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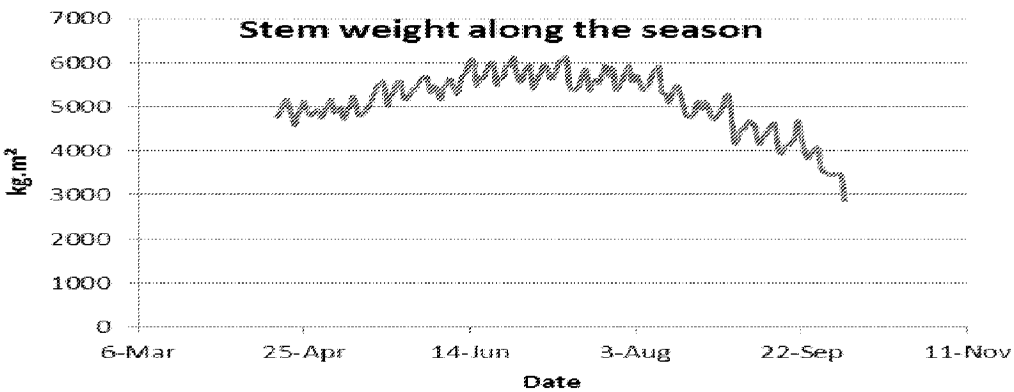

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The present invention discloses system and method for crop yield forecast of various fruit and vegetable plants grown for industrial purposes. The system forecasts actual crop yield, namely present and future yield, considering the particular efficiency of forecasted and actual radiation intensities of natural and possibly artificial lighting applied to the greenhouse on a specific plant species. The system and method are employed for planning including cost-effective management of a greenhouse including scheduling of operations intended for the planting, growing, harvesting, picking, shipping and marketing of selected amount of crops in a selected season of a particular year.

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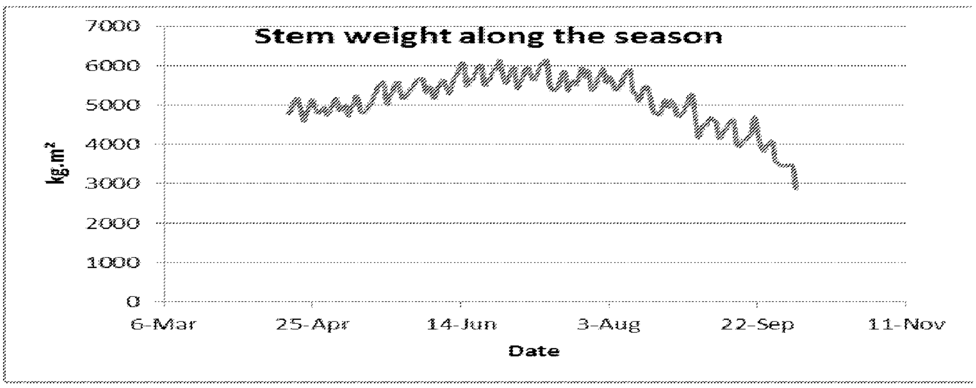

Fig. 1

(57) Abstract: The present invention discloses system and method for crop yield forecast of various fruit and vegetable plants grown for industrial purposes. The system forecasts actual crop yield, namely present and future yield, considering the particular efficiency of forecasted and actual radiation intensities of natural and possibly artificial lighting applied to the greenhouse on a specific plant species. The system and method are employed for planning including cost-effective management of a greenhouse including scheduling of operations intended for the planting, growing, harvesting, picking, shipping and marketing of selected amount of crops in a selected season of a particular year.

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Yield Forecast and Light Use Efficiency

Technical Field

The present invention pertains to crop yield forecast system of various fruit and vegetable plants grown for industrial purposes. More particularly, the present invention pertains to system and apparatus which are capable of measuring the vegetative and productive crop growth components, calculating the instantaneous yield and generating a prediction of yield forecast for several weeks ahead. Particularly, the system is configured to calculate and determine the completing amount of artificial radiation which is required to obtain an optimal crop yield for a certain type of plant in a certain area in the greenhouse according to the measured natural radiation.

Background

In a weight measuring system as disclosed in WO 2013/065043 assigned to the applicant of the present application, plants weight is continuously measured with weighing units trellising from an elevated wire and connected to the plants in a greenhouse. The weighing units wirelessly transmit the measurement data to a base station in the greenhouse that transmits them to a server for processing and analysis. Noise filtering and data analysis are carried out with dedicated filtering and analysis tools. The results may also be directly sent to the grower through the web.

The total measured fresh weight enables providing information on growth rate, identifying local deviations from normal growth, guiding towards a proper growth strategy and making instant comparison between current growth supporting technologies. However, the total measured fresh weight of the plants is not sufficient for assessing crop yield. In addition, the particular efficiency of lighting on crop yield is not fully investigated in the weight measuring system described above.

It is, therefore, an object of the present invention to adjust the weight measuring system described above to weigh and calculate the distribution between total vegetative and productive crop growth components in plants in a greenhouse.

It is yet another object of the present invention that the calculation and weighing of the vegetative and productive components is done in real-time.

It is yet another object of the present invention that this adjusted weight measuring system predicts crop yield.

It is yet another object of the present invention that this weight measuring system assesses the quantitative contribution of natural light and artificial lighting to enhanced photosynthesis in crops and optimizes it for greater crop yield per energy unit invested.

It is yet another object of the present invention that the adjusted weight measuring system makes the use of lighting more efficient in terms of energy saving and increased crop yield.

Summary of Invention

In one aspect, the present invention provides a system for determining the ratio between the Vegetative Calculated Component (VCC) and Productive Calculated Component (PCC) that make the Total Measured Fresh Weight (TMFW) of plants in real-time. Further, the system of the present invention enables predicting and forecasting the Actual Crop Yield (ACY) and better allocation of resources for achieving the predicted ACY. It should be pointed out that the TMFW represents that fresh weight, which is added to the plant and not the total weight of the plant after the addition of that fresh weight. The ACY represents the current yield that is forecasted for a certain point in time ahead, e.g., 3-4 weeks ahead, for a particular greenhouse under certain conditions and based on measured growth of the plants.

To obtain this, in one embodiment, the system of the present invention comprises a dedicated filter for identifying variations in plants weight, for example, measured weight losses. Generally, such losses in plants weight arise from harvesting or deleafing, i.e., leaf removal, and distinguishing between PCC and VCC weight is assisted by dedicating separate times, e.g., days or hours during a day, for the two activities.

In view of the above, the present invention provides a system for predicting the actual crop yield, ACY, that comprises:

– **a plurality of weighing units, the weighing units distributed** in the greenhouse, each one of the weighing units is attached to a single plant or group of plants and comprises means for weighing the plant or group of plants, the weighing units are trellising from an elevated wire on one end and connected to the top end of the plant or group of plants on the opposite end;

– **a communication network comprising means for communicating the** weight of the plant or group of plants from the weighing units to a central unit;

- a central unit. Such central unit comprises:

- a dedicated filter for identifying variations in plants weight, for example, measured weight losses. Generally, such losses in plants weight arise from harvesting or deleafing, and distinguishing between PCC and VCC weight is assisted by dedicating separate times, e.g., days or hours during a day, for the two activities;
- means for receiving, storing, processing and analyzing the data received from the weighing units through the communication network;
- a software tool component that is configured to determine the ratio between the Vegetative Calculated Component (VCC) and Productive Calculated Component (PCC) that make the Total Measured Fresh Weight (TMFW) of plants in real-time;
- a software tool component that is configured to calculate the contribution of light energy from natural and optional artificial sources to crop yield. Accordingly, if artificial radiation source is applied, the system of the present invention is configured to guide the grower on the intensity of artificial light and period of time of exposure of the plants for optimal ACY; Particularly, such guidance is useful in transition seasons with lower exposure to natural outside light radiation;
- a software tool component that is configured to generate a prior forecast of the total radiation, which will be applied in a specific greenhouse at a certain area on specific plant species in the greenhouse during its growing time period, and perform a further characterization and determination of its relation to other important parameters such as its accumulated plant crop performance during the growing time period; and

- a software tool component that is configured to perform a prediction and forecasting of Actual Crop Yield (ACY) for a future period of time based on measured TMFW (total measured fresh weight) of plants, VCC (vegetative calculated component) and PCC (productive calculated component) and allocation of resources for obtaining the predicted ACY.

Further, the central unit may comprise, a dedicated feedback control unit for optimization of the forecasted ACY that comprises:

- a software tool component that is configured to gather and analyze all the required processed and unprocessed data which are received at the central unit. The data comprises the measured plants weighing data, including the extracted VCC, PCC and TMFW parameters, the actual and forecasted radiation and ACY data of the greenhouse including other local environmental conditions and general climate required data obtained by the central unit from the various sensors which are distributed inside the greenhouse or from external general web and other external databases; and
- an optimization software tool component for the forecasted ACY and optimization of ACY distribution inside the greenhouse for a specific plant located in a specific area inside the greenhouse. This software tool component is configured to generate a set of executable actions and recommendations for correction and modification of various control parameters inside the greenhouse. Examples of such parameters are the greenhouse recommended distribution of environmental temperature and humidity, intensity of artificial radiation and recommended distribution inside the greenhouse for a given artificial light source configuration. In general, important parameters which affect the plant growth such as plant irrigation are also collected and processed by the optimization software tool for determining the correlation between optimal crop yield and light radiation.

