

SHELTERED OUTDOOR FARMING SYSTEM FOR FOOD CROPS

Field of invention

[001] The embodiments of the invention provide an innovative combination of i) a protective shelter construction producing energy, ii) steel tanks for growing plants/fungi/other microorganisms, iii) hydroponics for growing leafy vegetables/plant crops and iv) a water treatment system re-cycling generated wastewater while producing supplements for enhancing plant growth in hydroponics. The steel tanks, hydroponics and wastewater treatment are housed under a solar-panel structure forming a protective shelter which protects the cultivated plant crops from damaging environmental factors and also provides the energy required for operating the whole farming system.

Background

[002] With a fast growing global population, food production worldwide has to be extremely increased over the coming decades to be able to feed the global population. However, climate change and global crises, such as COVID-19, demonstrate that the supply chain of raw materials or food ingredients is highly vulnerable. Therefore, new ways of food production, which are more sustainable and resource-efficient, have to be developed to remain operational during such crises. Such new ways for saving resources are, for example, using liquid waste from the food and beverage industry for microalgae cultivation, which is high in phosphate, nitrogen and other nutrient sources. Furthermore, hydroponics and other farming approaches were introduced to increase efficiency in farming of food crops.

[003] Microalgae are nutrient-rich single cell plants. They can be used as fertiliser and feed, in the cosmetic industry, as biofuels and also in food products. Microalgae and fungi for food can be cultivated in special steel tanks achieving high yields without light source. The technology for this was adapted from the pharmaceutical industry where such steel tanks have been used for several decades. It has the advantage that productivity and achieved product yields are much higher compared to conventional farming approaches and hydroponics per m² space and also per growing time. However, the major disadvantage of the steel tank farming approach is that it is very energy consuming since the steel tanks have to be operated continuously for 24 hours per day, which increases production costs significantly. This makes it even more challenging to adapt this technology from the pharmaceutical industry for the food industry as food products typically have lower selling prices as compared to high-value pharmaceutical compounds produced in steel tanks. As a consequence, using such energy consuming approaches are often not economically sustainable for food production, especially in countries with high/strongly varying energy costs or with unstable energy supply.

[004] Furthermore, global warming and climate change make outdoor farming increasingly challenging. Extreme weather such as floods, heavy rain, extreme heat and dry seasons destroys substantial parts of cultivated plant crops. Therefore, new innovative ways of protecting the growing crops are required to reduce harvest loss due to such environmental factors.

[005] Conventionally, translucent protective shelters in outdoor farming, made of materials such as glass, plastic or shading nets, are able to protect against damaging environmental factors, such as e.g. heavy rain, hail, heat or high intensity of the sun rays. However, shading nets are unable to protect against heavy rain or hail whereas other translucent solutions do not protect plant crops against heat or light stress caused by too intense sun rays. Non-translucent protective shelter solutions are made of plastic, glass, metal, wood or concrete which protect against all environmental factors stated above. However, it has the disadvantage that they also shield sunlight completely, which is absolutely required as a natural light source for growing plant crops. Non-translucent solutions might have installed solar panels on their roof-tops for powering artificial light to overcome the problem of lacking a light source in the farming process.

[006] Another important point to consider is the availability of required raw-material for farming (e.g. components of fertiliser). They are dependent on the supply chains which are heavily affected by crisis as mentioned earlier. Therefore, solutions to make farming more resource efficient have also be introduced into new farming systems.

[007] One approach is the recycling of e.g. phosphate and nitrogen from wastewater which can be done by cultivation of microalgae. In hydroponics, wastewater is generated in certain intervals which cannot be used again for another plant growth cycle, since certain nutrients accumulate at high concentration over time in the hydroponic nutrient solution causing phytotoxicity. Reusing phosphate and nitrogen rich liquid waste has the advantages that i) saving resources like water and minerals for growing microalgae and ii) discharges such nutrients rich liquid waste can cause harm and damage to the environment (eutrophication, toxic algae bloom) and microalgae cultures can deplete these nutrients (bio-remediation).

Summary of invention

[008] The invented system comprises of steel tank farming component, hydroponic farming component and wastewater treatment component, the wastewater treatment component having a least a photo-bioreactor.

[0009] The steel tanks provide an optimal growing environment for producing plant/fungal/microbial biomass in high cell density cultures for food purposes and leafy vegetables/plant crops are grown in the hydroponic farming component.

[0010] In the photo-bioreactor, microalgae and other microorganisms can be grown in wastewater generated by steel tank farming component and hydroponic farming component. Artificial lighting components at the photo-bioreactor provide alternative growing conditions other than natural light.

[0011] The microalgal/microbial biomass grown in the photo-bioreactor is used as supplement to enhance plant crops growth in agriculture and horticulture (hydroponics).

