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(54) Titre : PROCEDE, SYSTEME ET DISPOSITIF D`EVALUATION D`EMISSIONS DES GAZ DES SOLS
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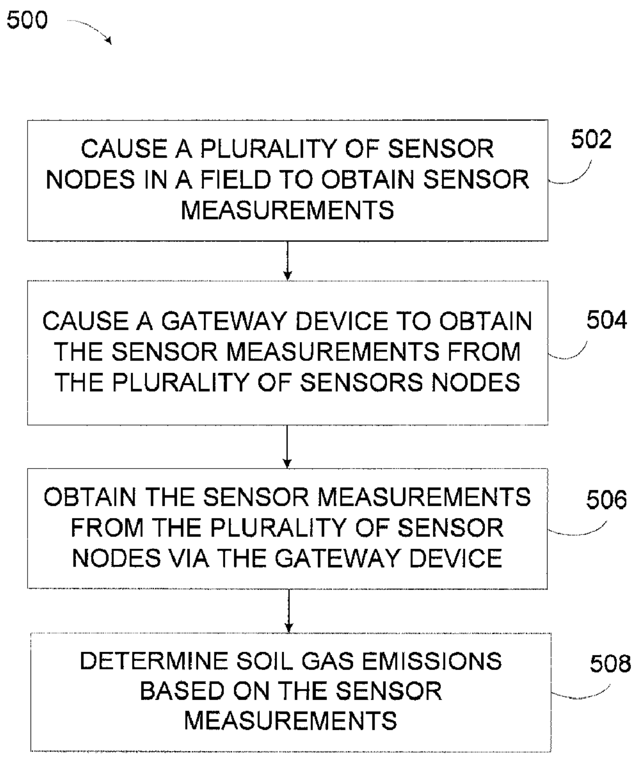

(57) Abrégé/Abstract:
Methods, systems and devices for assessing soil gas emissions are described herein. Sensor nodes are configured to obtain sensor measurements at different locations of a field of soil. Each sensor nodes comprise a non-dispersive infrared sensor that

(57) Abrégé(suite)/Abstract(continued):
obtains sensor measurements indicative of gas in a chamber at a corresponding location of the field. A gateway device is configured to obtain the sensor measurements from the plurality of sensors. A computer is configured to obtain the sensor measurements from the plurality of sensor nodes via the gateway device and to determine soil gas emissions based on the sensor measurements.

ABSTRACT

Methods, systems and devices for assessing soil gas emissions are described herein. Sensor nodes are configured to obtain sensor measurements at different locations of a field of soil. Each sensor nodes comprise a non-dispersive infrared sensor that obtains sensor measurements indicative of gas in a chamber at a corresponding location of the field. A gateway device is configured to obtain the sensor measurements from the plurality of sensors. A computer is configured to obtain the sensor measurements from the plurality of sensor nodes via the gateway device and to determine soil gas emissions based on the sensor measurements.

METHOD, SYSTEM AND DEVICE FOR ASSESSING SOIL GAS EMISSIONS

TECHNICAL FIELD

[0001] The present disclosure relates generally to measuring soil gas emissions, and, more particularly, to methods, and devices for assessing soil gas emissions.

BACKGROUND OF THE ART

[0002] Greenhouse gas emissions from agricultural soils have raised concerns about farming practices in North America. Consequently, these practices are being adapted to include strategies that mitigate soil gas emissions. Thus, the quantification of soil greenhouse gas emissions from agricultural fields is essential to understand the environmental impact of intensive crop and livestock production systems.

[0003] Current methods of analysis involve sampling with non-steady-state non-flow-through, or static, chambers and *ex situ* analysis methods, such as gas chromatography. These techniques often require expensive equipment, a tedious sampling process, and long data gathering times.

[0004] Some systems allow for on-site analysis using tubing networks connected to a manifold controller for dynamic on-field analysis. While these systems have been used for collecting soil gas measurements, repeated sampling of air from stationary chambers is a laborious process. The use of commercially available automated chambers connected via tubes to stationary gas analyzers is also limited by high instrumentation and analytical costs.

[0005] As such, there is a need for improved systems, methods and devices for assessing soil gas emissions.

SUMMARY

[0006] The present disclosure is generally drawn to systems, methods and devices for assessing soil gas emissions. A wireless sensor network system for obtaining *in situ* gas

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measurements is described herein, which may mitigate the use of expensive equipment, tedious sampling processes, and/or long data gathering times of *ex situ* analysis methods and may mitigate high instrumentation and/or analytical costs of on-site analysis systems that use tubing networks. The wireless sensor network system comprises a plurality of sensor nodes deployable at various regions of a field of soil. Each sensor node comprises at least one non-dispersive infrared sensor that measures gas in a chamber. The sensor nodes communicate the sensor measurements to a gateway device. The gateway devices communicate the sensor measurements of a computer. The computer processes the sensor measurements to determine soil gas emissions.

[0007] In one aspect, there is provided a method for assessing soil gas emissions, the method comprises: causing a plurality of sensor nodes in a field to obtain sensor measurements at different locations of the field, each one of the plurality of sensor nodes comprises a non-dispersive infrared sensor that obtains the sensor measurements indicative of gas in a chamber at a corresponding location of the field; causing a gateway device to obtain the sensor measurements from the plurality of sensor nodes; obtaining the sensor measurements from the plurality of sensor nodes via the gateway device; and determining soil gas emissions based on the sensor measurements.

[0008] In one aspect, there is provided a system for assessing soil gas emissions, the system comprises: at least one processing unit; and at least one non-transitory computer-readable memory having stored thereon program instructions executable by the at least one processing unit for: causing a plurality of sensor nodes in a field to obtain sensor measurements at different locations of the field, each one of the plurality of sensor nodes comprises a non-dispersive infrared sensor that obtains the sensor measurements indicative of gas in a chamber at a corresponding location of the field; causing a gateway device to obtain the sensor measurements from the plurality of sensor nodes; obtaining the sensor measurements from the plurality of sensor nodes via the gateway device; and determining soil gas emissions based on the sensor measurements.

[0009] In one aspect, there is provided a system for assessing soil gas emissions, the system comprises: a plurality of sensor nodes configured to obtain sensor measurements at different locations of a field, each one of the plurality of sensor nodes comprises a non-dispersive infrared sensor that obtains the sensor measurements indicative of gas in a chamber at a corresponding location of the field; a gateway device configured to obtain the sensor measurements from the plurality of sensors; a computer configured to obtain the sensor measurements from the plurality of sensor nodes via the gateway device and to determine soil gas emissions based on the sensor measurements.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] Reference is now made to the accompanying figures in which:

[0011] Figure 1 is a block diagram of an example system for assessing soil gas emissions;

[0012] Figure 2 is a block diagram of an example sensor node for obtaining gas measurements;

[0013] Figure 3 is a block diagram of an example gateway device for providing sensor measurements from the sensor nodes to a computer;

[0014] Figure 4 is a block diagram of an example computer for determining soil gas emissions based on the sensor measurements;

[0015] Figure 5 is a flowchart illustrating an example method for assessing soil gas emissions;

[0016] Figure 6 is a block diagram of an example computing system for implementing the sensor node of Figure 2, the gateway device of Figure 3, the computer of Figure 4 and/or the method of Figure 5;

[0017] Figure 7 is a graph illustrating CO_2 concentration correlation between a gas chromatography method and a non-dispersive infrared sensors method;

[0018] Figure 8 is a graph illustrating time response of the gas chromatography method and the non-dispersive infrared sensors method; and

[0019] Figure 9 is graph illustrating measured CO_2 flux in accordance with a study of treatments in a potato crop.

[0020] It will be noted that throughout the appended drawings, like features are identified by like reference numerals.