Such distribution is configured in conjunction with the natural light source. Optional artificial light radiation source apparatuses are configured, for example, in manual or automatic modes of control. In another embodiment of the present invention, the apparatuses are configured to communicate and be controlled by the central unit.

In one particular aspect, the dedicated filter of the system of the present invention is further configured to calculate the contribution of light energy from natural and artificial sources to crop yield. Accordingly, the system of the present invention is configured to guide the grower on the intensity of artificial light and period of time of exposure of the plants for optimal ACY. Such guidance is particularly useful in transition seasons with lower exposure to natural outside light radiation.

Further, based on TMFW, VCC and PCC, the central unit of the system of the present invention is also configured to predict future yield (ACY) in any particular greenhouse with known climate and environmental and growth conditions.

The central unit of the system of the present invention is also configured to provide a forecast of ACY based on accumulated data from measurements made in a particular greenhouse and for a variety of crops, e.g., tomato, cucumber. The system of the present invention is also configured to process and analyze data from a plurality of greenhouses in different climates and environment and growth conditions and provide at least short term forecast for a particular greenhouse based on such analysis. Particularly, the short term may be between three to four weeks ahead based on accumulated previous data obtained from a specific greenhouse and/or a plurality of greenhouses in different climate and environmental growth conditions in different parts of the world and in different seasons of the year. The forecasting of ACY with the system of the present invention enables to make more efficient use of the resources allocated for a grower for the preparation and marketing of crops. This way, the grower can minimize expenses and maximize profits. Therefore, in one embodiment, the present invention provides a system and method for planning cost-effective management of a greenhouse including scheduling of operations intended for the planting, growing, harvesting, packing, shipping and marketing of selected amount of crops in a selected season of a particular year.

In one particular aspect of the invention, the weighing measuring system is configured to make use of lighting more efficient in terms of energy saving and increased crop yield. In another particular aspect of the invention, the weighing measuring system is further configured to evaluate the forecast of the radiation and accordingly the system adjusts and optimizes the use of lighting more efficiently in terms of energy saving and increased crop yield.

In another further particular aspect of the present invention, the system including the weighing measuring system and the system for determining the radiation required and prediction of the actual crop yield is utilized for planning cost-effective management of a greenhouse including scheduling of operations intended for the planting, growing, harvesting, picking, shipping and marketing of selected amount of crops in a selected season of a particular year.

Discussion and related aspects in the presented forecast experimental method:

The crop forecast generation procedure is a relatively complex task, however its accuracy and reliability involve a detailed knowledge of the development and growing process of various plants species which are grown in greenhouses. There are two elementary processes which are involved in the related forecast process. The first elementary process is data collection of the relevant measured parameters related to specific plant species and its specific growing process. This involves calculations, analysis and extraction of mathematical relations between these parameters and other parameters that affect the plant growing process. Such are the calculated vegetative and productive components VCC and PCC, respectively. The second elementary process is the preliminary forecast of the total radiation intensity, which is applied on specific plant species in a certain area in the greenhouse throughout its growth period, and further characterization and determination of its relation to other parameters such as accumulated plant crop performance throughout its growth period.

In one particular aspect of the present invention, the first elementary process involves characterization of the vegetative system, including a collection of the required data and important relations between the various growing parameters. This task involves the determination of the relation and dependencies between accumulations of the total measured fresh weight with respect to the climate conditions and particularly the natural and artificial lighting radiation intensities, which are applied on the plants throughout their growth period. Specific available technological growth conditions in a certain greenhouse are also considered. The related analysis is performed separately for each specific plant species, taking into account its specific growth seasons and other possible local and global environmental conditions and parameters that affect the growth conditions.

In a further particular embodiment of the present invention, the collected data is taken over the plant total growth period by a **PGA** (Plant Growth Analysis) data collection system. In this case, it has been found that an analysis, which is done about 3 weeks or more before the forecast, yields an accurate and correct feedback for the continuation of this process. In this case, the root cause for the limited forecast time period is believed to be driven by the variations in the relations between the environmental conditions to the related conditions experienced by the fresh material of a specific plant species throughout its growth period. Hence, in the related embodiment of the invention, the processing and analysis of this data, including extraction and determination of relation between relevant growth parameters should be done prior to forecast generation process.

In a further one particular aspect of the present invention, the first elementary process and related aspects are involved in the determination of the relations between the accumulation of vegetative fresh weight (TMFW) and crop (PCC) parameters. In a further particular aspect, the relation between the vegetative fresh weight, TMFW, and accumulated variable productive calculated component, PCC, enables to predict the crop yield throughout the growth period in a particular season. In a further particular aspect and related embodiment of the present invention, the relation between the vegetative fresh weight, TMFW, and the accumulated variable productive calculated component, PCC, is calculated prior to the forecast procedure. The reason for this is that the relation between PCC and TMFW is believed to be related to the specific plant species and growing technologies which are employed by the grower in a certain greenhouse. In a further particular embodiment of the present invention, the calculation of the accumulated fresh material is determined by measurements of the crop reduction which is further used to extract the vegetative component (VCC), or alternatively can be done by direct measurement of crop weight during the picking period.

The following provides a more detailed description of the two elementary processes presented above and related aspects and embodiments, which are defined as follows:

Particular aspects and embodiments that relate to Crop Forecast Calculation:
Crop forecast is important to the growers and also marketing companies, where the required forecast time period varies in accordance with their requirements.

In one particular embodiment of the present invention, the experimental forecast of a specific plant crop is likely to be effective for a time period of about two to three weeks. In another particular aspect of the present invention, the light radiation intensity for a certain area in a greenhouse is the most important parameter which is used for the ACY forecast. This parameter is believed to be most important due to its effective contribution to the plants growth process, and is additionally considered as a fundamental parameter that affects crop accumulated rate during plant growth season.

In another particular embodiment of the present invention, the radiation forecast is measured by meteorological stations for long periods of time that may extend to five weeks ahead. Alternatively it can be evaluated from average radiation values which are calculated from the local radiation measurements data performed in a specific greenhouse location during several years. In another particular aspect of the present invention, the greenhouse local temperature is considered to be another highly important parameter in the growing process in greenhouses. However, in many greenhouses that employ advanced growing technologies, the most important contributors to the temperature variations are the external radiation sources during daylight hours and the heating system that manage and control the growing workforce. This is due to the fact that practically, in most cases, during the growth season, the temperature generated by the dedicated heating sources inside a greenhouse is sustained in a specific constant value with rather very low temperature variations. Hence, the accumulated fresh material factor, which is sensitive to temperature variations that result from the said greenhouse heating source temperature, is relatively stable and considered to be less relevant to the crop forecast during growth season. As a result, the heating applied to the greenhouse is considered to be the most important factor that impacts temperature variations and accordingly the growth factor variations associated with this parameter.

Yield forecast method and embodiments

Objective: To generate the yield forecast for a certain crop in a specific greenhouse subjected to some specific internal and external radiation illumination conditions. Two greenhouses in Holland and one in England were experimented to study the relation between the natural and artificial lighting radiation and the plant growth rate.

The general experimental methodology used for generating the forecasts of the fresh crop weight and yield has been implemented as follows:

1. In all experiments and related greenhouses the data collection time sampling rate was set to 20 min. The data included the total accumulated fresh weight, TMFW, composed of the weight of fruits and leaves. As described in the summary, by using time filter separation between the crop harvesting and deleafing, i.e. leaf removal, operational tasks it is possible to extract the VCC and PCC calculated parameters separately (as shown in **Figs. 1-2**). The collected data is classified by the greenhouse location and id, the certain plant type and the certain measurement technology which was used by the grower.
2. The accumulated radiation data outside and inside a specific greenhouse were measured in units of Mole m^2 (area (square meter)). The radiation sources comprised the external natural radiation and the internal artificial radiation, when applied. In addition, several other parameters were considered for each specific greenhouse out of the tested ones. These parameters included the greenhouse specific location, its geometrical shape, its type of cover and the specifications and type of the internal light radiation which were used by the grower for this specific greenhouse.
3. The mathematical relation between the radiation intensity and fresh weight, TMFW, was calculated. Furthermore, to eliminate the inherent experimental variations in this relation which are pronounced over different growth time periods, the corresponding relation is recalculated separately all over again for each one of the different experiment time periods.

4. The mathematical relation between the fresh weight and crop yield was calculated for every greenhouse according to its particular specifications, e.g., size, shading, specific location, geometrical shape and cover type and growth conditions, exposure to natural radiation, application of artificial radiation, heating, humidity. As in the previous case, the corresponding relation is recalculated all over again for each one of the different experiment time periods.
5. A time forecast for the crop yield and fresh accumulated weight is generated based on the extracted mathematical relations including the related polynomial fit coefficients between the radiation intensity and fresh weight and fresh weight and crop yield, with the relations extracted in steps 3 and 4. The yield and forecasts are considered to be accurate and valid over a time period of several weeks ahead.