[0012] Water-loss caused by evapo-transpiration in the hydroponic farming component during plant growth is compensated by using treated wastewater from the steel tank farming component. Wastewater from the steel tank farming is treated in the wastewater treatment component and from there, pumped to the hydroponic farming component to refill the reservoirs.

[0013] Solar panels, in combination with metal columns/beams, are arranged to form a protective shelter over the hydroponic farming component, the steel tank farming component and wastewater treatment component. This shelter made of solar panels harnesses solar energy to power the processes and equipment of the hydroponic farming component (liquid pumps, water chiller, LED lights), steel tank farming component (steel tanks including supplemental equipment) and, wastewater treatment component (photo-bioreactor, liquid pumps, tubular centrifuge, UV light disinfection device, ozone generator).

[0014] Overall, the invented system addresses the following issues:

- i) Improving efficiency of food production by combining two farming approaches, steel tank farming and hydroponics, in a compact farming space to address higher demand for food by growing global population
- ii) Recovery of nutrients in liquid waste for microalgal/microbial biomass production and reducing water consumption during farming process by implementing circular economy to save resources and raw-material
- iii) Minimising the generation of liquid waste during the farming process to make the process more environmental friendly.
- iv) Using solar energy to power the invented farming system to ensure a reliable energy supply and to make the steel tank farming approach economically sustainable by reducing energy costs

v) Protecting growing crops against extreme weather such as e.g. intense sunlight and heavy rain. The number of extreme weather amplitudes and natural disasters have increased globally obviously due to climate change, which have fatal effects on outdoor farming causing harvest loss.

[0015] In the invented farming system, two different farming approaches a) steel tank farming and b) hydroponics are used to grow at least two different or more plant crops and/or fungi for food.

[0016] In the invented farming solution, the generation of wastewater discharge is reduced to a minimum by applying circular economy. The wastewater from steel tank farming and hydroponics is used for cultivation of microalgae/microorganisms in photo-bioreactors to lower the concentration of accumulated nutrients, which would cause phytotoxicity in plant crops grown in the hydroponics. The wastewater can be reused after additional treatment in the hydroponics and the produced microalgal biomass can be used as plant growth enhancer in the hydroponics or other agricultural farms. Besides reducing the risk of phytotoxicity, using the nutrients in the wastewater for producing functional microbial biomass is a form of recycling of the nutrients, since otherwise, the nutrients would be disposed together with the liquid waste.

[0017] The invented system has an independent energy supply by using solar panels to harness abundant solar energy to power the whole farm system (including steel tank farming, hydroponic farming, photo-bioreactor farming and wastewater treatment). Conventionally, the energy supply, especially for operating the steel tanks to grow plants/fungi/other microorganisms, is provided by the local power grid. Solar energy at locations with sufficient amount of sun hours over the whole year, such as e.g. in the tropics, is used to fully power the whole invented farming system. During the night time, the steel tanks and other farm equipment are powered by batteries/energy storage device which have been charged during daytime.

[0018] Furthermore, the solar panels form a protective shelter for growing crops on their own. Conventionally, shelters are built to protect growing plant crops. On such shelters, solar panels can be installed on their roofs. Here in the invented farming system, the solar panels themselves form the protective shelter without requiring an existing roof as platform, which simplifies its construction and decreases its building costs.

[0019] The invented farming solution is very versatile and can grow different types of plants, such as leafy vegetables, plant crops or single cell plants/fungi/other microorganisms by combining steel tank farming and hydroponics. By using steel tank farming, it has a very high productivity of growing food crops in a small space which is important to cover the increasing demand for food of the growing global population.

[0020] By introducing circular economy, it is very water efficient and minimizes water-loss and the generation of liquid waste, which makes the farming process more sustainable and environmentally friendly. Furthermore, minimizing the generation of liquid waste reduces the costs for disposal charges if applicable. Therefore, the invented farming system might also be deployed as urban farm in cities where water consumption and waste management are critical factors.

[0021] Nutrients which are present in the wastewater from hydroponics and steel tank farming, are recovered by microalgae cultivation in photo-bioreactors. The resulting microalgal biomass can be used as plant growth enhancer in hydroponics improving the productivity of plant growth.

[0022] Another advantage of the invented system is the independent and sustainable energy supply. Since it is fully powered by solar energy, its power supply is reliable and stable. This system can also be deployed in rural areas where it might be difficult to have a stable power supply by the local power grid. The independent power supply also has the advantage that it is free of energy cost fluctuations. Crisis in recent years have shown the energy costs can vary a lot and become more expensive. This is major concern for such farming approaches such as steel tank farming because the energy costs are the major costs in such processes.

[0023] The present invention discloses an integrated farming system having a protective shelter formed with solar panel roofing, the protective shelter housing:

- a system for microorganism cultivation;
- a hydroponic system; and
- a wastewater treatment system,

whereby the wastewater treatment system is adapted to treat wastewater exiting from the system for microorganism cultivation and wastewater exiting from the hydroponic system.

