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- (56) Fremdragne publikationer:
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DESCRIPTION

FIELD OF THE INVENTION

[0001] The present invention relates to a system and method for drying and cooling greenhouse air and to a greenhouse equipped with the system according to the invention.

DESCRIPTION OF THE PRIOR ART

[0002] In modern greenhouse production, the aim is to control the climate in the greenhouse to correspond as closely as possible to optimal conditions of plant growth. In optimal growing conditions, the temperature in the greenhouse is about 18-30 °C, the humidity of air about 60-90% and the carbon dioxide content over 1000 ppm, depending on the plant cultivated and the situation. Optimal conditions of growth require good control of the temperature of air, humidity and carbon dioxide content.

[0003] In widespread use is a greenhouse in which the climate is controlled by means of vents and/or fans. In this case, excess heat produced by solar radiation is removed by ventilation. There is at least a partial need for ventilation also in Finland during about 8 months of the year.

[0004] The cooling of greenhouse air is enhanced by spraying water in the form of as fine a mist as possible into the greenhouse. When using spraying, the evaporating water binds heat from the greenhouse air and increases the humidity of the air. When spraying is used, typically 0,1-0,5 litres/m² of greenhouse/h is sprayed. Efficient use of spraying for cooling greenhouse air usually also requires ventilation for remove humid air from the greenhouse and to continue spraying.

[0005] In current greenhouses cannot be maintained a carbon dioxide level optimal for plant growth when a high radiation level prevails, which would give the greatest benefit. The carbon dioxide escaping with the ventilation air would increase the amount of carbon dioxide needed to such a high level that its dosing would not be economically cost-effective. Thus, when a high radiation level prevails, in the best conditions for plant growth usually has to be settled for the outdoor air level (about 350 ppm) in carbon dioxide level content instead of the carbon dioxide level (500 ppm - 1500 ppm) preferable for plant growth. Due to the foregoing, in current greenhouses plant growth usually remains markedly lower than what it could be if the carbon dioxide level of greenhouse air could be kept high also when the radiation level is high. For example in Finland, the best growth results are usually achieved in late winter when the radiation level is high and outside air is so cold that greenhouses do not need to be cooled by ventilation and thus an increased level of carbon dioxide can be maintained in greenhouses. In warmer climate conditions are not normally achieved growth results as high as this.

[0006] Because of the above, attempts have in recent years been made worldwide to develop different types of closed greenhouse solutions. In a closed greenhouse, the inside air is almost completely cut off from outdoor air. Outdoor air is not let in through vents, nor is it blown by fans into the greenhouse, but the excess heat is removed by other means. The carbon dioxide needed by the plants is provided through technical production and its content is preferably increased to a minimum level of 500-1500 ppm. Due to the optimally controllable climate, a closed greenhouse is considered an ideal solution for growing plants.

[0007] Several international patents have been filed concerning a greenhouse system where climate control is realised at least partly in accordance with the closed system:

Patent no. EP 0 517 432 A1 puts forth a thermal accumulator which collects the daily solar energy and which discharges it during the night, partly for heating the greenhouse and partly into the cooler night air. In this case, the size of the thermal accumulator must be about 400 cubic metres for a 1000 square metre greenhouse, which increases the investment costs of the system to an economically unprofitable level. In the method disclosed in the said patent, as in many other methods, the cooling of greenhouse air takes place in a separate heat exchanger located outside the greenhouse, into which the greenhouse air is conveyed, usually by means of ordinary fans, and from which it is returned cooled into the greenhouse.

[0008] As prior art, reference is also made to US patent no. 4,044,078 disclosing a device developed for cooling storage spaces, where cold water is sprayed from above through a grating frame against an air blast and the heated water is cooled by means of a cooler on the outside. In this device is also essential a separate apparatus and fan for cooling the air.

[0009] US publication no. 4,707,995 discloses a system for controlling the humidity of air and temperature in a greenhouse, the operation of which is based on using natural, concentrated salt water for dehumidification. As in the solution described above, air is conveyed through a water jet and the processed water is recovered outside the device. The device is not generally suitable for cooling or dehumidifying greenhouses.