To summarize the above, the present invention provides a method for forecasting crop yield in greenhouses according to the following steps:

- distributing a plurality of weighing units in the greenhouse, each of the weighing units is attached to a single plant or group of plants and comprises means for weighing the plant or group of plants, the weighing units are trellising from an elevated wire at one end and connected to the top end of the plant or group of plants at the opposite end;
- deploying a communication network in the greenhouse, the communicating network comprising means for communicating weight of the plant or group of plants from the weighing units to a central unit;
- connecting said weighing units to a central unit through the communication network; and
- performing the following operations in the central unit:
  - collecting data comprising TMFW in a defined time sampling rate;
  - classifying these data according to location and id of the greenhouse, plant type and measurement technology;
  - separating between crop harvesting and deleafing operational tasks with a time filter;
  - extracting VCC and PCC calculated parameters separately;
  - collecting accumulated radiation data outside and inside the greenhouse;

- collecting data on the greenhouse specific location, geometrical shape and cover type;
- analyzing and calculating mathematical relation between intensity of the radiation and TMFW;
- recalculating said relation separately all over again for every experimented time periods to eliminate the inherent experimental variations which are specifically pronounced in between different growing time periods;
- calculating mathematical relation between TMFW and ACY;
- recalculating this relation between the TMFW and ACY all over again for every one of the different experimented time periods;
- generating polynomial fit coefficients between intensity of the radiation and TMFW and between the TMFW and ACY; and
- time forecasting ACY and TMFW based on said polynomial fit coefficients for time period of 3-4 weeks ahead.

Further, the method may comprise collecting data on specifications and type of the artificial light radiation.

Further, the method may comprise modifying environmental condition parameters, intensity of artificial radiation source and distribution for optimizing future crop yield in the greenhouse.

Exemplary material and related embodiments of the present invention are schematically illustrated in **Figs. 1-8**. These figures are for illustration purposes and are not intended to be exhaustive or to limit the invention to the below description in any form. A detailed example and implantation of the present forecast method is provided in the detailed description of **Figs. 6-8**. In this example, the forecast method is employed for tomato plant grown in a one particular experiment greenhouse.

Brief Description of the Drawings

Fig. 1 shows the measured total fresh weight of a plant (in grams) over a period of about four months.

Figs. 2A-B show the accumulated TMFW and crop yield, respectively, in a greenhouse that is divided to "West" and "East" sections.

Figs. 3A-B show the measured crop yield (solid squares), correlating the ACY values with the TMFW values with polynomial fitting equation (solid line) for the East and West sides, respectively.

Fig. 4 shows the natural light radiation (left y-axis) and TMFW (right y-axis) throughout growth time period of about 8-9 months.

Fig. 5 shows the measured daily growth, presented in units of gr/m^2, during a period of about one month of December, demonstrating the contributing factors of outside natural light and artificial radiation components (HPS).

Fig. 6 shows the experimental results of the total radiation intensity versus the accumulated fresh weight for an experimented certain greenhouse and tomato crop with a quadratic correlation polynomial fit graph.

Fig. 7 shows the experimental results of the yield versus fresh weight measured for a tomato crop with a quadratic correlation polynomial fit graph.

Figs. 8A-B show the forecast calculation tables derived for tomato crop data presented in **Figs. 6-7**, where (**A**) shows a calculation of fresh weight resulting from the applied radiation (natural and artificial) intensity and (**B**) shows forecast calculation of the yield resulting from the fresh weight data.

Detailed Description of the Drawings

Fig. 1 shows the measured total vegetative fresh weight of a plant (in grams) over a period of about four months., The observed fluctuations in the graph make it possible to calculate the temporary PCC (productive calculated component) at each point in time by the filter. The filter is capable of differentiating between weight losses resulting form harvesting, e.g. crop or fruit, and deleafing, i.e., leaf removal. This capability of the filter is based on the inherent difference between the weights of leaves and fruits. Accordingly, the change monitored by the filter is also translated to actual activity carried out at the greenhouse, i.e., picking or deleafing. Then the data received is related to the proper variable, namely PCC for picking and VCC for deleafing. This way, real-time observation and analysis of plants growth is enabled.

Fig. 2A shows the accumulated TMFW in a greenhouse that is divided to "West" and "East" sections, where the yield, shown in **Fig. 2B**, is calculated from the TMFW graph in **Fig.1**. As can be seen from this graph, there is a slight difference in the accumulated TMFW between the two sections with a minor higher TMFW values shown at the West section.

Fig. 2B shows corresponding crop yield or the accumulated productive (PCC) and vegetative (VCC) calculated components for the two sections, West and East, correlated with the accumulated TMFW of the plants in the lower graph in **Fig. 2A**. In this case, the PCC values are calculated analytically utilizing the filter that distinguishes between the productive and vegetative calculated components, marked as PCC and VCC respectively, or are calculated by the grower over the same period of time. The accumulated PCC, and hence the crop yield, is higher for the East section relative to the West section, although both show consistent positive increase in TMFW with time. This spatial division exemplifies the capability of the system and filter to track and identify trends and non-uniformities in yield in the greenhouse.

Figs. 3A-B show the measured crop yield (solid squares) that correlates with the PCC values, with respect to TMFW, with the polynomial fitting equation (solid line) that is constructed according to measured results for the East and West sides, respectively. In these graphs, the measurements of plant TMFW and calculations of PCC generate the relevant correlation curve that is typical for a particular greenhouse or a particular section in the greenhouse in which the measurements were taken for a specific type of crop. The yield is calculated as a function of the TMFW of the plants in units of Kg per area (square meter). The polynomial equation is the correlation function with appropriate coefficients for each power, which are produced by the filter for the particular measured results. The fitted polynomial equation enables to forecast future ACY (actual crop yield) according to given measured data on TMFW and calculated VCC (vegetative calculated component). This is because the curves slopes enable identifying the characteristics of the greenhouse with a ratio between TMFW and PCC that is consistent over short periods of time. Accordingly, the ACY for the particular greenhouse may be forecasted for further growing events. Such curve continuously updates with the accumulation of data on TMFW and PCC and thus may be termed self-learning curve.

In one aspect of the invention, the crop yield forecasting, for example over a period of 3 to 4 weeks, is done in relation to climate data and growing conditions, light radiation in particular, which are processed by the system and reflected in the typical self-learning curve of a greenhouse or part of its area.

For the evaluation of the effect of natural outside light radiation on TMFW, the relation between the TMFW and light radiation is measured for a plurality of events in a greenhouse and selected areas in it.

Fig. 4 shows the natural light radiation (left y-axis) and TMFW (right y-axis) for a growing time period of about 8-9 months. In this graph, the radiation energy is provided by the outside natural light radiation, presented in units of mega joule per area, i.e. square meter, and the plant growth, reflected in TMFW of the plants, is presented in units of Kg per area. Practically a complete correspondence is observed between the two and the obtained curve is considered as a characteristic for the particular greenhouse in which measurements are taken for a certain type of plant from a variety of plants e.g., a certain type of vegetable crop , tomato, cucumber, which is weighed, and their combination. The polynomial equation obtained for the measured TMFW of plants and the crop yield as shown in the graph in **Figs. 3A-B** enable forecasting the yield for a period of time ahead, for example a time period of three weeks. Such equation is characteristic of the greenhouse, in which the measurements are taken, the variety, i.e., type of crop, e.g. tomato, cucumber, which is weighed, and their combination, under known conditions of outside light radiation.

In accordance with the above, the particular effect of light on TMFW of plants and crop yield was investigated. Data of natural light radiation absorbed in the greenhouse from external sources (in Mega joule per square meter) and TMFW of plants were accumulated in multiple events under different climate conditions around the world in different seasons. The accumulated data determined the ratio between the energy projected by natural light radiation and artificial lighting and growth rate and accordingly the light-to-growth coefficient (energy per weight - Mega joule per Kg – MJ/Kg). During a cycle of 24 hours per day, artificial lighting was turned on during night hours and partly during the day. The contribution of the natural outside light radiation to the total energy absorbed was determined according to the measured energy provided by natural light radiation and the energy contribution to growth. This contribution was calculated by multiplying the intensity of natural light radiation with the light-to-growth coefficient. Quantitative evaluation of the contribution of artificial lighting to growth was determined according to the growth rate for any selected area and period of time using the weight measuring units distributed in the greenhouse and by subtracting the calculated contribution of natural outside light radiation absorbed from the measured growth.

Fig. 5 shows the measured daily growth, presented in units of gr/m^2, during a period of about one month of December, showing the outside radiation natural light and artificial (HPS) radiation contributing factors. A particular area unit was determined and weight measuring units were used to provide growth rate data in a selected period of time. This time of year was selected to examine the effect of artificial lighting due to the lower exposure to natural light. The top curve shows the growth of TMFW of plants obtained from exposure to natural outside light radiation and artificial light sources; the lower curve shows the growth calculated for the contribution of natural outside light radiation; and the middle curve shows the growth calculated for the contribution of artificial lighting (HPS). These three curves show practically a correlation between the total contribution of light energy from all sources absorbed by the plants and the separate contribution of the natural outside light radiation and artificial light sources. The major part of growth depends on the energy provided by the natural outside light radiation, depending on the particular season. However, the use of artificial light proves its effectiveness by the increase of growth as reflected in the top curve especially in days or hours of a day with lower exposure to natural light or no light at all.