[0024] Preferably, the solar panel roofing of the present invention is formed by connecting a plurality of solar panels supported on a grid support.

[0025] Preferably, the hydroponic system and system for microorganism cultivation are powered by electrical energy generated by the solar panel roofing.

[0026] Preferably, an energy storage device is included for storing excess electrical energy generated by the solar panel roofing during the day.

[0027] Preferably, the system for microorganism cultivation employs steel tank food farming technology.

[0028] Preferably, the microorganism cultivated are microalgae or fungi wherein the microalgae is selected from at least one species of the following group: green microalgae such as *Chlorella* sp., *Auxenochlorella* sp., *Chlamydomonas* sp. and the fungi is selected from at least one species of the following groups: filamentous fungi such as *Aspergillus oryzae* and yeasts such as *Candida utilis*.

[0029] Preferably, the microorganisms are cultivated in liquid growth medium to a cell density suitable for harvesting.

[0030] Preferably, the cell density suitable for harvesting is 10g - 60g dry cell mass per liter.

[0031] Preferably, the water treatment system of the present invention comprises:

- a wastewater collection tank adapted to receive wastewater from the system for microorganism cultivation and wastewater from the hydroponic system;
- a photo-bioreactor adapted to receive wastewater from the wastewater collection tank;
- a collection tank adapted to receive liquid culture exiting from the photo-bioreactor;
- a clarifying device adapted to separate the liquid culture to solids and liquid waste;
- a disinfecting chamber adapted to disinfect the liquid waste;
- a water filtration system adapted to filter the disinfected liquid waste; and
- a collection tank for storing the filtered disinfected liquid waste.

[0032] Preferably, the filtered disinfected liquid waste of the water treatment system is channelled back to the hydroponic system to compensate water-loss which is caused by evapo-transpiration.

[0033] Preferably, liquid solution in the hydroponic system is removed and replaced using filtered disinfected liquid waste from the wastewater treatment system every 3 – 4 months.

[0034] Preferably, microalgae is cultivated in the photo-bioreactor and selected from at least one species of the following groups: green microalgae such as *Chlorella* sp., *Auxenochlorella* sp., *Chlamydomonas* sp. *Haematococcus* sp. and *Tetraselmis* sp., red microalgae such as *Rhodomonas* sp., blue-green microalgae such as *Arthrospira* sp.

[0035] Preferably, cultivation of the microalgae is conducted until concentration of accumulated nutrients from the wastewater is lowered to a level which does not lead to phytotoxicity.

[0036] Preferably, cultivation of the microalgae last from a couple of days to two weeks.

[0037] Preferably, the cultivated microalgae is harvested and treated such that the resulting treated biomass is suitable for use in the hydroponic system to enhance growth of the crop.

[0038] Preferably, leafy vegetables or herbs or a combination of both are grown in the hydroponic system.

[0039] Preferably, the hydroponic system comprises an artificial light source.

[0040] Preferably, the artificial light source is LED lights.

[0041] Preferably, the LED lights are switched on for 12 hours per day and generating a light intensity of 300 to 400 $\mu\text{mol per m}^2 \text{ per sec}$.

Brief description of drawings

[0042] An embodiment of the invented system will now be described by way of example only with reference to the accompanying drawings in which:

[0043] Fig 1 is a schematic flow diagram of the process flow in the invented farming system;

[0044] Fig 2A is a side elevation view of the protective shelter;

[0045] Fig 2B is the front elevation view of the protective shelter shown in Fig 2A;

- [0046] Fig 3A shows the footing detail of the columns in the protective shelter;
- [0047] Fig 3B shows the connection detail between purlins to metal beams;
- [0048] Fig 3C shows the connection detail between two purlins on the metal beam;
- [0049] Fig 3D shows the connection detail between vertical columns and horizontal beams;
- [0050] Fig 3E shows the sag-rod links between the purlins;
- [0051] Fig 3F shows the solar panels installation on a panel railing system;
- [0052] Fig 3G shows the installation of a solar panel railing system on a purlin
- [0053] Fig 4 shows the schematic diagram of an electric system involving solar energy harvesting;
- [0054] Fig 5 shows the schematic diagram of the steel tank farming component in the invented farming system stated in Fig 1;
- [0055] Fig 6 shows the schematic diagram of the hydroponic farming component in the invented farming system stated in Fig 1;
- [0056] Fig 7 shows the schematic diagram of the wastewater treatment system in the invented farming system stated in Fig 1;
- [0057] Fig 8A shows the top view on installed solar panels which are shown in Fig 3F;
- [0058] Fig 8B shows the bottom view on installed solar panels which are shown in Fig 3F;
- [0059] Fig 8C shows the side view of installed solar panel with U-channel.

Detailed description

[0060] Referring to Fig 1, the invented farming solution consists of protective shelter 1 made out of solar panel ceiling 2, steel tank farming component 3, hydroponic farming component 4 and wastewater treatment component 5. Steel tank farming component 3, hydroponic farming component 4 and wastewater treatment component 5 are located beneath the protective shelter 1 to be protected against environmental factors.