DETAILED DESCRIPTION

[0021] Soil in a field may act as either sinks or sources for greenhouse gases, such as CH_4, N_2O and/or CO_2, depending on the structural properties of the soil. To assess soil gas emissions, various systems, methods and devices are described herein. The systems, methods and devices are based on measuring gas in a chamber. A wireless sensor network is used to collect the gas measurements from multiple chambers and to provide the gas measurements to a computer for assessing soil gas emissions.

[0022] With reference to Figure 1, there is illustrated a wireless sensor network system 100 for assessing soil gas emissions. A plurality of sensor nodes 102 are configured to obtain gas measurements at different locations of a field of soil. Each one of the plurality of sensor nodes 102 comprises a non-dispersive infrared (NDIR) sensor (not illustrated in Figure 1) that obtains the gas measurements in a chamber (not illustrated in Figure 1) at a corresponding location of the field. A gateway device 104 is configured to wirelessly obtain the sensor measurements from the plurality of sensors nodes 102 and provide the sensor measurements to a computer 106. The computer 106 is configured to obtain the sensor measurements from the plurality of sensor nodes 102 via the gateway device 104 and is configured to determine soil gas emissions based on the sensor measurements. The soil gas emissions may be determined based on the sensor measurements and dimensions of each chamber. Determining soil gas emissions may comprise determining soil gas flux. The soil gas flux may be a greenhouse gas flux, a CO_2 flux and/or any other suitable soil gas flux. The soil gas flux may correspond to a flow rate per unit area. The computer may perform linear flux rate modeling to generate liner flux rate models of the field based on passive diffusion principles used in static chambers.

[0023] The sensor nodes 102 communicate wirelessly to the gateway device 104, thereby providing a wireless sensor network. Any suitable communication protocol may be used for the communication between the sensor nodes 102 and the gateway device 104. In some embodiments, the wireless communication protocol used may be any one of Bluetooth, Wi-Fi, ZigBee, WiMAX, low-power wide-area (LPWA) network, low-power network (LPN) and LoRa (Long Range) wireless communication technology. The communication may be one-way, i.e. from the sensor nodes 102 to the gateway device 104, or two-way, i.e., between both the sensor nodes 102 and the gateway device 104. The communication range may vary as a function of the type of connection. The communication between the sensor nodes 102 and the gateway device 104 may be in the 900 MHz Industrial, Scientific, and Medical (ISM) radio band in North America and 433 MHz in Europe. Any other suitable frequency band may be used.

[0024] The gateway device 104 may communicate to the computer 106 by wireless connection and/or by a wired connection. Examples of wired connections are cables or optical fibers, which may be underground or above ground. Any suitable one of the aforementioned wireless communication protocols may be used for the communication between the gateway device 104 and the computer 106. In some embodiments, gateway device 104 communicates to the computer 106 over a public network (e.g., the Internet) and/or a private network. The network(s) may comprise one or more of a personal area networks (PAN), local area networks (LAN), mesh networks, metropolitan area networks (MAN), wide area networks (WAN), Wi-Fi networks, and cellular networks.

[0025] The system 100 provides a wireless network of chambers equipped with NDIR sensors for simultaneous *in situ* analysis of soil gas emissions across agricultural production areas throughout a field of soil. A communication network of these chambers provides a spatiotemporal scale appropriate for the agricultural landscape. Thus, the system 100 may allow for the assessment of greenhouse gases fluxes at the spatiotemporal scale, which may be suitable for determining the variability present in farm-scale production areas. Furthermore, the system 100 may allow for real-time, or near real-time, measurement of physical soil conditions and provides both spatial and temporal insight into the conditions affecting greenhouse gas fluxes in soils. The network may be configured to consist of four (4) communication layers which include, the sensor nodes 102, the gateway device 104, the computer 106 and the application layers. A star network topology of the sensor nodes 102 and gateway device 104 is illustrated in Figure 1, which may allow for communication greater than 10 km (line of sight) with a single gateway device 104. Other network topologies may be used depending on practical applications. In some embodiments, a given sensor node may communicate through another sensor node to provide gas measurements obtained by the given sensor node to the gateway device 104.

[0026] It should be appreciated that the system 100 may provide a cost-effective wireless sensor network by using low-cost NDIR sensors at each sensor node. The system 100 at least in part addresses the deficiencies of non-steady-state non-flow-through, or static, chamber sampling technique and *ex situ* analysis methods, such as gas chromatography, and the high instrumentation and/or analytical costs of on-site analysis systems that use tubing networks, that are currently used to perform greenhouse gas flux analysis.

[0027] With reference to Figure 2, there is illustrated the sensor node 102, in accordance with one or more embodiments. The illustrated sensor node 102 comprises a power source 202 for powering at least one NDIR sensor 204, a transceiver module 208 and a computing device 210. While the sensor 204 is described herein as a NDIR sensor, this is for example purposes only and any other suitable type of sensor may be used depending on practical implementations. The sensor node 102 may vary depending on practical implementations. Each NDIR sensor 204 obtains gas measurements from chambers 206. Each NDIR sensor 204 may measures greenhouse gas concentration and/or other auxiliary properties in the chamber 206. In some embodiments, the NDIR sensor 204 is for measuring CO_2. Accordingly, each sensor node 102 is able obtain gas measurements from chambers 206 at various locations of the field. The controller 210 obtains the sensor measurements from the NDIR sensor 204 and provides the sensor measurements to the transceiver module 208 for transmitting the sensor measurements to the gateway device 104. In some embodiments, the sensor node 102 comprises a GPS unit for obtaining the GPS position of the sensor node 102.

[0028] The NDIR sensor 204 may be housed within the chamber 206. The chamber 206 may be a closed and open chamber. The chamber 206 may provide a headspace for collecting gas, for example, collecting trace gas concentrations. In particular, the chamber headspace allows for the accumulation of soil gas emissions in an enclosure of the chamber 206. By way of a specific and non-limiting example, the enclosure may be a 10-inch height by 4-inch diameter of a non-reactive PVC cylinder. A soil blade may be connected to the chamber 206 for installing the sensor node 102 in the soil of the field. The soil blade may be made of any suitable material for on-site installation of the sensor node 102 on various soil types with minimal disturbance to the area. The sensor measurements obtained may comprise, gas measurements indicative of the collected gas in the headspace of the chamber 206, CO2 concentrations (ppm), pressure (kPa), temperature (C), humidity (%), and ultrasonic depth measurement. In some embodiments, a sampling tube with a valve may be added to the chamber 206 for hand sampling of the headspace with a syringe. In some embodiments, the chamber 206 also incorporates a fan within the headspace for uniform air mixing to ensure that a homogeneous air sample is measured.

[0029] The power source 202 may be any suitable power source. For example, at least one battery or a combination of one or more batteries and one or more solar panels may be used. In accordance with a specific and non-limiting example of implementations, and powered by an 11.1 V (3 lithium ion 18650 batteries) source. A printed circuit board (PCB) may be used to configure the electronics used in the sensor node 102. The housing of the components of the sensor node 202 may comprise a 3D printed housing of polylactic acid (PLA) bioplastic material or any other suitable material. The computing device 210 may be any suitable computing device. By way of a specific and non-limiting example of implementation, the computing device 210 is a Arduino Nano microcontroller (Arduino, Italy).

[0030] A given sensor node 102 may transmit to the gateway device 104 the sensor measurements along with any other suitable information. For example, a given sensor node 102 may transmit timestamp information for the sensor measurements that indicates the date and time that the sensor measurements were obtained. A given sensor node 102 may transmit a unique identified assigned to that sensor node along with the sensor measurement, thereby allowing the gateway device to known which sensor node 102 provided the sensor measurement. In some embodiments, a given sensor node 102 may provide positioning information indicating where in the field that given sensor node 102 is positioned. The positioning information may comprise GPS position information or may comprise any other suitable information indicative of where in the field a given sensor node 102 is positioned.

