, ref. 10, fig. 10, refs. 17A, 17B). The novelty and importance of the self-scanning ability of the nozzle in the EMU may enables self-optimization wherein the EMU is able to repeatedly scan the nozzle and autonomously alter the signal thereby adjusting performance to continuously deliver results regardless of operational wear or structural damage. By utilizing the nozzle-scanning ability, for example, by generating a first acoustic profile of the nozzle wherein the profile corresponds with optimal operating parameters, and wherein throughout operation secondary profiles are generated to compare against the first profile, and further wherein deviations of secondary profiles from primary profiles are tracked and evaluated, the EMU may detect plaque, limescale, biofilm or other solid particle formation on the nozzle surface enabling fast autonomous self-clearing programs, wherein peak vibration is delivered at increased power and amplitude, resulting in increased oscillation. Furthermore, beneficially, liquid flow may be autonomously switched off for the period of increased oscillation. Advantageously, a library of deviations between primary and secondary profiles may be generated for diagnostic purposes and predictive maintenance recommendations. Moreover, the self-scanning ability may identify wear, mechanical damage and other factors that may affect the operating capacity of the ultrasonic nozzle.

Advantageously, the EMU may be operatively engaged with any or all carriage-mounted or externally mounted sensors, including light sensors, temperature sensors, three-dimensional space scanners and other sensors, in order to make decisions based on pre-programmed logic to adjust flowrates based on required flowrate estimations, which may be based on changing temperatures, changing lighting, or changes other changes that require to increase or decrease flowrate to reduce or eliminate watering stress that may affect the plants.

Advantageously, the EMU may be operatively engaged with any sensor to scan the root development and inform any systems or persons via wired or wireless communication about root development, which may be used to determine whether the plant roots are developing as expected or as required, and furthermore, enable the operators to inspect any under-developing areas for diseases or pests or other irritants, as well as enable the operators to inspect any over-developing areas to optionally learn about a combination of factors that may have affected the unexpected growth, and therefore design and implement new strategies to achieve the extra growth at the entire facility if so desired.

SOLUTION SUPPLY & DISTRIBUTION

An aqueous solution, which may be a water-based solution containing nutrient salts, may be supplied to the disclosed apparatus from any external storage (fig. 15, ref. 43), or from an on-board solution container (fig. 2, ref. 44) attached to the carriage (1) of the apparatus, or from a gutter engaged with the plant cultivation platform (figs. 18A, 18B, ref. 62), or from any such source of solution that is appropriate. Once the solution reaches the disclosed apparatus, the solution may be supplied to a solution distribution means (fig. 2, ref. 23) mounted to the carriage. The solution distribution system may be operatively engaged with one or more nozzles attached to the carriage, wherein the solution distribution system may provide the solution at a required flowrate between 1 LPH to 500 LPH to the nozzle inlet (fig. 8, ref. 11). The solution distribution means (Fig. 2, ref. 23) may be engaged with one or more of the nozzles via hoses (45), pipes displaced within the carriage frame, or any other suitable means. The solution distribution system may utilize a low-pressure pump to move the solution from the supply source to the nozzle inlet.

The solution distribution means may include valves that selectively open or close and required times, which is beneficial because each nozzle may operate at a different flowrate.

AEROPONIC IRRIGATION PROCESS

Aeroponic irrigation works by suspending plant roots in air in enclosed environments, and by irrigating the plant roots with aerosolized nutrient solution at a constant rate, at static intervals or at dynamic intervals. The plants may be suspended in aeroponic walls, aeroponic tables, aeroponic grow boxes, aeroponic A-Frames, trapezoids and any other appropriate structures designed to, at minimum, support the plant so that the direction of the foliar part is exposed to the arranged artificial light or the natural sunlight, and so that the structure protects the plant's roots from light, pests and other unwanted irritants. In the present disclosure, aeroponic mist is delivered to plant roots hanging inside any elongated structure by the use of ultrasonic nozzles, which operate as described above. Additional airflow may be used to provide additional inertia to the dispersed aerosol if required. Intervals are achieved through programming of the travel mechanism, therefore as the travel mechanism moves the mobile aeroponic irrigation system at any speed in a reciprocal manner, plants may be exposed to a specific volume of aerosol at a rate that may be proportional to the speed of the travel mechanism and the determined flowrate of the ultrasonic nozzle.

EXEMPLARY NON-RESTRICTIVE EMBODIMENTS

The disclosure may be understood by examining non-restrictive exemplary embodiments.