Protective solar panel shelter

[0061] The solar panels shelter is uniquely constructed to provide shelter structure as well as solar energy via photovoltaic (PV) module for farming activities or charging activities. The following components are required:

- a) Concrete footing
- b) Vertical metal columns
- c) Horizontal steel beams
- d) C channel beam purlins
- e) Solar panel railing
- f) Solar panels
- g) DC cable
- h) Inverter
- i) AC cable
- j) Main-switchboard
- k) Battery (energy storage device)

[0062] The protective shelter consists of components a) to f). The side elevation and the front elevation of the protective shelter are shown in Fig 2A and Fig 2B. The vertical metal columns 6 are made out of steel or comparable robust material. The diameter of the vertical metal columns 6 should not be smaller than 10 cm and are mounted to the ground. A concrete footing 10 is required to provide essential support to carry the load of the shelter and solar panels. The rebar mesh is laid flat on the installation site to add additional strength to the solar panel structure. Referring to Fig. 3A, the vertical metal column 6 is connected to the steel plate 11 via welding which is installed during the concrete footing casting 10 using 4 anchor bolts 12 with at least 100mm embedment. The vertical metal columns 6 should be in intervals of a few meters but not more than 7m. The height of the vertical metal columns 6 should be sufficient for farming but should not exceed 5m to endanger the stability of the shelter construction.

[0063] The details of the connections of the components with each other in the protective shelter are shown in Fig 3A-3G. The (horizontal) metal beams 7 connect the vertical metal columns 6 with each other to form a stable metal construction frame which is shown in Fig 3D. They (6 with 7 and also 7 with 7) are connected with each other by welding via a steel plate 13 that is fixed to the vertical metal columns 6 and metal beams 7 by fillet welding. The metal beams 7 should be made of steel or comparable robust material. The diameter should not be less than 10cm. They are fixed with bolts nuts to the steel column 6.

[0064] Referring to Fig 3B-C, C-channel beams are used as purlins 8 to form the base for the solar panel mounting structure. The purlins 8 should have a width not less than 5 cm and should be made of steel or comparable robust material. The distance of the purlins 8 to

each other depends on the size of the solar panels 9 which are used since their size determines where the solar panel railing system 18 has to be fixed to hold the solar panels 9. The purlins 8 are connected to the metal beams 7 using L-shaped angles 14, which are fixed to the metal beams 7 by fillet welding 15, and bolts 16. The purlins 8 are aligned in lines and their ends are connected by using bolts 16 fix them on the same L-shaped angle 14. Furthermore, the purlins 8 are connected with each other by using sag rods with lock nuts and washers at both ends 17 providing lateral support for the purlins 8 as it is shown in Fig 3E.

[0065] Referring to Fig 3F-G, a solar panel railing system 18 is used to hold the solar panel ceiling 2. L-feet 19 are installed on the purlins 8 to fix the solar panel railings. T-nuts 20 are used to hold the L-feet and the solar panel railing together. Mid clamps 21 are installed in the middle of the solar panel railing as a holder/clamp to prevent the solar panels from slipping. Additionally, end clamps 22 are installed at the ends of the solar panel railing as a holder/clamp to prevent the solar panel from slipping. Solar panels 9 are installed by slipping them on the solar panel railing system 18 forming the ceiling of the protective railing system.

[0066] Alternatively to the description above, the solar panel railing system 18 can be directly used as purlins without using C-channel beams 8. The solar panel railing system 18 will be fixed directly on the steel beams 7. The advantage of adopting the alternative construction method, i.e. not using the C-channel beams for building the protective solar panel shelter, is more cost saving.

[0067] Typically, solar panels 9 arranged on such railing systems have a gap of one to up to a few cm in between of the solar panels at their long side (with the mid clamp). Water can seep through this gap when it is raining.

[0068] Referring to Fig 8A-B, to make the solar panel ceiling 2 waterproof, U-channels 55 are mounted to the solar railing system 18 by welding/soldering directly beneath/parallel to those gaps. Alternatively, the U-channels 55 can be fixed to the solar panel railing systems 18 by using bolts with nuts and the linking points will be then sealed waterproof by using silicone or comparable material. Referring to Fig 8C, the downstream ending of the U-channels 55 is linked to a part of the solar panel railing system 18 which can be used as water channel. The rain water, which has been collected by the mounted U-channels 55, can flow through the solar panel railing system 18 channels to the side ends of the solar panel ceiling.