[0031] With reference to Figure 3, there is illustrated the gateway device 104, in accordance with one or more embodiments. The gateway device 104 comprises at least one transceiver module 302 for receiving the sensor measurements from the sensor nodes 102. Any other information transmitted by the sensor node 102 may be received the by the transceiver. A computing device 310 may receive the sensor measurements and any other information from the sensor nodes 102 via the transceiver module 302. The computing device 310 may cause the transceiver module 302 to return confirmation of receipt of sensor measurements to the sensor nodes 102. The computing device 310 may locally store the received sensor measurements and any other information in a storage device 304. The storage device 304 may be any suitable computer-based memory. Storing the sensor measurements and any other information may comprise storing the measurements and information in a database of the storage device 304. The computing device 310 may transmit the received sensor measurements and any other information to the computer 106 via the transceiver module 302. The transceiver module 302 may be any suitable commercially available module for sending and receiving data. In some embodiments, the gateway device 104 comprises first and second transceiver modules. For example, the first transceiver modules may be a LoRa transceiver for receiving the gas measurements from the sensor nodes 102 and the second transceiver module may be a Wi-Fi module for transmitting the gas measurements to the computer 106. The gateway device 104 may vary depending on practical implementations. The gateway device 104 may be any suitable mobile device that is capable of receiving the sensor measurements and other information from the sensor nodes 102 and forwarding the sensor measurements and other information to the computer 106.

[0032] In accordance with a specific and non-limiting example of implementation the gateway device 104 is implemented by a Raspberry Pi 3 Model B single board computer

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(Raspberry Pi, Cambridge, United Kingdom) equipped with a LoRa transceiver. The gateway device 104 may have a range of greater than 2 km. The actual distance can vary depending on the obstructions to the line of sight between the sensor nodes 102 and the gateway device 104 and/or practical implementations. For example, mature corn fields yields shorter reliable (~900 m) communication ranges depending on the positioning of the gateway device 104. A fixed gateway device 104 located at a strategic high position such as posts, for better line of sight, may yield greater than 20 km with the LoRa technology.

[0033] With reference to Figure 4, there is illustrated the computer 106, in accordance with one or more embodiments. The computer 106 may be any suitable computer, such as a desktop computer, a laptop computer, a mainframe, a server, a distributed computing system, a portable computing device, and the like. The computer comprises at least one transceiver module 402 for receiving the sensor measurements and any other information from the sensor nodes 102 via the gateway device 104. The transceiver module 402 may be any suitable commercially available module for sending and receiving data. For example, the transceiver module 402 may be a Ethernet or Wi-Fi module for connecting the computer 106 to a public network (e.g., the Internet) and/or a private network. The computing device 410 processes the sensor measurements and any other information to assess the soil gas emissions. The computing device 410 may cause the sensor measurements and any other information received by the transceiver module 402 to be stored in the storage device 404. The storage device 404 may be any suitable computer-based memory. Storing the sensor measurements and any other information may comprise storing the sensor measurements and the other information in a database of the storage device 404. The sensor measurements and the other information may then later be retrieved to asses soil gas emissions both spatially and temporally.

[0034] The computing device 410 processes the sensor measurements and any other information to determine soil gas flux. The computing device 410 may process the timestamp information and/or the positioning information along with sensor measurements to determine the soil gas flux. Determining soil gas emissions may comprise determining soil gas flux. The soil gas flux may be a greenhouse gas flux, a

CO_2 flux and/or any other suitable soil gas flux. The soil gas flux may correspond to a flow rate per unit area. The soil gas flux may correspond to the flow of gas emissions from a specific location relative to average background emissions. The computer device 410 may perform linear flux rate modeling to generate liner flux rate models of the field based on passive diffusion principles used in static chambers. This may allow for assessment of greenhouse gases fluxes at the spatiotemporal scale. The computing device 410 may process the sensor measurements and any other information in real-time, or near real-time, to assess soil gas emissions. For example, this may allow for real-time, or near real-time, generation of the soil gas flux, the liner flux rate models and/or any other assessment of the soil gas emissions.

[0035] The computer 106 may comprise a display device 408 or may be connected to an external display device 408. The display device 408 may be any suitable display device, for example, such as a cathode ray tube display screen, a light-emitting diode display screen, a liquid crystal display screen or any other suitable display screen. The computer 106 may cause the display device 408 to display the determined soil gas flux, the generated liner flux rate models and/or any other assessment of the soil gas emissions. The aforementioned may be displayed in real-time, or near real-time.

[0036] With reference to Figure 5, there is shown a flowchart illustrating an example method 500 for assessing soil gas emissions. The method 500 may be implemented by the system 100 and/or the computer 106. Step 502 comprises causing a plurality of sensor nodes 102 in a field to obtain sensor measurements at different locations of the field. Each one of the plurality of sensor nodes 102 comprises a non-dispersive infrared sensor 204 that obtains the sensor measurements indicative of gas in a chamber 206 at a corresponding location of the field. Step 504 comprises causing a gateway device 104 to obtain the sensor measurements from the plurality of sensors nodes 102. Step 506 comprises obtaining the sensor measurements from the plurality of sensor nodes 102 via the gateway device 104. Step 508 comprises determining soil gas emissions based on the sensor measurements. Each step 502, 504, 506, 508 may be implemented according to one or more of the embodiments described elsewhere in this document.

[0037] With reference to Figure 6, the computing device 210, 310, 410, comprising a processing unit 612 and a memory 614 which has stored therein computer-executable instructions 616. The processing unit 612 may comprise any suitable devices configured to implement the method 500 such that instructions 916, when executed by the computing device(s) 210, 310, and/or 410 or other programmable apparatus, may cause the functions/acts/steps performed as part of the method 500 as described herein to be executed. The processing unit 612 may comprise, for example, any type of general-purpose microprocessor or microcontroller, a digital signal processing (DSP) processor, a central processing unit (CPU), an integrated circuit, a field programmable gate array (FPGA), a reconfigurable processor, other suitably programmed or programmable logic circuits, or any combination thereof.

[0038] The memory 614 may comprise any suitable known or other machine-readable storage medium. The memory 614 may comprise non-transitory computer readable storage medium, for example, but not limited to, an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system, apparatus, or device, or any suitable combination of the foregoing. The memory 614 may include a suitable combination of any type of computer memory that is located either internally or externally to device, for example random-access memory (RAM), read-only memory (ROM), compact disc read-only memory (CDROM), electro-optical memory, magneto-optical memory, erasable programmable read-only memory (EPROM), and electrically-erasable programmable read-only memory (EEPROM), Ferroelectric RAM (FRAM) or the like. Memory 614 may comprise any storage means (e.g., devices) suitable for retrievably storing machine-readable instructions 616 executable by processing unit 612.

[0039] The methods and systems for assessing soil gas emissions described herein may be implemented in a high level procedural or object oriented programming or scripting language, or a combination thereof, to communicate with or assist in the operation of a computer system, for example the computing device 210, 310, 410. Alternatively, the methods and systems for assessing soil gas emissions may be implemented in assembly or machine language. The language may be a compiled or interpreted language. Program code for implementing the methods and systems for assessing soil gas emissions may be stored on a storage media or a device, for example a ROM, a magnetic disk, an optical disc, a flash drive, or any other suitable storage media or device. The program code may be readable by a general or special-purpose programmable computer for configuring and operating the computer when the storage media or device is read by the computer to perform the procedures described herein. Embodiments of the methods and systems for assessing soil gas emissions may also be considered to be implemented by way of a non-transitory computer-readable storage medium having a computer program stored thereon. The computer program may comprise computer-readable instructions which cause a computer, or in some embodiments the processing unit 912 of the computing device 210, 310, 410, to operate in a specific and predefined manner to perform the functions described herein.

[0040] Computer-executable instructions may be in many forms, including program modules, executed by one or more computers or other devices. Generally, program modules include routines, programs, objects, components, data structures, etc., that perform particular tasks or implement particular abstract data types. Typically the functionality of the program modules may be combined or distributed as desired in various embodiments.