According to the first preferred embodiment of the apparatus (Figs. 17A, 17B), said apparatus comprises a triangle-shaped carriage (Fig. 2, ref. 1A) wherein the angles are configured to be 60 degrees. The carriage is further configured to operatively engage with an A-Frame cultivation structure with angles of 60 degrees wherein plants with short lifecycles (such as lettuce) are grown in a commercial greenhouse. According to the present embodiment, the carriage carries ten nozzles (8) attached to said carriage, wherein the nozzles are ultrasonic nozzles with internal channels of 4 millimeters in diameter and wherein the nozzles are displaced in casings that are attached to the carriage in fixed positions. According to the present embodiment, the nozzles may atomize solution at a rate between 1 LPH to 20 LPH per nozzle. According to the present embodiment, the nozzles are configurable to provide droplet diameters of either 30 μ m, 50 μ m, 70 μ m or 100 μ m. The mobility means comprises an electric motor (Fig. 17A, ref. 46) and a gearing system (47) designed to engage with a belt (48), wherein the belt is attached to both ends of said cultivation platform and creates a longitudinal travel path along the center of said A-Frame cultivation structure. According to the present embodiment, the travel means may propel the apparatus at a variable speed between 1 cm/second and 100 cm/second. Further, according to the present embodiment, the apparatus is configured so that the exact location of the sprayer is calculated by the steps of the motor. The carriage also has a solution distribution means attached to it, wherein the solution distribution means is operatively engaged with a solution supply on one end, and the nozzles on the other end. The carriage further comprises a self-reeling drum (49), wherein a solution supply hose (Fig. 17B, ref. 50) and a power supply cable (51) are connected to a greenhouse irrigation solution supply system (52) and a greenhouse power supply system (53) respectively outside of the A-frame cultivation structure, and wherein the solution supply hose and the power cable are engaged together (54) so as to engage with the self-reeling drum (49), and wherein the self-reeling drum and the power supply cable are engaged with the solution distribution system and electronic management unit (Fig. 17A, ref. 55), respectively, on the carriage. As

the carriage travels and performs the irrigation function, the irrigation means starts spraying the plants on one end, wherein each plant receives approximately 2 seconds of spray time at 10 LPH, further, the carriage reaches the preferred end of travel path, switches off the spray means and returns to the preferred starting point. According to the preferred embodiment, the apparatus further comprises an integrated airflow unit (56), wherein a central fan is engaged with nozzle casings (20) via soft tubes displaced within the frame of the carriage. According to the present embodiment, the apparatus is programmable to increase or decrease the irrigation intensity based on the apparatus' location within the cultivation system as young plants may be displaced on one side of the cultivation platform, and older plants may be displaced on the other end of the cultivation platform.

According to the second preferred embodiment (Figs. 18A, 18B), the apparatus comprises a rectangle-shaped carriage wherein the height of the apparatus exceeds the width of the apparatus by at least an order of three. The carriage is further configured to operatively engage with a rectangular cultivation structure with annual-lifecycle plants displaced at regular intervals in the top of the cultivation platform so as to provide for a travel path for the irrigation apparatus between the plant roots, as well as to maximize foliage access to light. According to the present embodiment, the carriage carries 6 nozzles attached to said carriage, wherein the nozzles are ultrasonic nozzles with internal channels of 6 millimeters in diameter and wherein the nozzles are displaced in casings that are attached to the carriage with ball-joints in manually adjustable positions. According to the present embodiment, the nozzles may atomize solution at a rate between 1 LPH to 50 LPH per nozzle. According to the present embodiment, the nozzles are configurable to provide droplet diameters between 50 μ m and 150 μ m. According to the present embodiment, additional airflow means, which are individual fans (57), are attached to each nozzle casing. The mobility means comprises a caterpillar system (58) engaged with the ground of said cultivation structure, and is configured to travel longitudinally between two ends of the cultivation structure in a reciprocal manner. According to the present embodiment, a means of sensing (59) the start and end point of travel path are mounted on the front and back side of the carriage and are operatively engaged with the electronic management unit (60). According to the present embodiment, the travel means may travel at a variable speed between 1 cm/second and 50 cm/second. The carriage also has a solution distribution means attached to the carriage (61), wherein the solution distribution means is operatively engaged with the nozzles. According to the present embodiment, the solution distribution means is engaged with a solution supply gutter (62) with flowing nutrient solution displaced within the cultivation structure. The power supply means is a battery (63) displaced within a waterproof casing on the apparatus, wherein the battery charge port (64) engages with an external recharge plug (65) mounted at the start point of the preferred travel path, further, wherein the battery is rapidly recharged at appropriate times. As the carriage travels and performs the irrigation function, the irrigation means starts spraying the plants on one end, wherein 1 plant receives approximately 3 seconds of spray time at 15 LPH, further, the carriage reaches the preferred end point of the travel path, switches off the spray means and returns to the preferred starting point. According to the present embodiment, the apparatus is programmable to increase or decrease the irrigation intensity based on inputs from the greenhouse environment monitoring system.

According to the third exemplary embodiment (fig. 19), more than one A-frame cultivation structure row may be irrigated by more than one triangle-shaped apparatus, wherein each carriage (1) is equipped with any number of nozzles (8), and wherein each carriage is engaged with a boom (66), wherein said boom is also engaged with a motor (67), wherein a motor is travelling along the longitudinal path of the irrigation

structure on a rail while moving the boom accordingly. According to the present embodiment, the boom contains power supply, the solution supply and the airflow supply, wherein the connections are displaced within the frame on the apparatus, and wherein the inputs engaged with the boom may be displaced in the greenhouse facility outside the cultivation structure.