[0069] Solar panel ceiling 2 generates electricity in DC current. The silicon solar cell as the base absorbs sunlight in which the photons from the sunlight excites electrons to high energy states. Activated electrons are flown to the external circuit or load. Referring to Fig

4, solar panels 9 are electrically linked to arrays and DC cables 23 in trunking connect them via DC combiner box 24 and charge controller 25 to an inverter 26. The inverter 26 converts the harnessed energy from DC to AC. An AC cable 27 in trunking runs through a riser to the Main Switchboard (MSB)/AC Distribution box 28. Breakers 29 are implemented for safety reasons. The harnessed energy is transmitted through the MSB/AC distribution box to facility or building loads. An energy storage device/battery 30 is used to store excessive energy which is harnessed during the day and can be used to power the equipment overnight when there is no sunlight. The usage of a substation with a connection to the power grid is optional but can have the advantage of additional security in energy supply for the farming system when there is a problem with the solar system.

Steel tank farming component

[0070] The term "steel tanks for farming" refers to steel tanks 31, which can be used for growing fungal/plant/microbial biomass for food purposes. Different sizes of steel tanks 31 are used in the invented farming system from seed culture to scaled-up culture, which can range from 10L to 3000L steel tank volume. These steel tanks 31 might have the following supplemental equipment:

- i) heating unit
- ii) cooling unit
- iii) air compressor/pump
- iv) cleaning unit (CIP)
- v) sterilization system
- vi) motor/engine for stirrer
- vii) harvesting device

[0071] By using such steel tank technology, one or several of the following factors/parameters can be provided and/or regulated to optimise the growth of plants/fungi/other microorganisms:

- a) temperature measurement of the interior liquid culture medium
- b) aeration of the culture
- c) pH measurement of the culture medium
- d) foam formation detection and adding anti-foam to the culture
- e) agitation and stirring of the liquid culture
- f) feeding the culture with nutrients
- g) dissolved oxygen measurement in liquid medium
- h) Cleaning and sterilization process

[0072] Referring to Fig 5, the factors/parameters to optimize cell growth can be controlled via a farming control panel 33. The piping which connects the steel tanks 31 with the supplemental equipment, is made of stainless steel and should not have a diameter less than 5 cm. The liquid pumps for pumping water, liquid medium, liquid plant/fungi culture or wastewater are either centrifugal pumps and/or screw pumps. All steel tanks are linked with each other by stainless steel pipes 32, which allows the operator to pump the seed cultures to the next larger steel tank 31 to scale up the cultivation without risking contamination of the cultures. The temperature of the cultures can be changed by using a cooling system 34. Aeration in the tanks is provided by an air-compressor system 35. A sterilization system 36 and a cleaning unit 37 are integrated in the steel tank system to ensure that the steel tanks 31 are kept clean and that no unintended contamination occurs in the system.

[0073] The growth medium with its nutrients for growing microorganisms is prepared in a mixer tank 38. After adding the nutrients and preparing the growth medium, it undergoes sterile filtration 39, which is a necessary step to avoid any contamination caused by water or other medium ingredients. After sterile filtration 39, the fresh growth medium is ready to use and can be pumped into each steel tank via stainless steel pipes 40.

[0074] After cultivation of plant/fungi cells in the steel tanks 31, the culture is pumped to the harvesting device which can be a disc centrifuge 41 or a vacuum/pressure filtration system. In the disc centrifuge 41, the fungal/microalgal/microbial biomass produce (solids) is separated from the liquid waste.

Hydroponic farming component

[0075] Referring to Fig 6, the hydroponic farming component consist of rack systems with several tiers or other hydroponic systems such as Mobile Gully systems 42. Water reservoirs with liquid pumps 43 provide a circulation of the nutrient solution in the hydroponic system 42 via piping 44 made of stainless steel or plastic (e.g. PVC). Water chillers 45 located at the water reservoirs 43 maintain the water temperature within a tolerable range.

[0076] During the growing process, there is a water-loss caused by evapo-transpiration of the growing plants, which also leads to an accumulation of certain nutrients in the nutrient solution over time. As a consequence, the nutrient solution has to be

- a) topped up frequently with fresh nutrient solution to compensate the water-loss
- b) replaced completely with fresh nutrient solution in certain time intervals because of the accumulation of certain nutrients and other compounds which reduces plant growth efficiency.

[0077] The expended nutrient solution, which has to be replaced, is filtered first and used for cultivation in the photo-bioreactor of the wastewater treatment component. For this, the water reservoirs 43 are connected with the wastewater treatment component via pipes 46 which are made out of stainless steel or plastic (e.g. PVC). Furthermore, another pipe system, (whose pipes are also made out of stainless steel or plastic (e.g. PVC)) coming from the wastewater treatment component to the water reservoirs, is for pumping the treated up-cycled wastewater back into the hydroponic farming component. The diameter of the pipes in the hydroponic farming component should not be less than 2cm and larger than 8cm.