[0041] Simultaneous deployment of multiple sensor nodes 102 at different regions of a field allows for high spatial and temporal analysis of CO_2 measurements and mapping. As CO_2 plays an important role in the soil and atmosphere gas exchange of agricultural operations, a case study will now be described where CO_2 is the greenhouse gas considered; however, the embodiments described in this case study may be extended to cover any other suitable greenhouse gas emission.

[0042] This system 100 was tested against a controlled experiment on the soil microbial activity of potato crops grown in soils amended with various substrates, including compost, biochar, and (TiO2) nanoparticles. Gas chromatography (GC) validation of samples collected from the chamber's headspace showed a linear relationship with the corresponding NDIR sensor outputs and yielded a R2 of 0.96 with no significant difference in the population mean at a $\alpha = 0.05$ significance level. A model of the effects of the soil treatments and sampling dates on NDIR measured CO_2 gas flux was obtained from this study and was found to be statistically significant using a two-way ANOVA.

Based on the analysis described herein, the system developed provides a practical tool for rapid assessment of soil CO_2 emission from agricultural fields.

[0043] Testing of the NDIR based closed chamber system was performed parallel with two on-going experiments on the soil microbial activity of potato and green pepper crops grown in soils amended with various substrates. These experiments were performed under controlled environmental conditions with the main effects of the various soil conditions being tested. In this study, air samples were collected manually from within the chamber headspace alongside the readings collected from the NDIR sensor. The purpose of this study is to test the precision and accuracy of the NDIR-based chambers by comparing the output obtained from the *in situ* system to the standard *ex situ* analysis of the gas using a GC. Thus, samples from within the chamber headspace, are taken simultaneously with the chamber readings. One of the goals of this study is to test whether a sensor-based approach can consistently observe the differences in the microbial activity of soils amended with various substrates. The objectives are to measure CO_2 concentrations over time for all treatments, calculate soil gas flux based on sensor readings and chamber dimensions in order to determine the microbial activity and to test the effectiveness of using a wireless sensor network for soil gas measurements.

[0044] Samples were collected from lysimeters located at the Macdonald Campus of McGill University, Ste. Anne de Bellevue QC, Canada (45°24'48.6" N latitude and 73°56'28.1" W longitude). The PVC lysimeters (1 m height x 0.45 m inner diameter) provide a controlled environment for the soil and the crop. They are sealed at the bottom with a PVC sheet and provided with a perforated drainage pipe. The lysimeters are filled with sandy soil obtained from the farm of the Macdonald Campus of McGill University. The experimental design of this study was set up as Completely Randomized Design (CRD). The experimental setup of the potato study includes 9 treatments with three replicates per treatment. The setup of the potted green pepper crops includes 7 treatments with 4 replicates per treatment. Testing of the NDIR wireless sensor network consisted of randomly assigning chambers, using a MATLAB generated random number assignment, to each treatment for both studies and measuring the CO_2 emission as one measure of gauging the soil microbial activity. Testing of the NDIR wireless sensor network was repeated on multiple days for each treatment during the end of the summer/beginning of the fall season of 2018. The sampling schedule includes four days of measurement of the potato study: August 10, August 23, August 30, September 9, and two days of measurements performed on the potted green pepper crops: September 12, September 16. The potato and green pepper experimental study was used to compare NDIR obtained measurements with GC obtained measurements by performing further manual sampling. The potato crop study was further used as a demonstration of the capabilities of the NDIR wireless sensor network on the application of measuring soil gas emissions for various soil treatment.

[0045] In order to test the wireless sensor network NDIR's ability to effectively measure gas accumulation concentrations from within the chamber's headspace, CO_2 measurements obtained from the NDIR sensor output were compared with GC obtained measurements. This is done by collecting air samples from within the chamber's headspace using a syringe to pull air from the sampling tube found on the NDIR chambers, storing the samples in 20 ml evacuated exetainers, and finally analyzing the samples in the GC. For each trial, samples were collected at the 0 min, 15 min, 30 min, 45 min, and 60 min to simulate the process used to calculate flux in the non-steady state non-flow through method. Thus, 5 samples (and observations) are obtained for each trial. Since it is not possible to perform this process for every chamber, due to logistical constraints, 9 chambers were randomly selected during the potato and green pepper study for manual sampling trials. Thus, 45 samples were collected, analyzed by the GC, and compared to the corresponding NDIR chamber output using. The application of the NDIR wireless sensor network chamber to measure soil gas emissions in various soil treatments was demonstrated in the potato crop study. The study examined the soil microbial activity of potato crops grown in contaminated soils amended with various substrates. Using the same experimental design described previously for the potato crop only, the NDIR wireless sensor was deployed to examine the effect of these various treatments on soil CO_2 Flux.

[0046] Statistical analysis of the comparisons of CO_2 gas concentration, measured in parts per million (ppm), between the NDIR and GC output include a two-tailed paired difference t-test and a simple linear regression between the two measurements. Since measurements collected from both methods are used to assess the same sample of air within the chamber, the two variables are paired, thus the t-test is paired and investigates the differences between the two parameters. The differences between the measurements showed a normal distribution, thus, establishing that the test was appropriate. The null hypothesis (Ho) is that the population mean (μ) of the differences between the NDIR and GC measurements is equal to 0, meaning that there are no differences between the two measurements. A 95% confidence interval shows that the true population mean of the differences is between -6.27 and 48.28 ppm. Thus, using a two-tailed paired t-test, Ho cannot be rejected leading to the conclusion that there is no statistically significant difference between the NDIR and GC measurement of CO2 concentrations at $\alpha = 0.05$ significance level. A linear regression between the two measurements was performed to see whether there was a linear correlation between the two techniques. Based on the coefficient of determination (R2) obtained from this model (R2= 0.96), there is a very strong linear correlation between the NDIR and GC measurements. The plot of the least squared regressions along with the correlation between the two measurements are shown in Figure 7.

[0047] The data obtained from this statistical analysis is used as the validation of the measurements obtained by the NDIR wireless sensor network. As shown in literature, the GC lab technique is widely used as a standard for measuring gas concentration. Thus, comparing the NDIR chambers to the GC would show the precision and accuracy of the NDIR system to analyze gas concentrations on-site. Based on preliminary visual inspection of Figure 8, it was hypothesized that the two measurement techniques would yield very similar results. Further analysis of a linear regression of the two techniques show that there is a very strong linear relationship between the two methods of gas analysis.

[0048] The application of the NDIR wireless sensor network for measuring soil gas emissions for various soil conditions was demonstrated on the potato crop study under controlled environmental conditions. The NDIR chambers were used as the method for measuring soil CO_2 flux for this study. Results of the measured soil CO_2 flux of all treatments are shown in Figure 9. Preliminary visual assessment of the various fluxes shows very clear patterns between the soil treatments. Based on this initial inspection of the treatment fluxes, it is speculated that there are mean differences between the treatment groups and the date that the fluxes were measured. Thus, a two-way ANOVA was selected to assess these differences.

[0049] The ANOVA results found that all parameter effects in the model, except for the fixed effects of the interactions of the treatments and dates, are statistically significant with a significance level of $\alpha = 0.05$. Since the treatment parameter is statistically significant, there is a difference in the means of at least one of the treatments. Similarly, the date parameter is statistically significant; thus, there is a statistically significant difference in the means of at least one of the sampling dates. A multiple comparison was performed using a Tukey test in order to determine which treatments and dates were significantly different from each other. The treatments with significant differences are shown in Figure 8. With an R2 of 0.73, this model is quite effective at predicting fluxes of a given treatment and date.