[0010] JP publication no. 4148123 A 19920521 discloses a solution, where air is blown into water sprayed from above, the air being intended to come into heat exchange contact with the water sprayed inside.

[0011] JP publication 2104222 A 19900417 also utilizes directly heat exchange between water and air for cooling greenhouse air. The device comprises a heat exchanger functioning with cold groundwater, by means of which the greenhouse is cooled in night-time with air entered from above and humidity removed at the bottom of the device. The system is intended for night-time cooling and is not powerful enough for daytime removal of heat from a closed greenhouse.

[0012] JP publication 10165002 A discloses a solution, where cooled water is pumped into nozzles near a ceiling of greenhouse. The nozzles spray the cooled water creating mist into the air space of the greenhouse. A fan is provided for stirring the air in the greenhouse.

[0013] In methods where greenhouse air is conveyed for cooling in separate condensers or heat exchangers, the central problem that arises is the high fan power required for moving the greenhouse air. Due to the fan power required, the fans generally account for a considerable share of the investment and operating costs of the apparatus as a whole. The use of powerful fans is also a quite considerable source of noise in the greenhouse and its vicinity.

[0014] In addition to solutions described above, in some implementations of closed greenhouses cooling is carried out using normal heat pump technology. In this solution, the cost level of equipment is very high because the cooling capacity required during a high radiation level is high (500-1000 W/m² of greenhouse at the highest).

[0015] All current solutions for cooling and drying the air in a closed greenhouse are very expensive in terms of investment costs and partly also operating costs. This is why the solutions presented so far have not been taken into use in practice in greenhouse cultivation, with the exception of some applications constructed on a test basis.

Description of the invention

[0016] In the present patent application is described an invention by means of which the drying and cooling of air in a closed or partly closed greenhouse can be carried out in a substantially more economical manner than in earlier solutions.

[0017] In the system and method according to the present invention, the dehumidification and cooling of greenhouse air takes place by spraying water cooler than the dewpoint temperature of air directly into the greenhouse air space and by allowing it to fall as drops or by flowing in the air space of the room. In this way, condensing humidity and heat transfer from the greenhouse air into the water.

[0018] Characteristic features of the present invention are:

- In the system and method according to the invention, cooling water is conveyed directly into the air space of the greenhouse, which means that separate condensers and heat exchangers are not required. The entire air space of the greenhouse acts as a condenser space. In the solution according to the invention are also not required fans for moving the air to be cooled because cooling takes place immediately in the air space of the greenhouse. The air flow brought about by the movement of the water being sprayed, the cooling of air, the intrinsic movement of air in a greenhouse or low-power fans conventionally intended for circulating the air space of a greenhouse even out the humidity and temperature differences in the greenhouse, whereupon the climate in the greenhouse remains sufficiently constant from the viewpoint of plant growth.
- The amount of water used is very high, typically 100-500 litres (at least 50 litres)/m² of greenhouse/h while current cooling systems based on spraying typically use less than 1

litre/m² of greenhouse/h.

- The temperature of the water used is low, preferably 0-15 °C, however so that even after the fall through the air the temperature of the water will have risen at most to the desired dewpoint temperature.
- The system according to the invention differs from conventional spraying devices and systems in that the amount of water used is high (hundredfold to thousandfold) and the temperature of the water is low. This means that both heat and humidity is bound to the water sprayed into the greenhouse air.

[0019] In conventional spraying, the aim is to evaporate water into the greenhouse air, whereupon the humidity of the greenhouse air increases and the temperature decreases in proportion to the evaporation temperature of the water. Continued spraying thus requires that excess humidity is removed from the greenhouse through ventilation.

[0020] In an embodiment, conventional spraying may be combined with the greenhouse air drying and cooling system according to the invention by maintaining by spraying the relatively high humidity level (preferably over 70% RH) of the greenhouse air and at the same time efficiently cooling the greenhouse air by means of the apparatus and method of the invention and condensing humidity from the air. This will dry the air and allow the spraying to be continued without having to reduce humidity by ventilation. If there is such growth in the greenhouse that is able to evaporate enough water, spraying can be given up and the method and apparatus according to the invention can be used alone to remove excess humidity and to cool the greenhouse air.