Wastewater treatment component

[0078] The wastewater treatment component consists of

- a) liquid pumps,
- b) tubular centrifuge,
- c) UV light disinfection device,
- d) ozone generator,
- e) liquid filtration systems (particle filtration), and
- f) liquid collection tanks, and
- g) one or more photo-bioreactors

[0079] All pipes of the wastewater treatment component are made of stainless steel or plastic (e.g. PVC) and should not have a diameter less than 5cm. Referring to Fig 7, wastewater from the hydroponic farming component and the steel tank farming component is collected in a wastewater collection tank 47 which is made of PE or other plastic. From the wastewater collection tank 47, the wastewater is pumped into a photo-bioreactor 48. The photo-bioreactor system 48 is made of a transparent material which can be either glass, acrylic glass, or PE/PPP plastic, so artificial or natural external light can penetrate into the liquid culture for photo-synthetic growth. LED lights are used as artificial light during cultivation with a light intensity of 200-600 $\mu\text{mol per m}^2 \text{ per sec}$ for 12-16 hours per day. The shape of the photo-bioreactors can be vertical and/or horizontal tube-shaped. Further components in a photo-bioreactor system are liquid pumps and air-pumps which are necessary to perform agitation/aeration of microbial cultures during cultivation process. In the invented farming system, one photo-bioreactor can have the volume of 1000L-5000L.

[0080] The cultivation process is performed for a duration of several days to two weeks until the concentration of accumulated nutrients is lowered to a level which does not lead to phytotoxicity. After this cultivation step, the liquid culture is collected in a collection tank 49 which is made of PE or comparable plastic. A tubular centrifuge 50 separates solids such as e.g. Microalgae cells from the liquid culture. The liquid waste is disinfected by i) UV

disinfection 51 and ii) Ozone treatment 52. After the disinfection process, it is filtered to remove particles larger than 5µm using a water filtration system 53.

[0081] The filtered liquid is collected in collection tank 54, which is made of PE or comparable plastic, and can be reused in the hydroponic farming component.

Fungal/plant/microbial biomass

[0082] The fungal/plant/microbial biomass grown in the steel tank farming component comprises at least one species of the following groups: green microalgae (such as *Chlorella* sp., *Auxenochlorella* sp., *Chlamydomonas* sp.), filamentous fungi such as *Aspergillus oryzae* or yeasts such as *Candida utilis*.

[0083] Such microalgae and fungi are grown using a nutrient-rich growth medium containing organic and inorganic nutrients.

[0084] Microalgae are grown in steel tanks 31 for food applications as well as in photo-bioreactor 48 for wastewater treatment (bio-remediation) producing plant growth enhancing supplements as by-product.

[0085] In a first embodiment, the cultivation of the microalga *Chlorella* sp. which can grow heterotrophically (without the need of a light source) in steel tanks 31 is performed. The pH value in the growing culture is maintained within 6-8. A stirrer permanently mixes the culture homogeneously. An air-compressor system 35 pumps sterile air into the steel tank cultures (0.5-1vvm) providing the growing cells with oxygen. For this, the dissolved oxygen level in the steel tank cultures is kept in a range of 20-40%. The temperature of the cultures is maintained within a range of 25-38°C using a cooling system 34.

[0086] The cultivation of *Chlorella* sp. in steel tanks 31 is performed in up-scaling steps. As example, seed-culture 1 has a culture volume of 10-20L which is used for inoculation of seed-culture 2 with a culture volume of 100-200L. Seed-culture 2 is used for inoculation of the steel tank culture for *Chlorella* sp. production, which has a volume of 2000-3000L. The *Chlorella* sp. cultures in steel tanks 31 are cultivated for 3-5 days until a cell density of 10-60g dry cell mass per liter has been reached. Then the *Chlorella* sp. cultures can be harvested.

[0087] The cultivation of the *Chlorella* sp. in the steel tanks 31 is performed under sterile conditions using axenic microalgae strains. The steel tanks 31 are washed with hot water using a cleaning unit 37 after each cultivation cycle and sterilised by a sterilisation system 36 using water steam. Furthermore, to avoid contamination from the culture medium, water

and nutrient components are sterilised either by sterile filtration 39 or sterilised by heat reaching 100°C or 121°C using water steam, respectively. Sterile filtration is performed with a pore size of 0.2microns or 0.4microns, respectively.

[0088] In this embodiment, *Chlorella* sp. which have been grown in the steel tanks 31, are harvested by using a disc centrifuge 41, which generate gravitational forces of >10000 g, to produce dewatered *Chlorella* sp. paste. This *Chlorella* sp. paste can be either dried or stored in a chiller/freezer or directly implemented into food.

Hydroponic farming component

[0089] In this same embodiment, leafy vegetables *Lactuca sativa* (butterhead lettuce) and herbs *Ocimum basilicum* (sweet basil) are grown in the hydroponic farming component. The nutrient solution for growing these crops contains organic compounds and inorganic minerals.