[0050] The results of the controlled experiments provide us with significant insight into the NDIR wireless sensor network CO_2 measurement techniques. The controlled experiment compared the raw CO_2 concentrations (pre-flux calculation), in ppm, measured within the chamber headspace by the NDIR sensor with samples collected simultaneously within the headspace and analyzed by GC analyzer, also in ppm. Based on the analysis, we see a very strong linear relationship with a R2 value of 0.96. The 95% confidence from this study indicated that the true mean difference is negligible between the NDIR measurements and GC analyzed samples. This study demonstrates the NDIR wireless sensor network chamber's accuracy with the standard GC analysis of samples within the same headspace. The CO_2 data collected from the potato lysimeter site of this study further explores the NDIR wireless sensor network's ability to determine treatment differences consistently. The results of the ANOVA showed significant differences between the treatments and date effects on CO_2 flux, however there was no significant effects of the interaction between the dates and the treatment on the estimated flux. This indicates that the differences in the treatment effects on flux and the differences in the date effects on the flux can be observed separately. The results of the tukey test show that the treatment with the highest least square mean is the soils amended with compost and waste water, directly after application (August 10), as expected. This wireless sensor network provides both famers and researchers access to cheaper farm monitoring technology while providing the data infrastructure for better land management practices.

[0051] The above description is meant to be exemplary only, and one skilled in the art will recognize that changes may be made to the embodiments described without departing from the scope of the invention disclosed. Still other modifications which fall within the scope of the present invention will be apparent to those skilled in the art, in light of a review of this disclosure.

Various aspects of the methods, systems and devices for assessing soil gas emissions may be used alone, in combination, or in a variety of arrangements not specifically discussed in the embodiments described in the foregoing and is therefore not limited in its application to the details and arrangement of components set forth in the foregoing description or illustrated in the drawings. For example, aspects described in one embodiment may be combined in any manner with aspects described in other embodiments. Although particular embodiments have been shown and described, it will be obvious to those skilled in the art that changes and modifications may be made without departing from this invention in its broader aspects. The scope of the following claims should not be limited by the embodiments set forth in the examples, but should be given the broadest reasonable interpretation consistent with the description as a whole.