Yield forecast method, experimental demonstration and graph for tomato crop in a greenhouse

In the following section, a demonstration is provided for the yield forecast method described in the summary section. This demonstration is the case for tomato vegetables grown at the corresponding experimented greenhouses described in this section. In this case, the crop yield forecast is provided for certain fresh weight and illumination by natural and artificial lighting conditions inside and outside the experimented greenhouses. The experimental methodology for the experiment data collection of accumulated radiation conditions were repeated exactly as described in steps 1 and 2 for the yield forecast general description section in the summary section.

In what follows, the forecast method further comprises steps 3-5, which are applied and presented in **Figs. 6-7** and the equations below. **Fig. 6** shows the experimental relation between the radiation and the accumulated fresh weight of a tomato crop with a quadratic polynomial fit graph. The insert of the graph shows the specific quadratic polynomial equation including its specific extracted linear and quadratic coefficients and the related fit accuracy factor, R.

According to step 3 of this method, the quadratic polynomial fitting equation yields the following relation between the radiation and the accumulated fresh weight of a tomato crop:

$$y = 4E\text{-}06x^2 + 0.0188x$$
$$R^2 = 0.9984$$

Fig. 7 shows the experimental relation between the yield and the fresh weight measured for tomato crop with a quadratic correlation polynomial fit graph. The insert in the graph shows the specific polynomial equation including the specific extracted linear and quadratic coefficients and the related fit accuracy factor, R.

According to step 4 of this method, the quadratic polynomial fit equation yields the following relation between the yield and the fresh weight measured for tomato crop:

$$y = -0.0035x^2 + 0.4486x$$
$$R^2 = 1$$

Figs. 8A-B show the forecast calculation tables derived from tomato growth data presented in **Figs. 6-7,** where (**A**) shows calculation of the fresh weight resulting from the applied light radiation intensity and (**B**) shows a forecast calculation of the yield resulting from the fresh weight data.

In step 5 and as further shown in the related table, a forecast for the tomato crop yield is derived from the polynomial relation obtained in steps 3 and 4 for the tomato crop data. This enables to evaluate the total light radiation conditions as well. This is done as follows: The fresh weight can be calculated for any value of light radiation conditions, as shown in **Fig. 8A**. Since the radiation is measured in $mole \cdot m^2$ and the fresh weight is calculated in $Kg \cdot m^2$, the coefficients obtained are pure numbers and may be used to obtain the polynomial fit equation that forecasts the yield as shown in **Fig. 8B**. The yield can be forecasted for any fresh weight values and hence light radiation conditions, as shown in **Fig. 8B**. Finally a forecast of the yield under certain light conditions can be derived for several weeks ahead.

This method can be applied experimentally for different types of plants, and has been found to be relatively accurate and valid over growing time periods of several weeks, generally 3-4 weeks. Further, it can be re implemented after such time period again. Moreover, this method can also be implemented constantly under greenhouse conditions to produce an inline monitor of the forecast crop yield 3-4 weeks ahead to the grower, and enable him to optimize the radiation, temperature and all other growth conditions that sustain a relatively high yield of crop production for a variety of plant types, fruits and vegetables.

In summary, the system of the present invention provides forecasting of ACY (actual crop yield) for future periods of time based on measured data. Furthermore, the system of the present invention provides guidance on how much artificial lighting should be applied to obtain optimal TMFW of plants and crop yield based on the relation between previously measured natural outside light radiation and TMFW of plants. This is particularly useful for seasons with lower exposure to natural outside light radiation, where efficient use of energy resources is required, e.g., transition seasons. The recommendation for the amount of artificial lighting to be used is particularly important for places where such transition seasons take a substantial part of the year, thus requiring a more efficient use of artificial lighting and energy spending.

Claims

1. A system for forecasting actual crop yield (ACY) in a greenhouse comprising:
   - a plurality of weighing units, the weighing units distributed in the greenhouse, each of the weighing units is attached to a single plant or group of plants and comprises means for weighing the plant or group of plants, the weighing units are trellising from an elevated wire at one end and connected to the top end of the plant or group of plants at the opposite end;
   - a communication network comprising means for communicating weight of the plant or group of plants from the weighing units to a central unit; and
   - a central unit comprising:
     - means for receiving, storing, processing and analyzing data received from the weighing units through the communication network;
     - a dedicated filter for identifying variations in the plants weight and distinguishing between PCC (Productive Calculated Component) and VCC (Vegetative Calculated Component) of said weight;
     - a software tool component that is configured to determine the ratio between the VCC and PCC that make the Total Measured Fresh Weight (TMFW) of plants in real-time;
     - a software tool component that is configured to calculate the contribution of light radiation from natural and optional artificial sources to crop yield with polynomial equation fit to identify relation between total amount of said light radiation and said TMFW, said polynomial equation fit receiving said light radiation and producing said TMFW;
     - a software tool component that is configured to generate a prior forecast of the total radiation, which will be applied in a specific greenhouse with specific geographic location, geometrical shape and type of cover a on specific plant species in the greenhouse during growing time period of said specific plant species, and perform a further characterization and determination of relation between said radiation and accumulated plant crop performance during the growing time period, said software tool component is configured to provide forecasting of said PCC and VCC of said growing time period considering growth data of a most recent growth period preceding said

growing time period of said specific plant species in said specific greenhouse; and

- a software tool component that is configured to perform a prediction and forecasting of Actual Crop Yield (ACY) for a future period of time based on measured said TMFW of plants, VCC and PCC and allocation of resources for obtaining the predicted ACY, said software tool component is configured to calculate relation between said ACY and TMFW with a polynomial fit equation to obtain said prediction and forecasting.

2. The system according to claim 1, wherein said dedicated feedback control unit comprises:
   - a software tool component configured to gather and analyze processed and unprocessed data received form said means for receiving, storing, processing and analyzing data; and
   - an optimization software tool configured for optimization of distribution of said ACY inside the greenhouse for said specific plant species located at said specific area in the greenhouse, said optimization software tool components is configured to generate a set of executable actions and recommendations for correction and modification of various control parameters inside the greenhouse.

3. The system according to claim 2, wherein said data comprises measured plants weighing data, extracted said VCC, PCC and TMFW parameters, current and forecasted radiation and ACY data of the greenhouse, local environmental conditions and general climate data received from said central unit and sensors distributed inside the greenhouse and/or external databases.

4. The system according to claim 2, wherein said parameters comprise environmental temperature and humidity recommended distribution parameters.

5. The system according to claim 4, further comprising at least one artificial light radiation source apparatus distributed in the greenhouse, wherein said parameters

further comprising artificial radiation intensity and recommended configuration of distribution of said artificial light source apparatuses.

6. The system according to claim 5, wherein said at least one artificial light radiation source apparatus distributed in the greenhouse is operated according to said forecasting of said ACY.

7. The system according to claim 5, wherein said at least one artificial light radiation source apparatus is manually controlled.

8. The system according to claim 5, wherein said at least one artificial light radiation source apparatus is automatically controlled with short wavelength communication means.

9. The system according to claim 1, wherein said central unit is configured to predict ACY in said greenhouse with known climate and environmental and growth conditions based on said TMFW, VCC and PCC parameters.

10. The system according to claim 1, wherein said VCC and PCC are determined by direct measurement of weight reduction of said crop, wherein said measurement is performed immediately after a picking action, wherein measured values of said VCC and PCC are fed into the said software tool component for determining ratio between the VCC and PCC that make the TMFW of plants in real-time.

11. The system according to claim 1, wherein said short term is between three to four weeks ahead based on accumulated previous data obtained from a specific greenhouse and/or a plurality of greenhouses.

12. The system according to claim 1, wherein said central unit is further configured to produce scheduling of operations intended for planting, growing, harvesting, picking, shipping and marketing of selected amount of said crops in a selected season of a particular year based on said forecasting of said ACY.

13. The system according to claim 1, wherein said radiation forecast is measured by meteorological stations.

14. The system according to claim 1, wherein said radiation forecast is evaluated from average radiation values calculated from local radiation experimental measurements performed at location of the greenhouse during several years.

15. The system according to claim 1, wherein local temperature variations in the greenhouse are measured according to variations in radiation and heating source system in the greenhouse.