[0021] In another embodiment, the humidity of greenhouse air can be made constant as desired by adjusting the temperature of the cooling water to correspond to the dewpoint temperature of the desired humidity of air and temperature, in which case no separate spraying equipment is required.

[0022] The apparatus and method according to the invention can be dimensioned so that no ventilation devices are required in the greenhouse. However, in many cases it is more economical to use ventilation during the highest thermal load, which means that the apparatus according to the invention can be dimensioned to a lower capacity.

[0023] In the system, method and greenhouse according to the invention is needed a substantial amount of cool water, preferably having a temperature below 15 °C, for drying and cooling the greenhouse air. The dimensioning of the apparatus is determined according to the temperature of the water available. The colder the water available, the smaller can the apparatus of the invention be dimensioned.

[0024] The water required to be conveyed into the greenhouse air for drying and cooling the air can, be taken directly from natural waters, for example, in Finnish conditions also in

summer from the cool hypolimnion below the metalimnion of the water. The cool water needed for drying and cooling may also be produced in an evaporator apparatus located outside the greenhouse when the outdoor air is sufficiently cool or correspondingly sufficiently dry for cooling the water by means of the evaporator.

[0025] Cool water obtained from outside the greenhouse may be circulated either directly in the system intended for drying and cooling greenhouse air or it may be used indirectly by means of a heat exchanger for cooling the water circulated in the system.

[0026] When using a heat exchanger, pure water condensing from the greenhouse air can be recovered from the system and then used as spraying and watering water in the greenhouse. This is highly significant in areas with a shortage of clean watering water for greenhouse production.

Advantages of the invention compared with the prior art

[0027] By means of the method and apparatus according to the invention, the humidity and temperature of greenhouse air can be controlled by means of substantially more economical equipment and operating costs than with known solutions intended for controlling the climate of a closed greenhouse.

[0028] Differing from earlier solutions, in the system according to the invention, the entire greenhouse acts as a condenser, and no separate condenser chambers or fans are required. They are replaced by the normal movement of air in a greenhouse and by the fact that these "open sprinkler condensers" may easily be located in different places in the greenhouse, whereby the cooled air will be distributed evenly in the greenhouse by means of the natural movement of air. As regards condensers possibly used for cooling the water circulating in the system, fans and condensers are correspondingly replaced by the free movement of outdoor air.

[0029] Major advantages compared with other known greenhouse dehumidification and cooling systems and methods are:

- Equipment costs are lower, because no separate condensation chambers or fans are required for conveying the greenhouse air into the condenser.
- Operating costs are substantially lower, because it has been possible to exclude the parts that consumed essentially the most energy in earlier systems, that is, the fans.
- The method works globally everywhere, where there is sufficient cool water available or where water can be cooled by means of sufficiently dry outdoor air.
- The use of this method does not cause the type of noise problem in the greenhouse and its surroundings as methods using fans do.

[0030] On the basis of the system and method according to the invention can be designed a closed greenhouse, where the structures required by the method are combined with normal greenhouse constructions and the automatic control required by the system is built as a part of the conventional automation of the greenhouse.

[0031] Embodiments of the invention are described in the accompanying drawings, to which the invention is, however, not limited.

Figure 1

shows the system according to the invention,

Figure 2

shows a typical greenhouse arrangement, and

Figure 3

shows an embodiment of the invention for growing low-growth plants.

[0032] Figure 1 shows a general embodiment of the invention, where water distribution devices 1 are arranged in the upper part of the greenhouse and water is sprayed into the air space of the greenhouse without separate condensation chambers, structures or fans. The temperature of the water is below its dewpoint. The devices are preferably dimensioned so that by using them, at least about 50 litres of water per square meter of greenhouse can be sprayed into the greenhouse air space in an hour. The water distribution devices 1 are located in the central part of the upper part of the greenhouse and/or on the sides and/or under the cultivation tables in the greenhouse.