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CLAIMS:

1. A method for assessing soil gas emissions, the method comprising:

causing a plurality of sensor nodes in a field to obtain sensor measurements at different locations of the field, each one of the plurality of sensor nodes comprises a non-dispersive infrared sensor that obtains the sensor measurements indicative of gas in a chamber at a corresponding location of the field;

causing a gateway device to obtain the sensor measurements from the plurality of sensor nodes;

obtaining the sensor measurements from the plurality of sensor nodes via the gateway device; and

determining soil gas emissions based on the sensor measurements.

2. A system for assessing soil gas emissions, the system comprising:

at least one processing unit; and

at least one non-transitory computer-readable memory having stored thereon program instructions executable by the at least one processing unit for:

causing a plurality of sensor nodes in a field to obtain sensor measurements at different locations of the field, each one of the plurality of sensor nodes comprises a non-dispersive infrared sensor that obtains the sensor measurements indicative of gas in a chamber at a corresponding location of the field;

causing a gateway device to obtain the sensor measurements from the plurality of sensor nodes;

obtaining the sensor measurements from the plurality of sensor nodes via the gateway device; and

determining soil gas emissions based on the sensor measurements.

3. A system for assessing soil gas emissions, the system comprising:

a plurality of sensor nodes configured to obtain sensor measurements at different locations of a field, each one of the plurality of sensor nodes comprises a non-dispersive infrared sensor that obtains the sensor measurements indicative of gas in a chamber at a corresponding location of the field;

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a gateway device configured to obtain the sensor measurements from the plurality of sensors;

a computer configured to obtain the sensor measurements from the plurality of sensor nodes via the gateway device and to determine soil gas emissions based on the sensor measurements.

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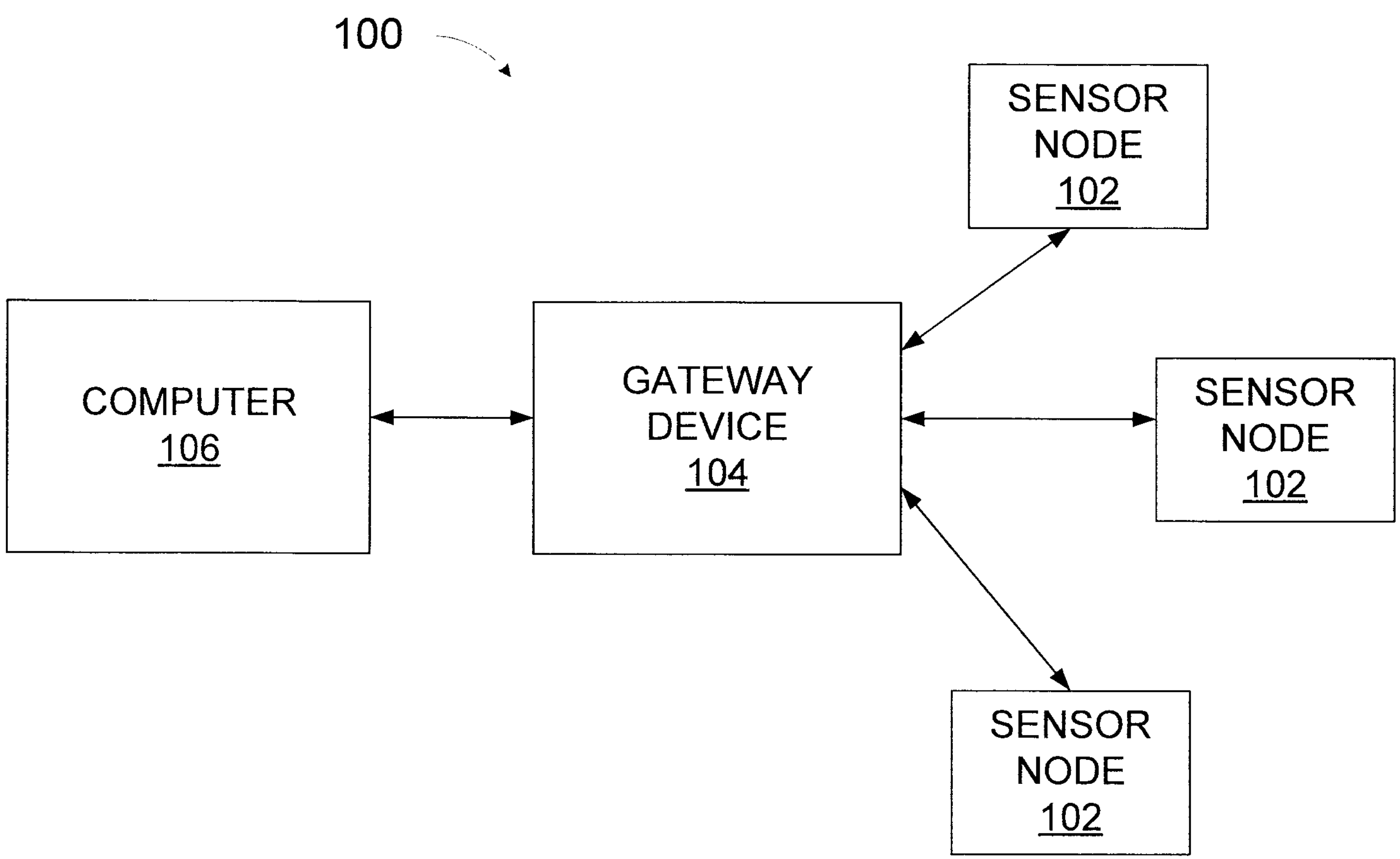
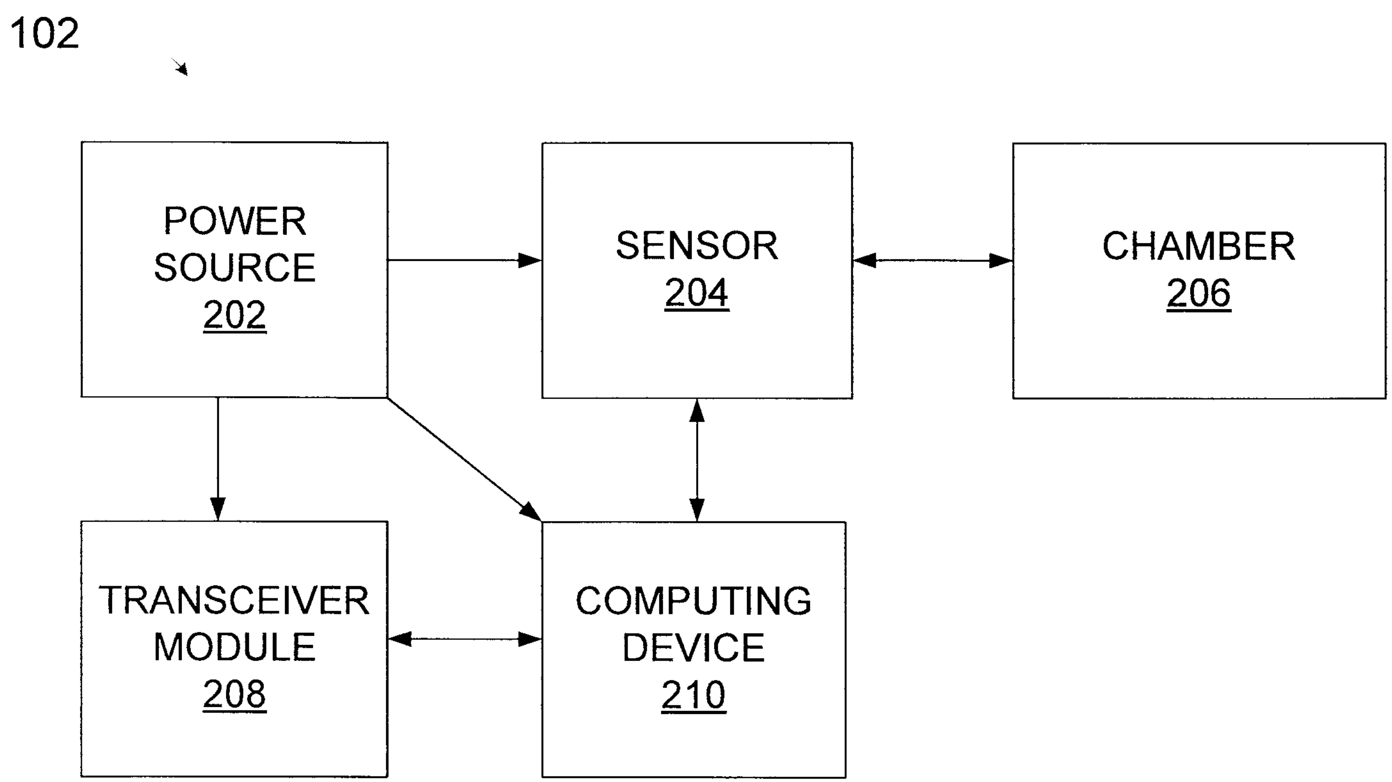