16. A method for forecasting ACY of selected crop species in a greenhouse, said method comprising:
    - distributing a plurality of weighing units in the greenhouse, each of the weighing units is attached to a single plant or group of plants and comprises means for weighing the plant or group of plants, the weighing units are trellising from an elevated wire at one end and connected to the top end of the plant or group of plants at the opposite end;
    - deploying a communication network in the greenhouse, the communicating network comprising means for communicating weight of the plant or group of plants from the weighing units to a central unit;
    - connecting said weighing units to said central unit through said communication network; and
    - performing following operations in said central unit:
    - collecting data comprising TMFW in a defined time sampling rate;
    - classifying said data according to location and id of the greenhouse, plant type and measurement technology;
    - separating between crop harvesting and deleafing operational tasks with a time filter;
    - extracting VCC and PCC calculated parameters separately;
    - collecting accumulated radiation data outside and inside the greenhouse;
    - collecting data on the greenhouse specific location, geometrical shape and cover type;

- analyzing and calculating polynomial fit relation between intensity of said radiation and TMFW;
- recalculating said relation separately all over again for every experimented time period to eliminate inherent experimental variations which are specifically pronounced between different growing time periods;
- calculating polynomial fit relation between ACY and said TMFW ;
- recalculating said relation between said TMFW and ACY all over again for every one of said different experimented time periods;
- generating polynomial fit coefficients between intensity of said radiation and TMFW and between said TMFW and ACY; and
- time forecasting said ACY and TMFW based on said polynomial fit coefficients for time period of 3-4 weeks ahead.

17. The method according to claim 16, further comprising collecting data on specifications and type of artificial light radiation.

18. The method according to claim 16, further comprising modifying environmental condition parameters, intensity of artificial radiation source and distribution for optimizing future crop yield in the greenhouse.

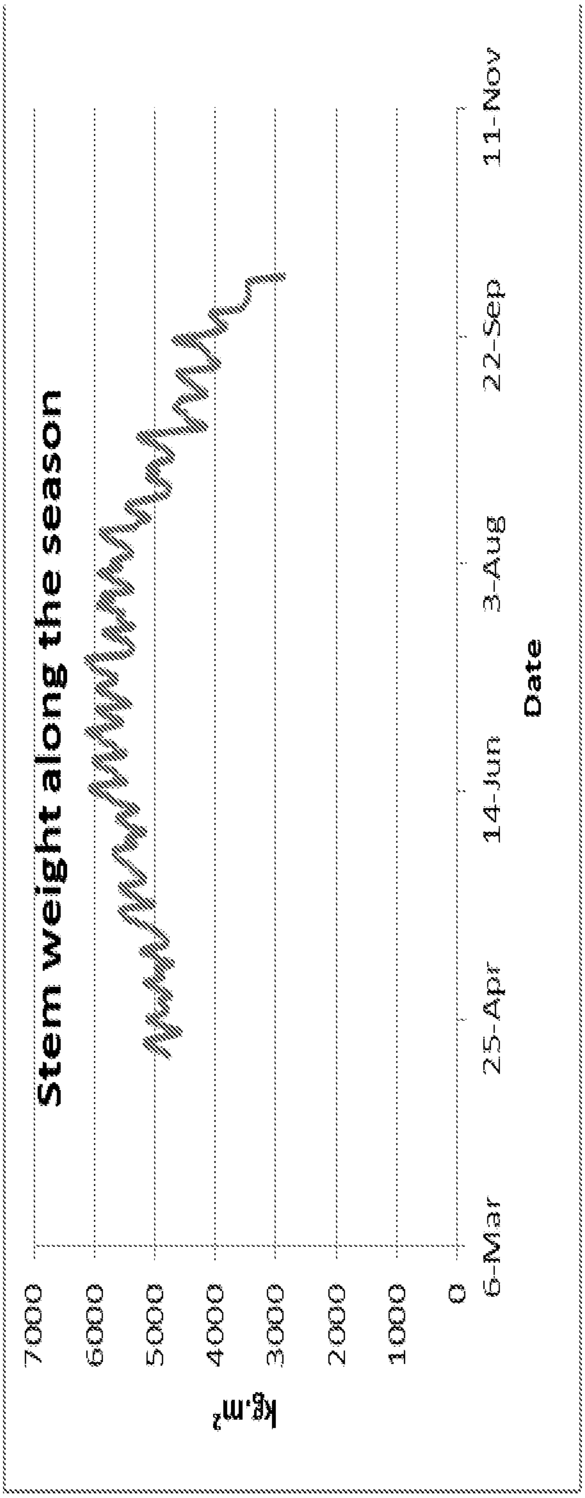

Stem weight along the season
kg.m2
7000
6000
5000
4000
3000
2000
1000
0
6-Mar
25-Apr
14-Jun
3-Aug
22-Sep
11-Nov
Date

Fig. 1

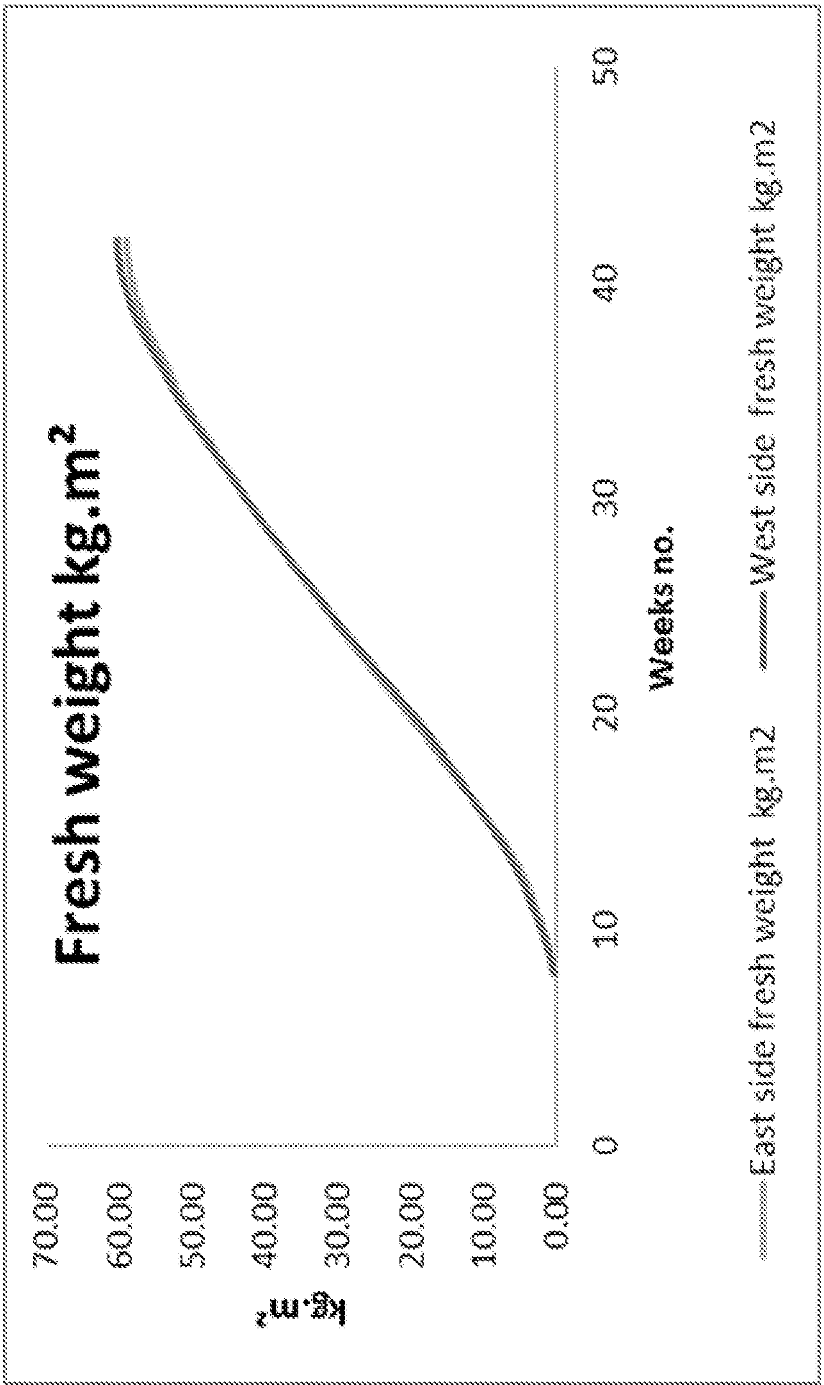

Fresh weight kg.m^2
kg.m^2
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0
10
20
30
40
50
Weeks no.
East side fresh weight kg.m2
West side fresh weight kg.m2