[0033] In the lower part of the greenhouse are water collection devices 2 for collecting the water sprayed from the upper part and for returning it into the devices of the system.

[0034] The water collected is conveyed from the greenhouse along a discharge pipe 5. Outside the greenhouse, a heat exchanger 6 is connected to the discharge pipe 5 for cooling the water discharging from the greenhouse.

[0035] The apparatus may, in addition, be equipped with an evaporator apparatus 8 for cooling the water discharged from the greenhouse. This condenser apparatus 8 is in addition connected to a water supply 7 and a pump device 9 for spraying the water. The water in the water supply can be sprayed into the air in such a way that the water being sprayed comes into contact with the outdoor air and after this, returns again to the water supply or directly to the greenhouse air drying and cooling apparatus.

[0036] Figure 2 depicts a typical embodiment of the system and method. In this embodiment, there is a pipe system 1 in the upper part of the greenhouse with 0,3-1 mm nozzle holes 2, through which water 3 cooler than the dewpoint temperature of the greenhouse is sprayed into the air space of the upper part of the greenhouse, between the rows of plants, so that water is

able to fall freely as drops into the collection troughs 4 below, from where it is conveyed into a collection tank and recirculated or alternatively conveyed completely or partly into the water system and replaced by cooler water from the water system.

[0037] The amount of water sprayed in this embodiment is typically 100-500 litres of water/m² of greenhouse/h. Correspondingly, the area required by sprinkler irrigation in the greenhouse is 1-4% of the greenhouse area in a typical embodiment. This free area required is usually easy to find between the rows of plants in the greenhouse. The spray pipes 1 may alternatively also be located on the sides of the greenhouse.

[0038] If the layering of cold and hot air in the greenhouse (e.g. in the case of high tomato and cucumber growths) proves to be problematic, the layering of the greenhouse air can be mixed in the conventional manner by using relatively low-powered fans.

[0039] In this method, heat exchange can be improved by using a markedly smaller drop size than in the methods where the cooling water comes into contact with the rapidly flowing air.

[0040] Figure 3 shows another typical embodiment, which can be applied when growing low-growth plants. In this, the water distribution pipes 1 are located in the same way in the upper part of the greenhouse as in Figure 1, but the water collection troughs 4 are positioned above the growths. The troughs used in this application are preferably made of light-permeable material, for example polyethylene sheet or film.

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- [EP0517432A1](#) **[0007]**
- [US4044078A](#) **[0008]**
- [US4707995A](#) **[0009]**
- [JP4148123A](#) **[0010]**
- [JP2104222A](#) **[0011]**
- [JP10165002A](#) **[0012]**

Krav

1. System til tørring og køling af drivhusluft ved hjælp af vand, som er køligere end drivhusluftens dugpunktstemperatur, hvor systemet omfatter vandfordelingsanordninger (1), der er indrettet til at sprøjte nævnte vand, som er køligere end drivhusluftens dugpunktstemperatur, direkte ind i drivhusets luftrum uden brug af separate fortætterkamre, strukturer og ventilatorer til at transportere drivhusluften ind i fortætteren, **kendetegnet** ved, at nævnte vandfordelingsanordninger er dimensioneret til at sprøjte mindst 50 liter vand pr. kvadratmeter drivhus ind i drivhusets luftrum i timen, hvor systemet endvidere omfatter vandopsamlingsanordninger (4), som er indrettet til at opsamle det vand, der sprøjtes ind i drivhusets luftrum, og til at returnere det i det mindste delvis til systemets anordninger.
2. System ifølge krav 1, hvor vandfordelingsanordningerne (1) er placeret i den øvre del af drivhuset for at sprøjte vand ind imellem planterækkerne.
3. System ifølge et af de foregående krav, hvor vandfordelingsanordningerne (1) er placeret i den øvre del af drivhuset, og opsamlingsanordningerne er placeret over bevoksningen.
4. System ifølge krav 1, hvor vandfordelingsanordningerne (1) er placeret lateralt i drivhuset.
5. System ifølge krav 1, hvor vandfordelingsanordningerne (1) er placeret under dyrkningsbordene i drivhuset.
6. System ifølge et af kravene 1 til 5, som endvidere omfatter en varmeveksler (6), via hvilken det vand (5), der cirkuleres i tørrings- og køleapparatet, afkøles.
7. System ifølge et af kravene 1 til 5, som endvidere omfatter et fordamperapparat (8), der er placeret uden for det drivhusrum, der skal tørres og afkøles, ved hjælp af hvilket apparat det vand, der cirkuleres i tørrings- og køleudstyret, afkøles.
8. System ifølge krav 7, hvor fordamperapparatet, der består af en vandforsyning (7) og anordninger (9), som er beregnet til sprøjtning af vand, ved hjælp af hvilket