[0090] LED lights are used as artificial light source since the hydroponic farming component is located beneath a protective shelter. Plants are transferred as seedlings from a nursery to the hydroponic racks. The growing cycles of *Lactuca sativa* and *Ocimum basilicum* take about 4-5 weeks when grown in hydroponics until being harvested. The LED lights are switched on for 12h per day generating a light intensity of 300 to 400 μmol per m^2 per sec. Ventilators can be used to remove the hot air which is heated up by the LED lights.

[0091] The pH and electric conductivity (EC) of the nutrient solution is measured frequently and maintained between 5.5-6.2 (pH) and 0.5-2mS/cm (EC), respectively. The pH is regulated by using pH adjusters such as pH-up or pH-down solutions which can be added to the solution in the water reservoirs 43. EC is maintained by either replenishing nutrients or regulating the water refilling in the water reservoirs 43.

[0092] If required, the temperature of the nutrient solution is maintained at 25-27°C by using water chillers 45 to prevent heat stress on the plants. A water pump at the water reservoirs 43 permanently pumps the cooled nutrient solution from the water reservoir to the hydroponic racks. Then, the water flows back down to the water reservoir 43 due to gravity forming a closed loop.

Up-cycling of liquid waste for hydroponics

[0093] In this same embodiment, the generated clear nutrient-rich liquid in the centrifugation process of the microalgae harvest process from the steel tank farming component is used for the cultivation of microalgae in the photo-bioreactor 48 for the bio-remediation process. In general, this liquid should still have a sufficient amount of nutrients (remnants from the cultivation in the steel tanks) for microalgae cell cultivation in photo-

bioreactor 48. However, if one of the essential nutrients has been depleted at the end of the cultivation cycle in the steel tanks, it can be easily replenished by adding to the photo-bioreactor culture for a healthy cell growth.

[0094] *Chlorella* sp. in the photo-bioreactor 48 for bio-remediation are grown either photo-autotrophically or mixotrophically using LED light as a light source. Other species of microalgae from the following groups: green microalgae (such as *Auxenochlorella* sp., *Chlamydomonas* sp. *Haematococcus* and *Tetraselmis* sp.), blue-green microalgae (such as *Arthrospira* sp.), red microalgae (such as *Rhodomonas* sp.) can be grown for this purpose.

[0095] The pH value of the *Chlorella* sp. cultures in the photo-bioreactor 48 is maintained between 6-8. The aeration of the culture is achieved by exposing the culture surface to the atmospheric air. To keep the growing conditions homogenous in the culture, the *Chlorella* sp. cells are either agitated by stirring devices or by moving air-bubbles generated by an air-pump in a tubular photo-bioreactor system. The temperature of the culture is monitored but not regulated since *Chlorella* sp. grow well at ambient temperatures and extreme heating up of the cultures in the photo-bioreactor 48 is not expected. The *Chlorella* sp. cultures in the photo-bioreactor 48 are cultivated for 1-2 weeks until reaching a cell density of 1-3g dry cell mass per liter.

[0096] The produced *Chlorella* sp. biomass will be separated from the liquid by a tubular centrifuge 50, which generate gravitational forces of >10000 g producing a *Chlorella* sp. paste and a clear liquid. This *Chlorella* sp. biomass can be used as a plant growth enhancing supplement. For this, the cell wall of the *Chlorella* sp. cells in the produced biomass has to be "softened" by certain treatments such as e.g. enzymatic treatment (such as e.g. Hemicellulases, cellulases and xylanases) before killing the cells by exposing them to 75°C, 88°C, 100°C or 121°C for several minutes. The resulting treated biomass can be added to the hydroponic farming component to enhance the growth of the selected crops.

[0097] The clear liquid gained from the centrifugation step undergoes instant UV disinfection 51 treatment to kill the vegetative cells before being collected in a collection tank 54. The instant UV light treatment is performed with a wavelength of 250-260nm and an intensity of 40mJ/cm². In the next step, the liquid is exposed to ozone treatment 52 (ozone water concentration of 0.8-1.5 ppm) in a closed loop system at the ozone generator for a few hours to make sure that spores, viruses and even non-desired free enzymes are also inactivated. These contaminants are difficult to eliminate and can cause severe harvest losses in hydroponic systems by infecting growing plant crops. After ozone treatment 52, the liquid is filtered at the filtration system 53 to remove precipitates and other solids larger than 5 microns which might have been formed during the treatment process. After filtration, the electric conductivity (EC) and pH of the treated liquid are measured and, if necessary, also set to a suitable range (0.5-2mS/cm for EC and 5.5-6.2 for pH) for the

selected plant crops. Then, the treated liquid can be up-cycled to the hydroponic farm to compensate for the water-loss caused by evapo-transpiration.