Fig. 2A

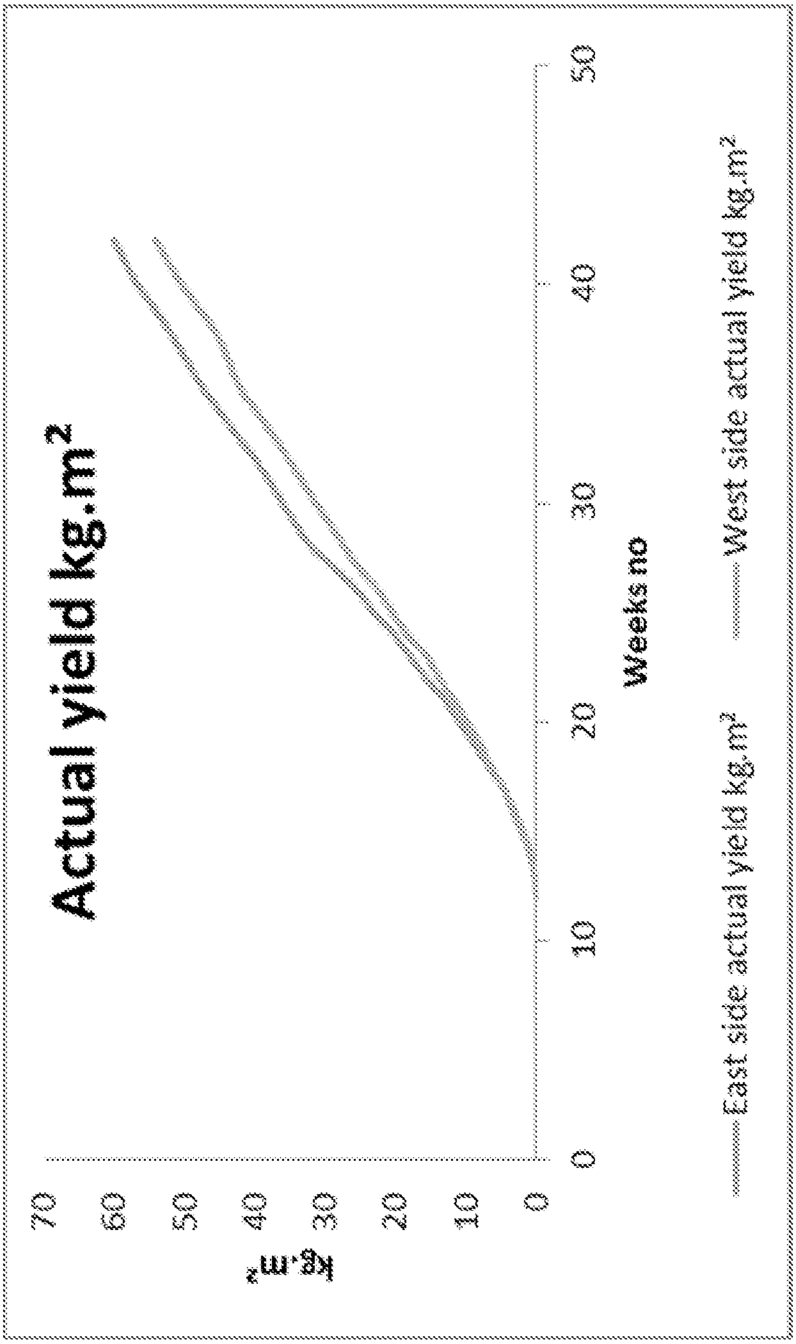

Actual yield kg.m2
kg.m2
70
60
50
40
30
20
10
0
0
10
20
30
40
50
Weeks no
East side actual yield kg.m2
West side actual yield kg.m2

Fig. 2B

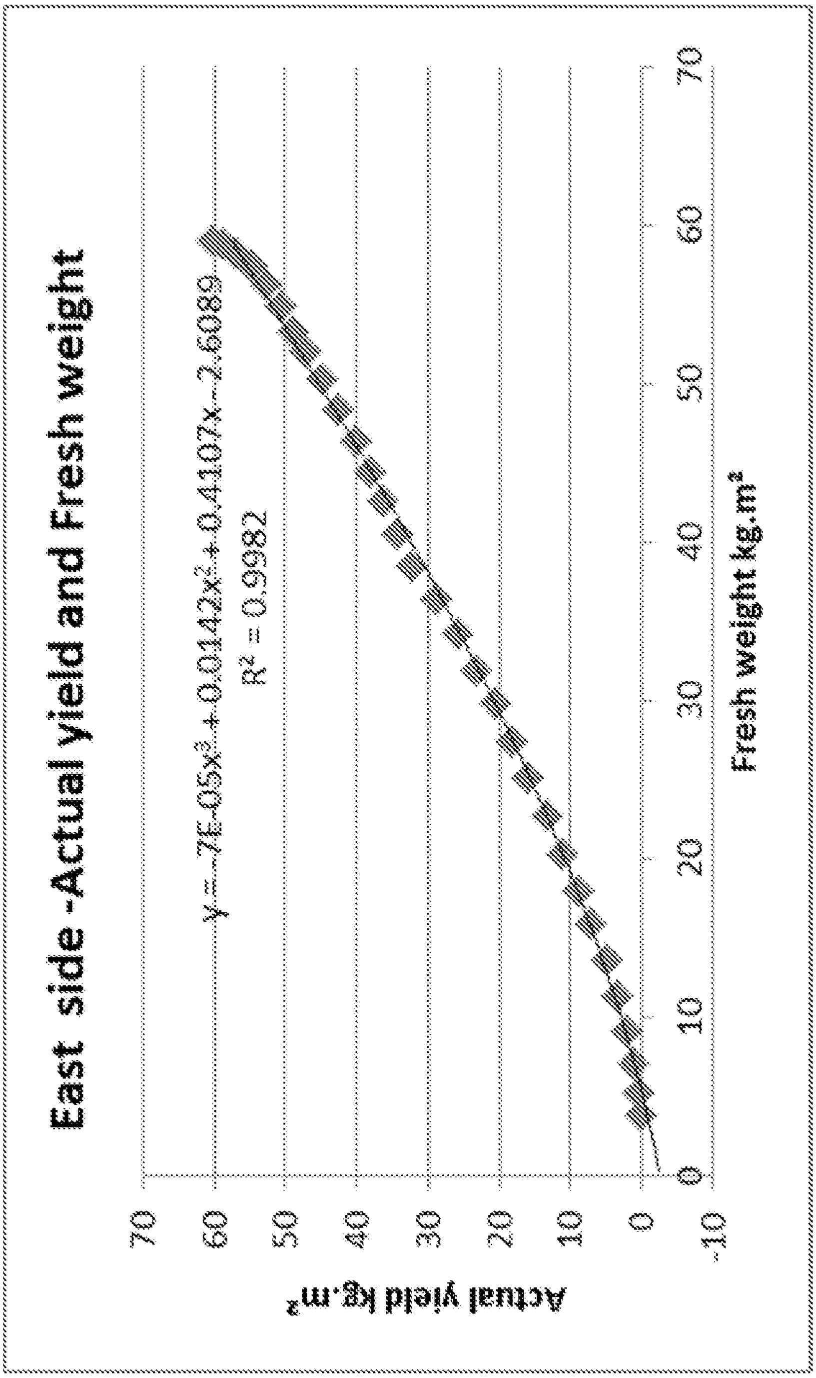

East side -Actual yield and Fresh weight
y = -7E-05x³ + 0.0142x² + 0.4107x - 2.6089
R² = 0.9982
Actual yield kg.m²
Fresh weight kg.m²
70
60
50
40
30
20
10
0
-10
0
10
20
30
40
50
60
70

Fig. 3A

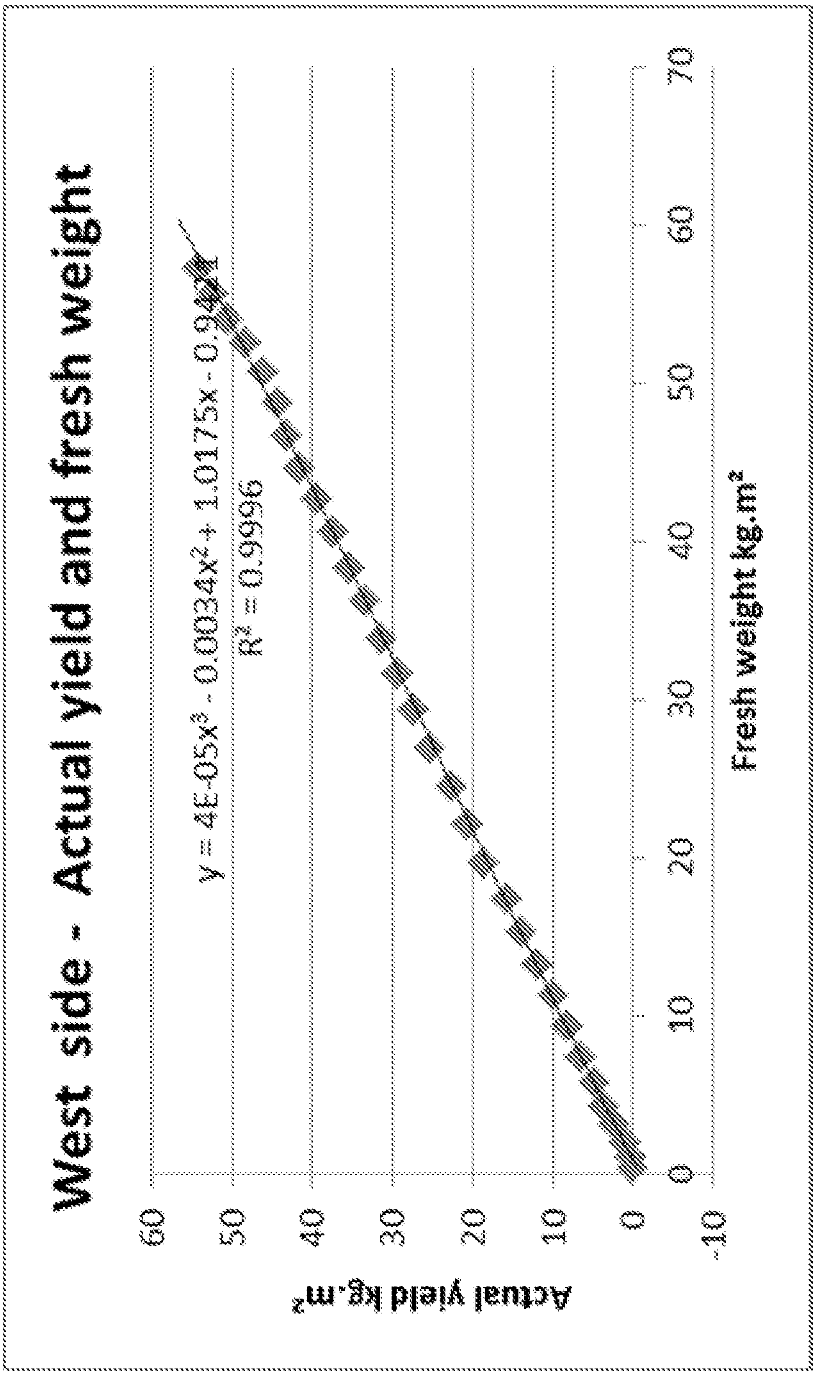

West side - Actual yield and fresh weight
y = 4E-05x³ - 0.0034x² + 1.0175x
R² = 0.9996
Actual yield kg.m²
Fresh weight kg.m²
60
50
40
30
20
10
0
-10
0
10
20
30
40
50
60
70