FIGURE 1



102
POWER SOURCE 202
SENSOR 204
CHAMBER 206
TRANSCEIVER MODULE 208
COMPUTING DEVICE 210

FIGURE 2

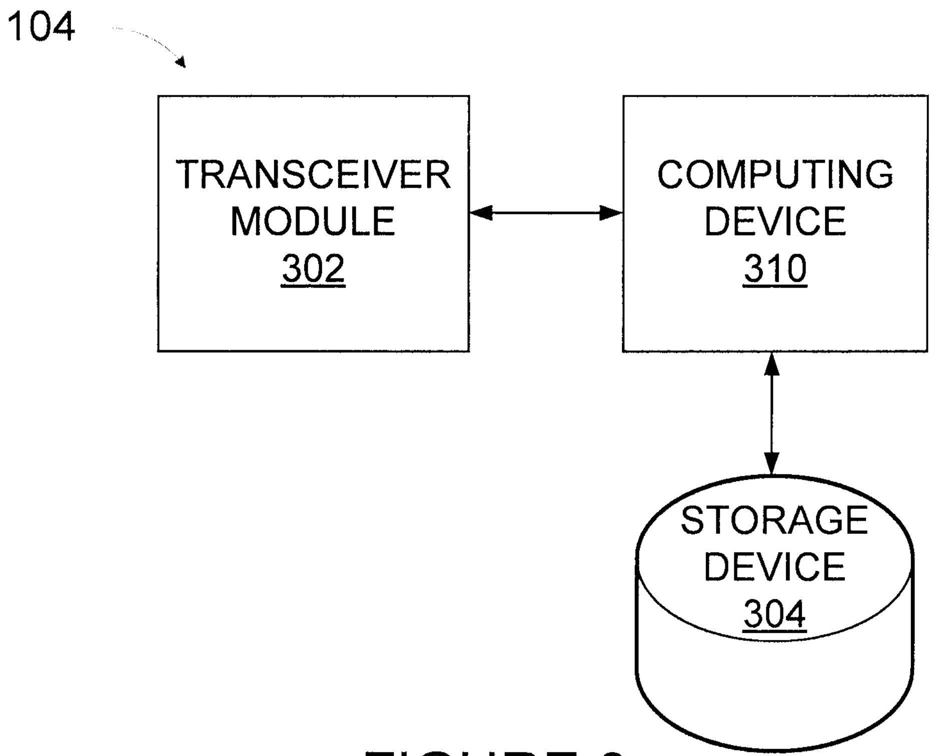


FIGURE 3

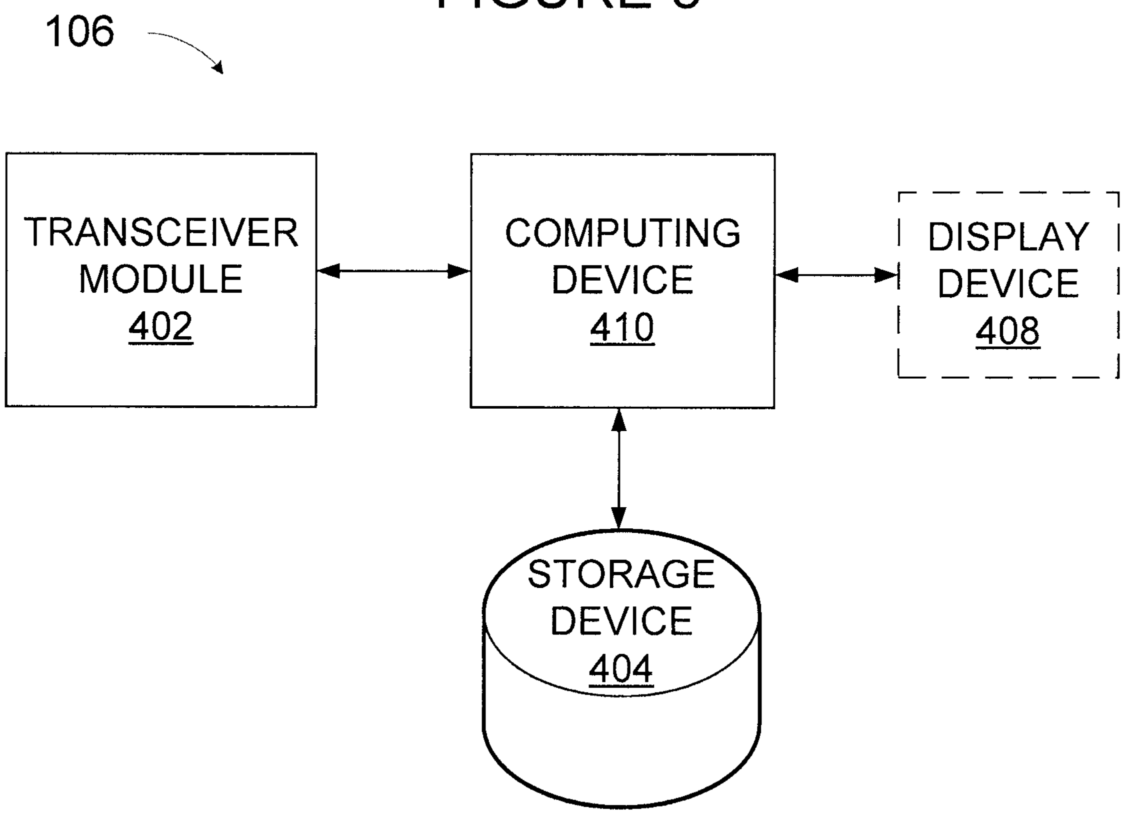


FIGURE 4

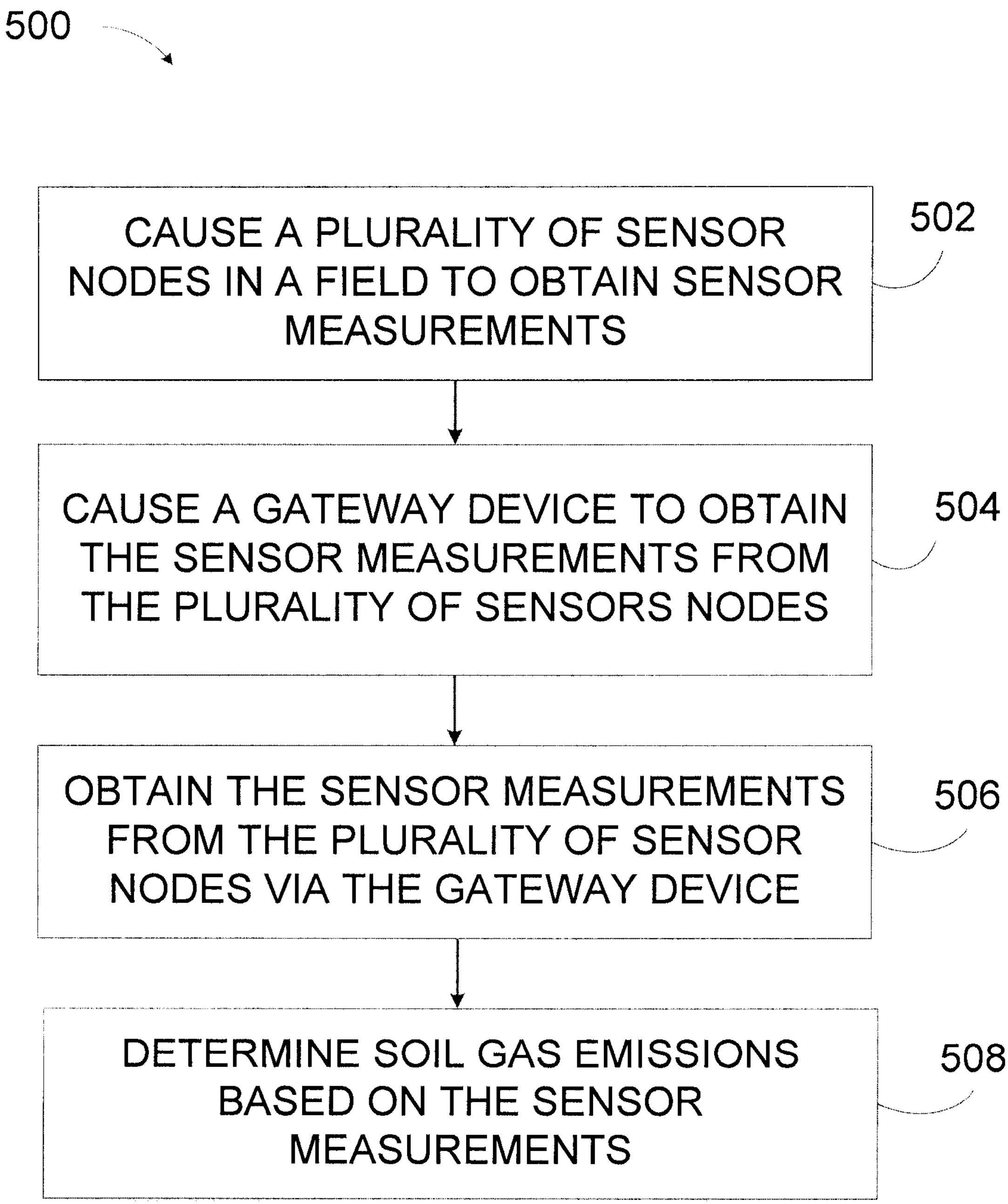

500
CAUSE A PLURALITY OF SENSOR NODES IN A FIELD TO OBTAIN SENSOR MEASUREMENTS
502
CAUSE A GATEWAY DEVICE TO OBTAIN THE SENSOR MEASUREMENTS FROM THE PLURALITY OF SENSORS NODES
504
OBTAIN THE SENSOR MEASUREMENTS FROM THE PLURALITY OF SENSOR NODES VIA THE GATEWAY DEVICE
506
DETERMINE SOIL GAS EMISSIONS BASED ON THE SENSOR MEASUREMENTS
508