vandet i vandforsyningen kan sprøjtes ind i luften på en sådan måde, at det vand, der sprøjtes, kommer i kontakt med udendørsluften og herefter atter returnerer til vandforsyningen eller direkte til drivhusets tørrings- og køleapparat.

- 5 9. Fremgangsmåde til køling og tørring af drivhusluft ved hjælp af vand, som er køligere end drivhusluftens dugpunktstemperatur, hvor kølingen og tørringen af luften finder sted direkte i drivhusets luftrum uden brug af separate fortætter- eller varmevekslerstrukturer eller ventilatorer til transport af drivhusluften ind i fortætteren ved at transportere nævnte vand (3), der er køligere end drivhusluftens
- 10 dugpunkt, ind i drivhusrummets luftrum via sprøjtning eller på anden måde, **kendetegnet** ved, at den mængde vand, der transporteres pr. tidsenhed, og temperaturen er dimensioneret på en sådan måde, at når det transporterede vand passerer igennem drivhusets luftrum, fortættes der mere fugtighed ind i det fra drivhusluften, end der fordamper vand fra det ind i drivhusluften, hvor den mængde
- 15 vand, der transporteres pr. tidsenhed, er mindst 50 liter vand pr. kvadratmeter drivhus sprøjtet ind i drivhusrummet i timen, og hvor i det mindste noget af det vand, der transporteres ind i drivhusets luftrum, genvindes for igen at blive transporteret til recirkulation i drivhusets luftrum.
- 20 10. Fremgangsmåde ifølge krav 9, hvor temperaturen af det vand, der cirkuleres i det apparat, som er beregnet til tørring og køling af drivhusluft, sænkes, og luftens fortættede luftfugtighed genvindes ved at cirkulere vandet gennem en varmeveksler (6).
- 25 11. Fremgangsmåde ifølge krav 9 eller 10, hvor temperaturen af det vand, der cirkuleres i det apparat, der er beregnet til tørring og køling af drivhusluft, sænkes ved hjælp af en fordamper (8), som er placeret uden for det drivhus, der afkøles.
- 30 12. Drivhus, hvis luft kan tørres og afkøles ved hjælp af vand (3), som er køligere end drivhusluftens dugpunktstemperatur, hvor drivhuset omfatter anordninger (1) til transport af nævnte vand, der er køligere end drivhusets dugpunktstemperatur, ind i drivhusets luftrum uden brug af separate fortætterkamre, strukturer og ventilatorer til at transportere drivhusluften ind i fortætteren, **kendetegnet** ved, at nævnte anordninger er dimensioneret således, at mængden af nævnte vand, er
- 35 bruges til afkøling, kan være mere end 50 liter/m² af drivhusarealet/h, hvor driv-

huset endvidere omfatter anordninger (4), som er indrettet til at genvinde i det mindste noget af det vand, der falder eller strømmer gennem luftrummet, samt anordninger, der er indrettet til at transportere i det mindste noget af det genvundne vand igen ind i drivhusets luftrum.

5

13. Drivhus ifølge krav 12, hvor vandfordelingsanordningerne, der bruges til tørring og afkøling af drivhusluften, er placeret i den øvre del af drivhuset for at sprøjte vand ind imellem planterækkerne.