List of numbered elements in drawings:

Protective shelter	1
Solar panels ceiling	2
Steel tank farm	3
Hydroponics	4
Wastewater treatment part	5
Vertical metal columns	6
(horizontal) metal beams	7
Purlins	8
Solar panels	9
Concrete footing	10
Steel plate	11
Anchor bolts	12
Steel plate	13
L-shaped angles	14
Fillet welding	15
Bolts	16
Sag rods with lock nuts and washers	17
Solar panel railing system	18
L-feet	19
T-nuts	20
Mid clamps	21
End clamps	22
DC cables	23
DC combiner box	24
Charge controller	25
Inverter	26
AC cable	27
Main Switchboard (MSB)/AC Distribution box	28
Breakers	29
Energy storage device/battery	30
Steel tanks	31
Stainless steel pipes	32
Farming control panel	33
Cooling system	34
Air-compressor system	35

Sterilization system	36
Cleaning unit	37
Mixer tank	38
Sterile filtration	39
Stainless steel pipes	40
Disc centrifuge	41
Rack systems with several tiers or other hydroponic systems	42
Water reservoirs with liquid pumps	43
Piping	44
Water chillers	45
Pipes	46
Wastewater collection tank	47
Photo-bioreactor	48
Collection tank	49
Tubular centrifuge	50
UV disinfection	51
Ozone treatment	52
Filtration system	53
Collection tank	54
U-channel	55

What is claimed is

1. An integrated farming system having a protective shelter formed with solar panel roofing, the protective shelter housing:
 - a system for microorganism cultivation;
 - a hydroponic system; and
 - a wastewater treatment system,whereby the wastewater treatment system is adapted to treat wastewater exiting from the system for microorganism cultivation and wastewater exiting from the hydroponic system.
2. The integrated farming system of claim 1, wherein the solar panel roofing is formed by connecting a plurality of solar panels supported on a grid support.
3. The integrated farming system of claim 2, wherein the hydroponic system and system for microorganism cultivation are powered by electrical energy generated by the solar panel roofing.
4. The integrated farming system of claim 3, further comprising an energy storage device for storing excess electrical energy generated by the solar panel roofing during the day.
5. The integrated farming system of claim 1, wherein the system for microorganism cultivation employs steel tank food farming technology.
6. The integrated farming system of claim 5, wherein the microorganism cultivated are microalgae or fungi wherein the microalgae is selected from at least one species of the following group: green microalgae such as *Chlorella* sp., *Auxenochlorella* sp., *Chlamydomonas* sp. and the fungi is selected from at least one species of the following groups: filamentous fungi such as *Aspergillus oryzae* and yeasts such as *Candida utilis*.
7. The integrated farming system of claim 6, wherein microorganisms are cultivated in liquid growth medium to a cell density suitable for harvesting.
8. The integrated farming system of claim 7, wherein the cell density suitable for harvesting is 10g - 60g dry cell mass per liter.

9. The integrated farming system of claim 1, wherein the water treatment system comprises:
- a wastewater collection tank adapted to receive wastewater from the system for microorganism cultivation and wastewater from the hydroponic system;
 - a photo-bioreactor adapted to receive wastewater from the wastewater collection tank;
 - a collection tank adapted to receive liquid culture exiting from the photo-bioreactor;
 - a clarifying device adapted to separate the liquid culture to solids and liquid waste;
 - a disinfecting chamber adapted to disinfect the liquid waste;
 - a water filtration system adapted to filter the disinfected liquid waste; and
 - a collection tank for storing the filtered disinfected liquid waste.
10. The integrated farming system of claim 9, wherein the filtered disinfected liquid waste is channelled back to the hydroponic system to compensate water-loss which is caused by evapo-transpiration.
11. The integrated farming system of claim 9, wherein liquid solution in the hydroponic system is removed and replaced using filtered disinfected liquid waste from the wastewater treatment system every 3 – 4 months.
12. The integrated farming system of claim 9, wherein microalgae is cultivated in the photo-bioreactor and selected from at least one species of the following groups: green microalgae such as *Chlorella* sp., *Auxenochlorella* sp., *Chlamydomonas* sp., *Haematococcus* sp. and *Tetraselmis* sp., red microalgae such as *Rhodomonas* sp., blue-green microalgae such as *Arthrospira* sp.
13. The integrated farming system of claim 12, wherein cultivation of the microalgae is conducted until concentration of accumulated nutrients from the wastewater is lowered to a level which does not lead to phytotoxicity.
14. The integrated farming system of claim 13, wherein cultivation of the microalgae last from a couple of days to two weeks.

15. The integrated farming system of claim 14, wherein the cultivated microalgae is harvested and treated such that the resulting treated biomass is suitable for use in the hydroponic system to enhance growth of the crop.
16. The integrated farming system of claim 1, wherein leafy vegetables or herbs or a combination of both are grown in the hydroponic system.
17. The integrated farming system of claim 1, wherein the hydroponic system comprises an artificial light source.
18. The integrated farming system of claim 17, wherein the artificial light source is LED lights.
19. The integrated farming system of claim 18, wherein the LED lights are switched on for 12 hours per day and generating a light intensity of 300 to 400 $\mu\text{mol per m}^2 \text{ per sec}$.