Fig. 3B

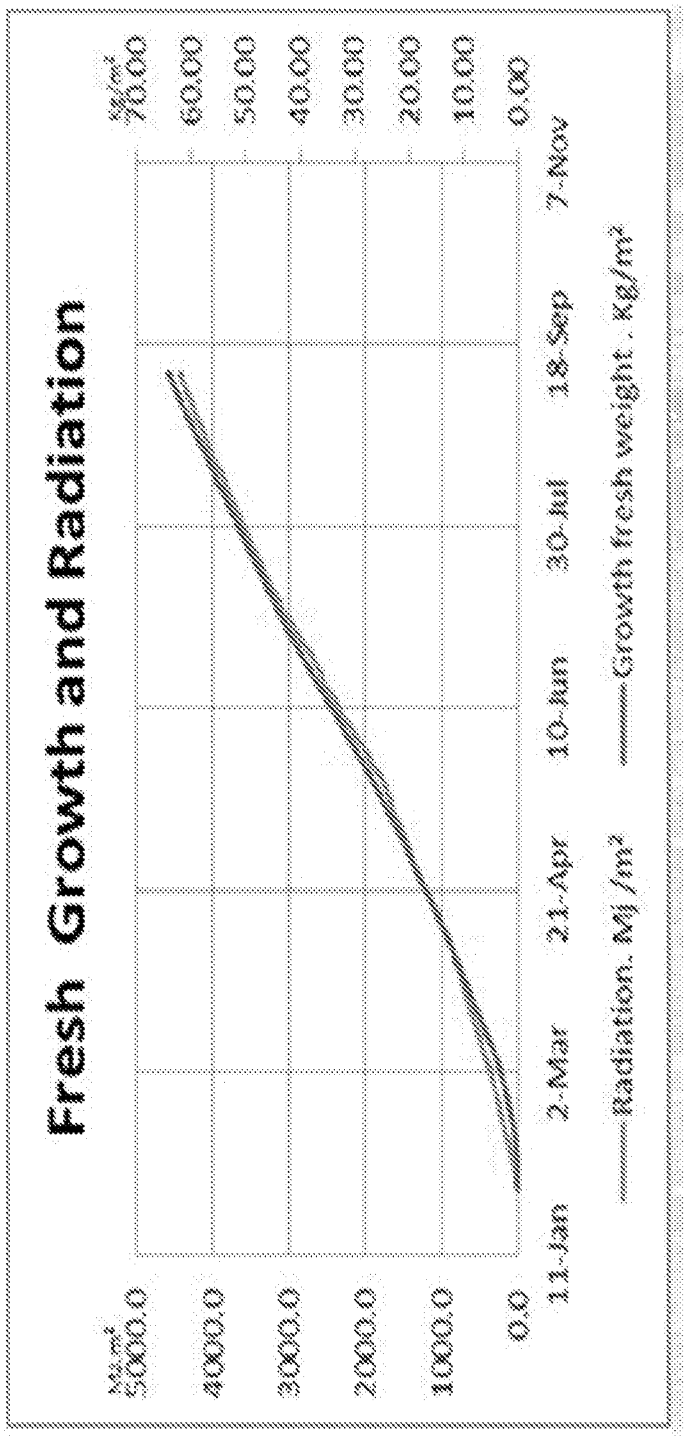

Fresh Growth and Radiation
Mj.m²
5000.0
4000.0
3000.0
2000.0
1000.0
0.0
Kg/m²
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
11-Jan
2-Mar
21-Apr
10-Jun
30-Jul
18-Sep
7-Nov
Radiation. Mj /m²
Growth fresh weight . Kg/m²

Fig. 4

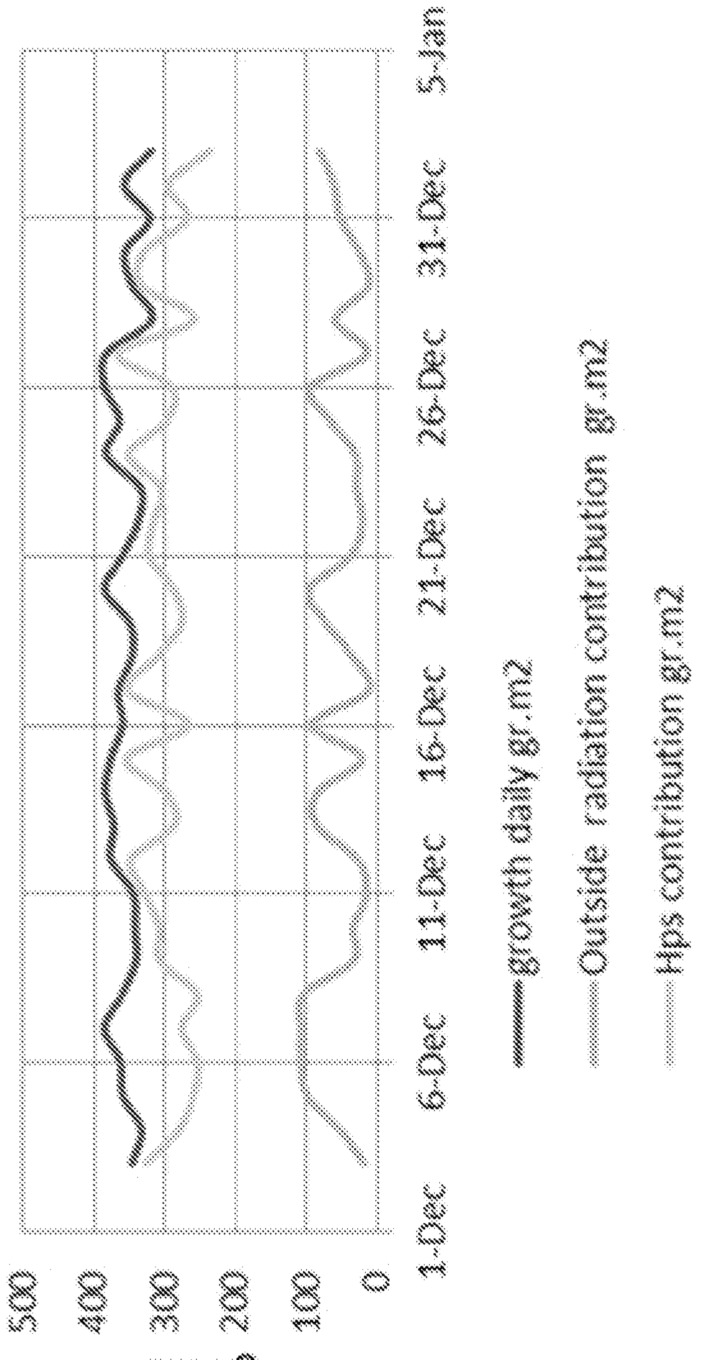

gr. m2
500
400
300
200
100
0
1-Dec
6-Dec
11-Dec
16-Dec
21-Dec
26-Dec
31-Dec
5-Jan
growth daily gr.m2
Outside radiation contribution gr.m2
Hps contribution gr.m2