10 14. Drivhus ifølge krav 12, hvor vandfordelingsanordningerne, der bruges til tørring og afkøling af drivhusluften, er placeret i den øvre del af drivhuset, og opsamlingsanordningerne er placeret over bevoksningen.

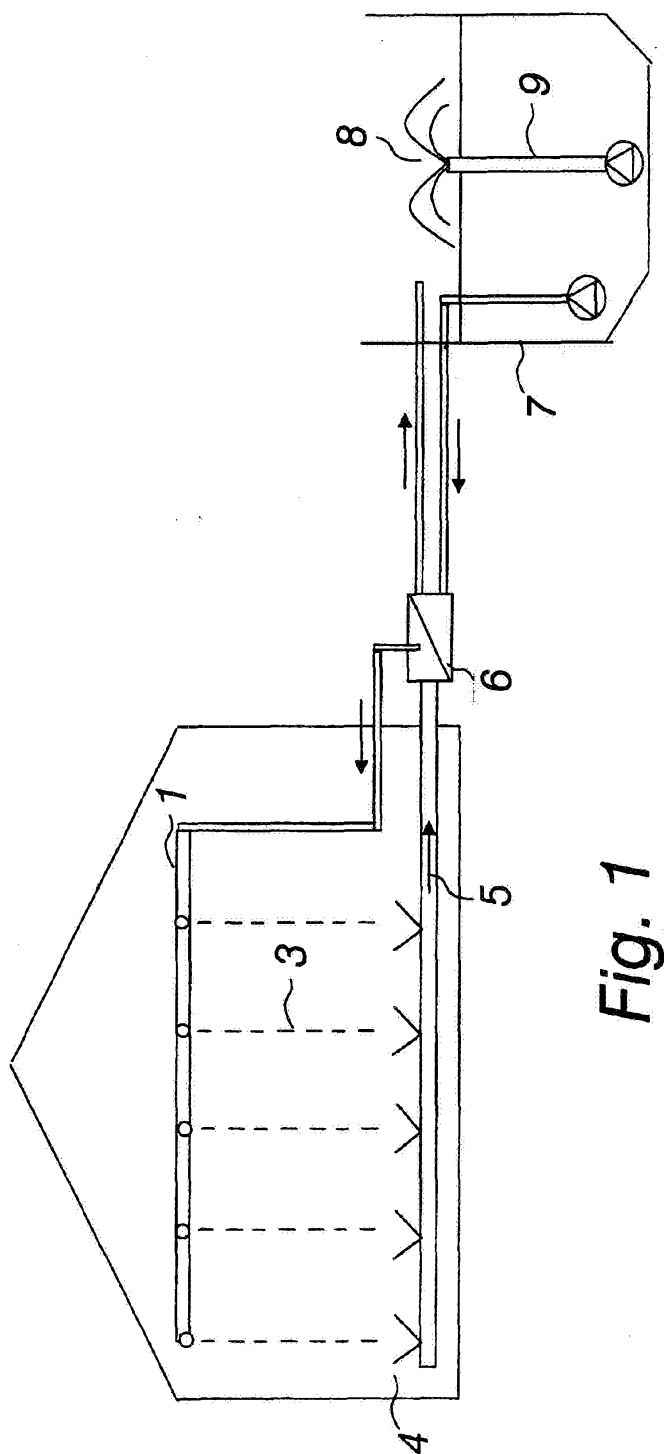
15 15. Drivhus ifølge krav 12, hvor vandfordelingsanordningerne, der bruges til tørring og afkøling af drivhusluften, er placeret lateralt i drivhuset.

16. Drivhus ifølge krav 12, hvor vandfordelingsanordningerne, der bruges til tørring og afkøling af drivhusluften, er placeret under dyrkningsbordene i drivhuset.

20 17. Drivhus ifølge et af kravene 12 til 16, som endvidere omfatter en varmeveksler (6) til afkøling af det vand, der cirkulerer i tørrings- og køleanordningerne, og til genvinding af det fortættede vand.