According to the fourth exemplary embodiment, more than one A-frame cultivation structure row may be irrigated by one or more apparatuses, wherein the carriage (1) is equipped with any number of nozzles (8), and wherein each apparatus is engaged with any appropriate mobility mechanism, and wherein the apparatus is engaged to travel inside more than one cultivation structure, and wherein the apparatus is engaged with any appropriate liquid and power supply mechanism, and wherein the apparatus may travel in an endless loop between cultivation structures. Beneficially, this embodiment may eliminate return time and maximize resource utilization within a CEA facility.

CLAIMS

1. A mobile irrigation apparatus comprising:

a carriage (1), one or more ultrasonic nozzles (8), a supply of aqueous solution, a means of distribution of the aqueous solution (23), a power source, and an electronic management unit (18),

wherein the carriage further comprises a means of travel (3),

wherein the one or more nozzles are attached to the carriage (1),

wherein each of the one or more ultrasonic nozzles (8) oscillates between a frequency of 10kHz and 3MHz,

wherein each of the one or more ultrasonic nozzles (8) is operatively engaged with the supply of aqueous solution via the distribution means (23),

wherein the supply of aqueous solution is sufficient to supply aqueous solution to each ultrasonic nozzle (8) at a flow rate of 1 LPH to 50 LPH via the distribution means (23),

wherein each ultrasonic nozzle (8) is capable of atomizing the supplied aqueous solution at a flow rate of 1 LPH to 50 LPH,

wherein each ultrasonic nozzle (8) is operatively engaged with the electronic management unit (18),

wherein the electronic management unit (18) individually controls the oscillating frequency of each ultrasonic nozzle (8),

wherein the distribution means (23) is operatively engaged with the electronic management unit (18),

and wherein the means of travel (3) is operatively engaged with the electronic management unit (18).

2. The mobile irrigation apparatus according to Claim 1:

wherein the electronic management unit (18) is a programmable controller.

3. The mobile irrigation apparatus according to Claims 1 or 2:

wherein the aqueous solution distribution means (23) comprises one or more valves,

wherein the one or more valves is operatively engaged with the electronic management unit (18),

wherein the one or more valves are controlled individually by the electronic management unit (18),

wherein the one or more valves are capable of modulating the flow rate from the supply of aqueous solution, through the distribution means (23), to the one or more nozzles (8).

4. The mobile irrigation apparatus according to any preceding claims:

wherein the apparatus comprises more than one ultrasonic nozzle (8),

wherein the electronic management unit (18) increases or decreases the flow rate of the supply of aqueous solution to each ultrasonic nozzle (8) individually by modulating the flow through the one or more valves,

and wherein the electronic management unit (18) increases or decreases the atomization rate of each ultrasonic nozzle (8) individually.

5. The mobile irrigation apparatus according to any preceding claims:

wherein the aqueous solution is atomized by the one or more nozzles (8) into droplets with variable mean diameters between 20 μ m and 200 μ m, preferably between 20 μ m and 100 μ m.

6. The mobile irrigation apparatus according to any preceding claims:

wherein the power source of the mobile irrigation apparatus is a battery or an external power source.

7. The mobile irrigation apparatus according to any preceding claims:

wherein the electronic management unit (18) generates a first acoustic profile for each ultrasonic nozzle (8),

wherein the electronic management unit (18) periodically generates a second acoustic profile for each ultrasonic nozzle (8),

and wherein the electronic management unit (18) compares the second acoustic profile to the first acoustic profile for each ultrasonic nozzle (8) to identify a deviation value.

8. The mobile irrigation apparatus according to claim 7:

wherein, when the deviation value exceeds a predetermined threshold value, the electronic management unit (18) adjusts the oscillation of the deviant ultrasonic nozzle (8) for a period of time.

9. The mobile irrigation apparatus according to claim 8:

wherein the electronic management unit (18) records a reduction of the deviation value below a predetermined threshold value during the period of time,

and wherein a new first acoustic profile is recorded for the ultrasonic nozzle (8).

10. The mobile irrigation apparatus according to claim 8:

wherein the electronic management unit (18) does not record a reduction of the deviation value below a predetermined threshold value during the period of time,

and wherein the electronic management unit (18) disables the deviant ultrasonic nozzle.

11. The mobile irrigation apparatus according to Claim 10:

wherein the electronic management unit (18) is engaged with more than one ultrasonic nozzle,

and wherein the electronic management unit (18) adjusts the flow rates of the nozzles to compensate for the disabled deviant ultrasonic nozzle.

12. The mobile irrigation apparatus according to Claim 10:

wherein the electronic management unit (18) is engaged to communicate with external systems,

and wherein the electronic management unit (18) informs external systems about the ultrasonic nozzle (8) failure.

13. A method of manufacturing the mobile irrigation apparatus according to any preceding claims.

14. The use of the mobile irrigation apparatus according to claims 1 to 12 for aeroponic cultivation.

15. The mobile irrigation apparatus according to Claim 1:

wherein the apparatus is operatively engaged with at least one more apparatus,

and wherein the travel means is operatively engaged with more than one apparatus.