Fig. 5

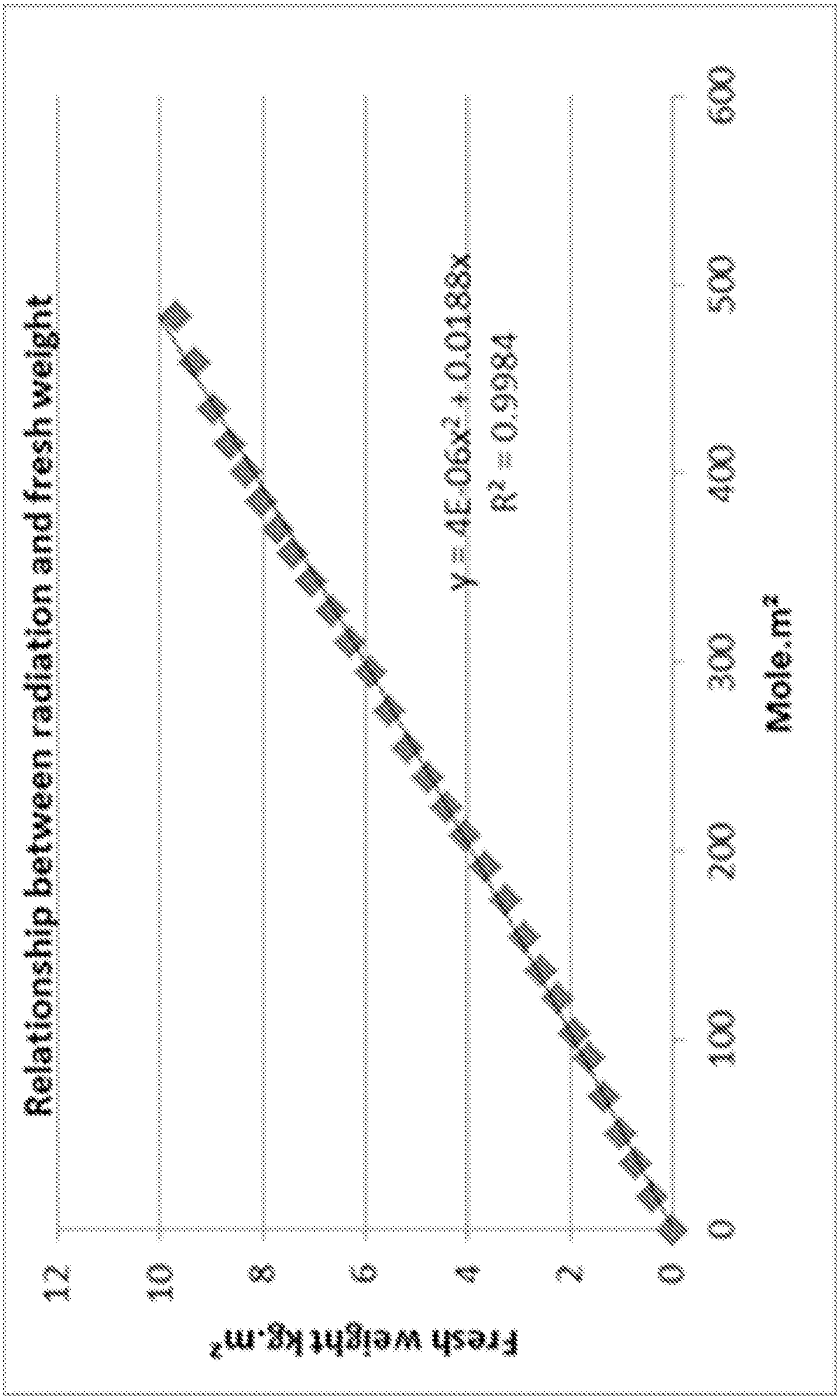

Relationship between radiation and fresh weight
y = 4E-06x² + 0.0188x
R² = 0.9984
Fresh weight kg.m²
0
2
4
6
8
10
12
0
100
200
300
400
500
600
Mole.m²

Fig. 6

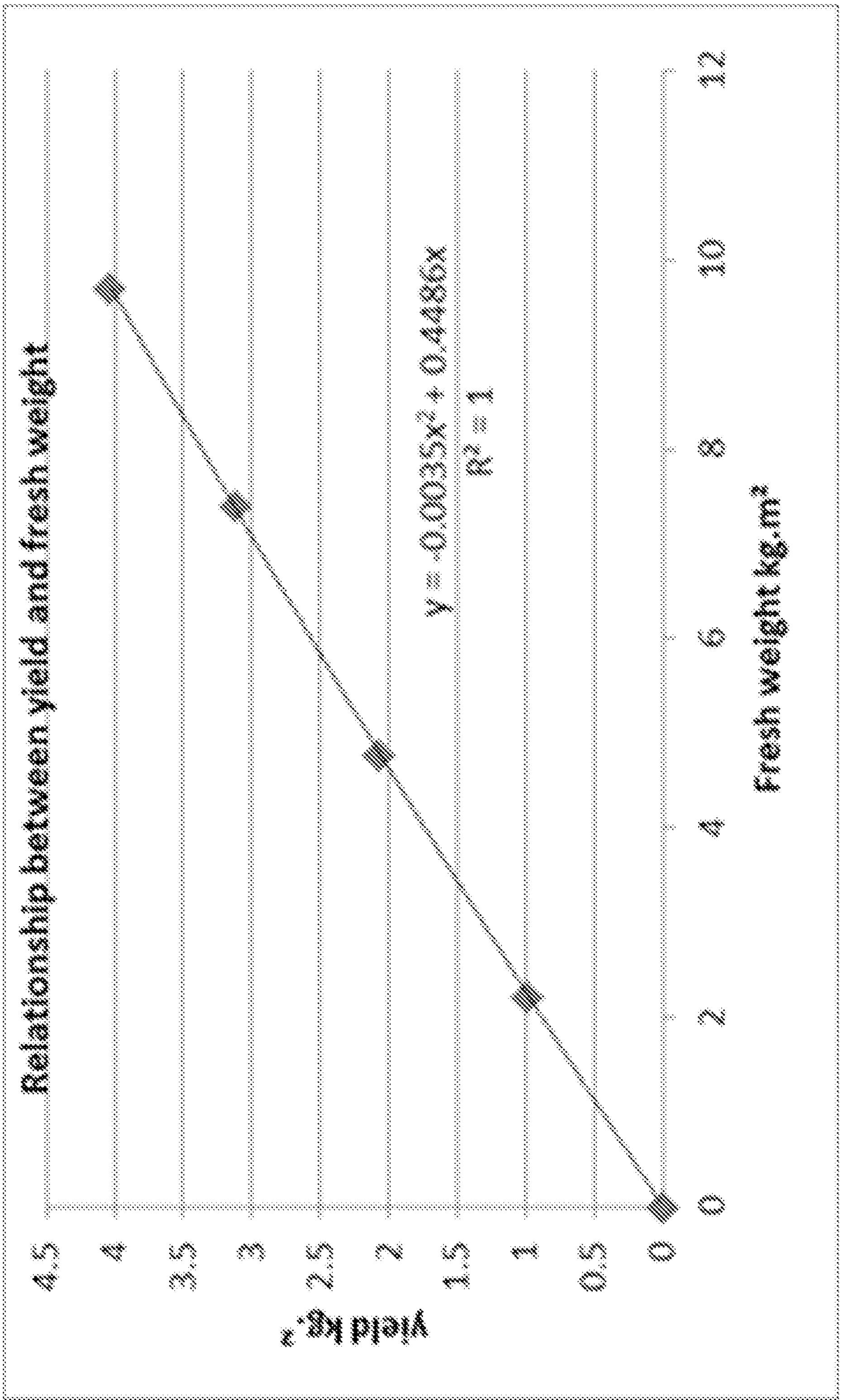

Relationship between yield and fresh weight
y = -0.0035x² + 0.4486x
R² = 1
Fresh weight kg.m²
yield kg.
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
0
2
4
6
8
10
12

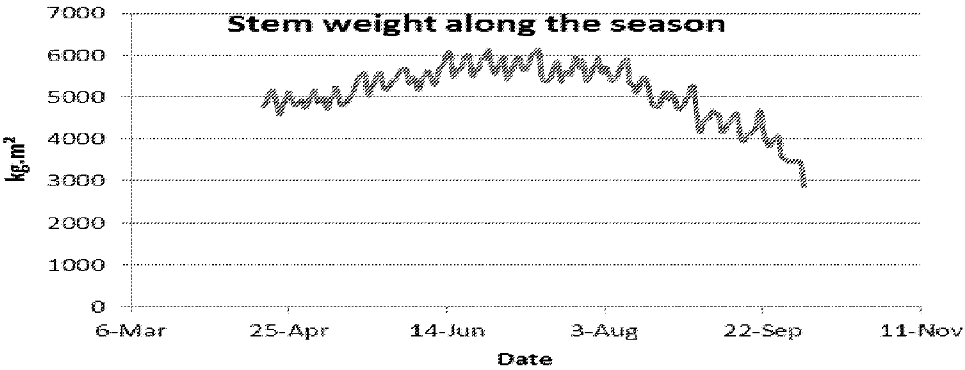
Fig. 7

Calculate fresh weight (2y) resulting from radiation (1x)					
1.X = Radiation mole.m²			a	b	c
459			4.00E-06	0.0188	
			2.Y=Calculated fresh weight kg.m²		
			9.471924		

Fig. 8A

Calculation of forecast yield (4y) resulting from calculated fresh weight (3x					
(3) X= Calculated fresh weight			a	b	c
9.471924			-0.0035	0.4486	
			(4) Y= Forecast calculated yield kg.n		
			4.249221		

Fig. 8B



Stem weight along the season
7000
6000
5000
4000
3000
2000
1000
0
kg.m2
6-Mar
25-Apr
14-Jun
3-Aug
22-Sep
11-Nov
Date