25 18. Drivhus ifølge et af kravene 12 til 17, i forbindelse med hvilket der endvidere er placeret et fordamperapparat (8) til afkøling af det vand, der cirkulerer i drivhusets tørrings- og køleapparat.

DRAWINGS



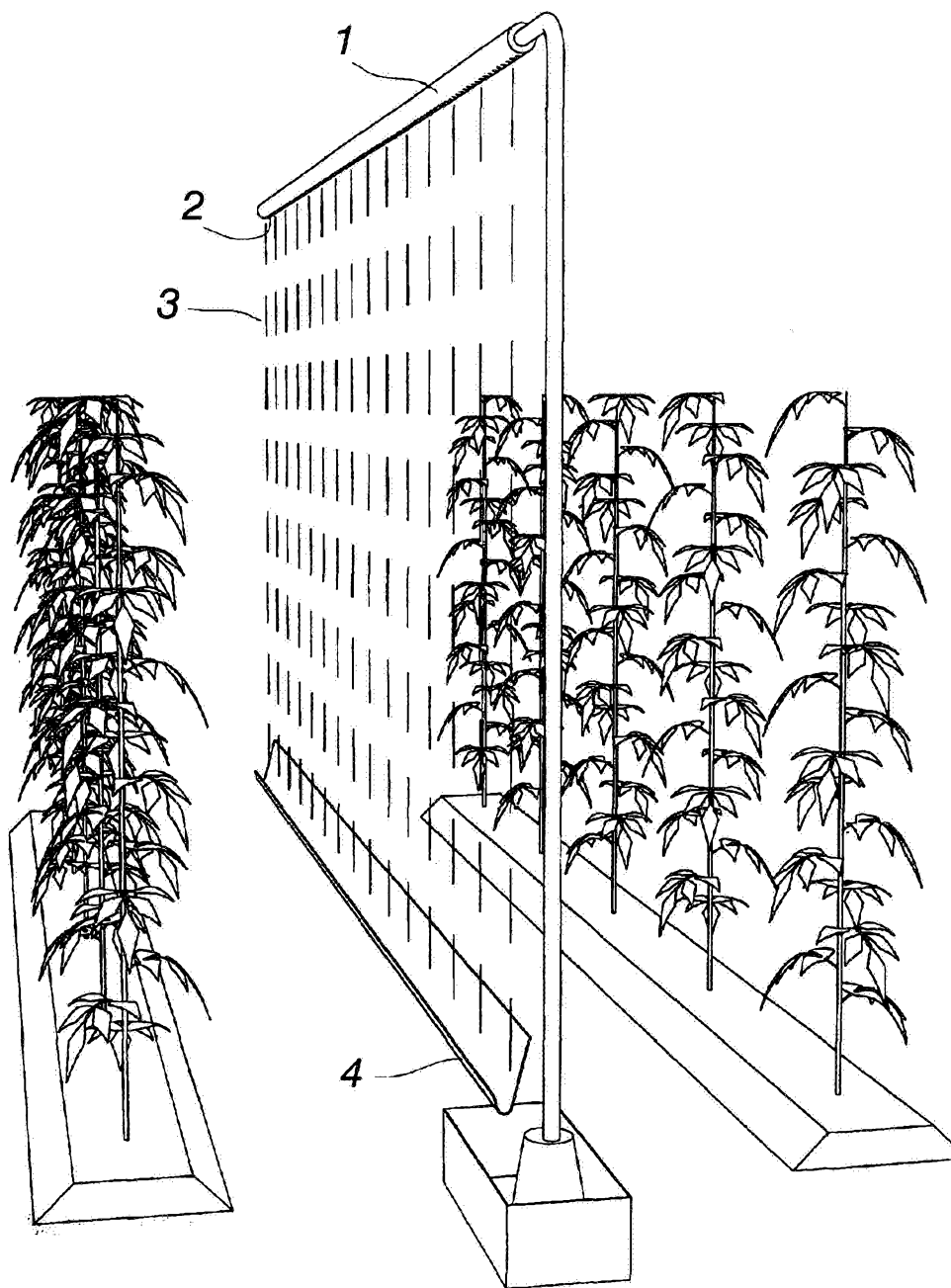


Fig. 2

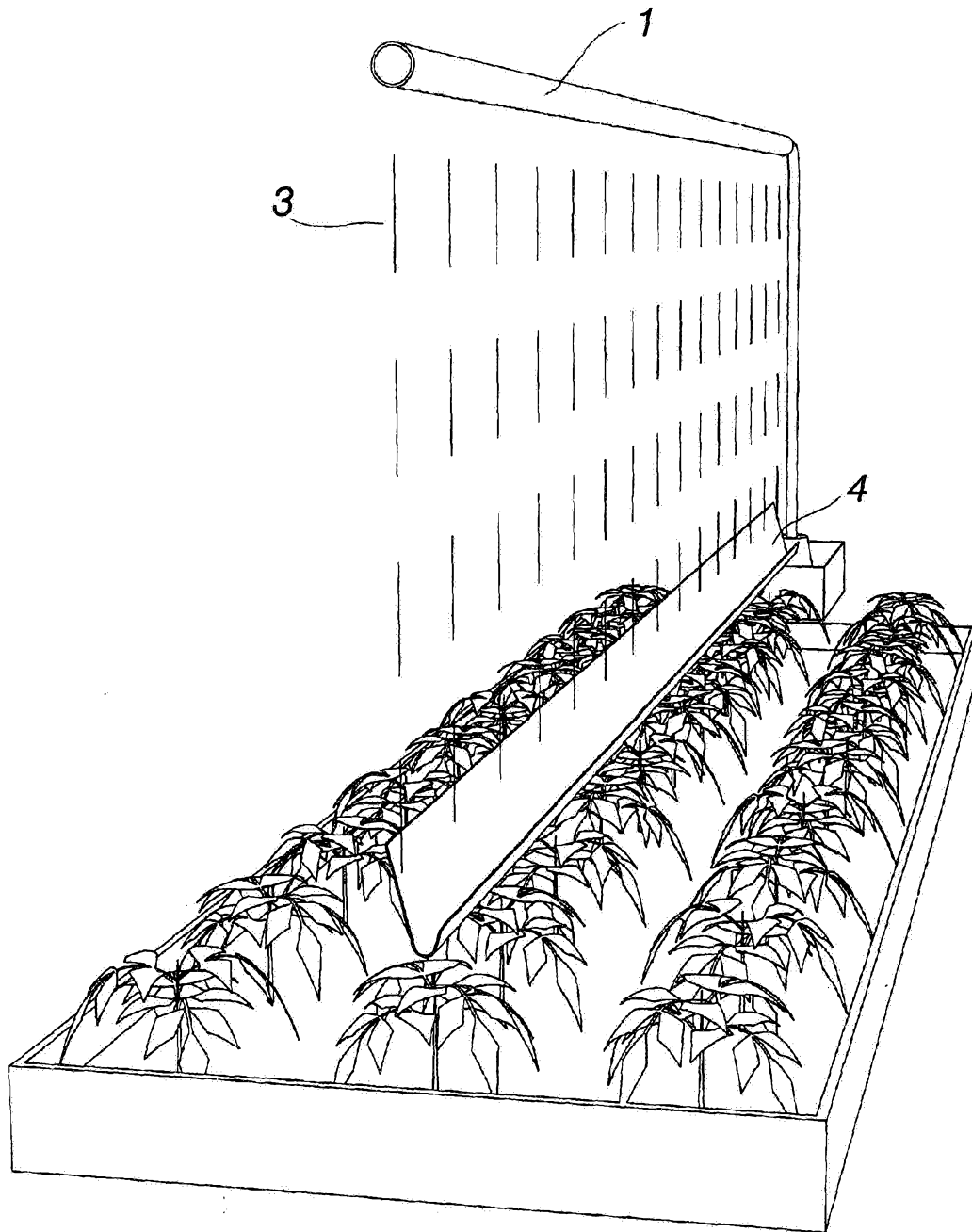


Fig . 3