FIGURE 5

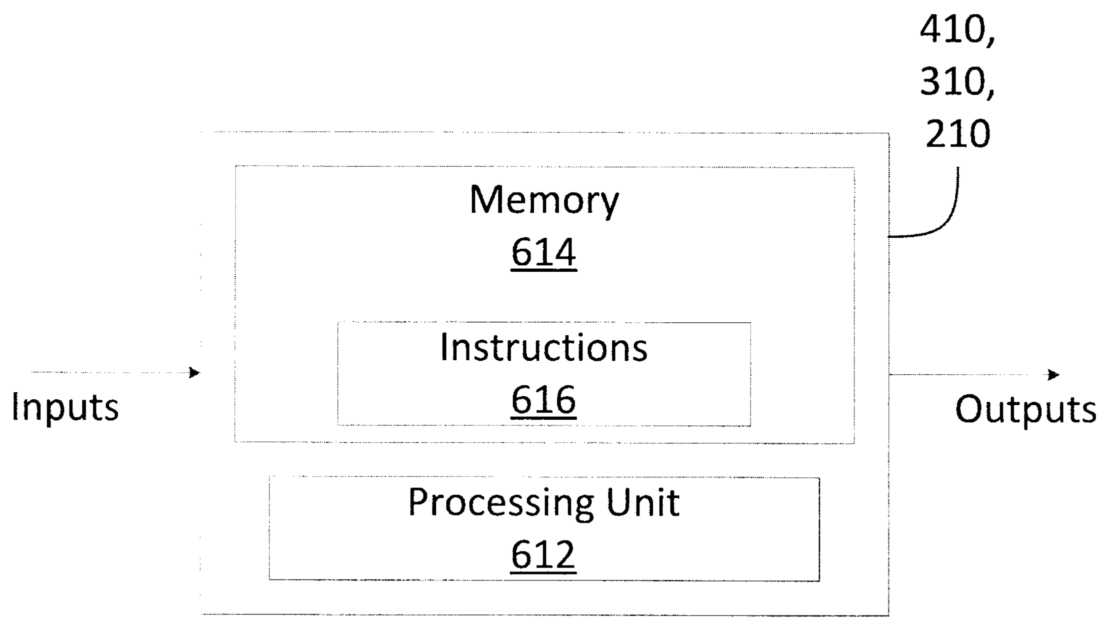

410,
310,
210
Memory
614
Instructions
616
Inputs
Outputs
Processing Unit
612

FIGURE 6

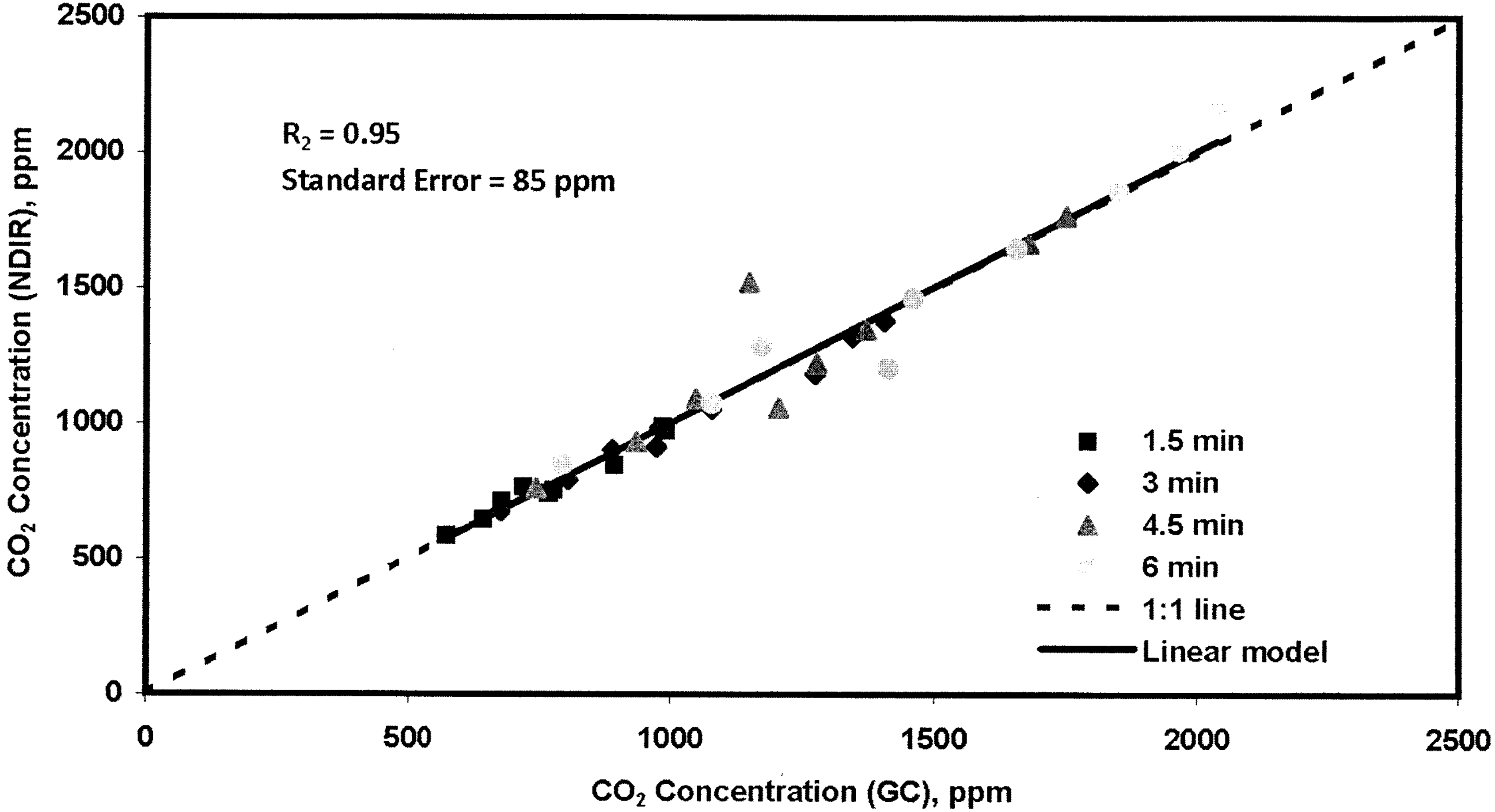

R2 = 0.95
Standard Error = 85 ppm
CO2 Concentration (NDIR), ppm
CO2 Concentration (GC), ppm
0
500
1000
1500
2000
2500
1.5 min
3 min
4.5 min
6 min
1:1 line
Linear model

FIGURE 7

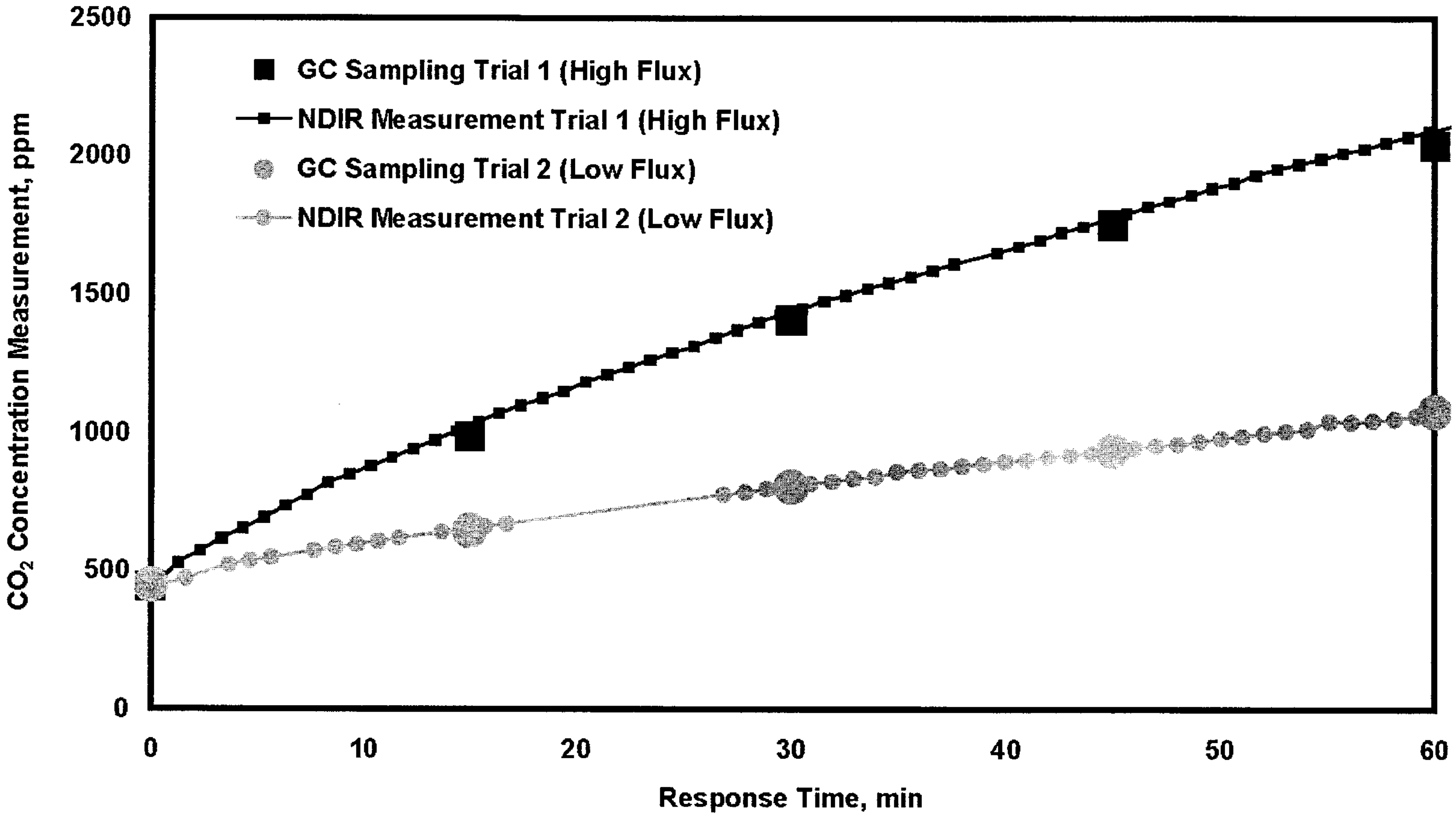

GC Sampling Trial 1 (High Flux)
NDIR Measurement Trial 1 (High Flux)
GC Sampling Trial 2 (Low Flux)
NDIR Measurement Trial 2 (Low Flux)
CO_2 Concentration Measurement, ppm
0
500
1000
1500
2000
2500
0
10
20
30
40
50
60
Response Time, min

FIGURE 8

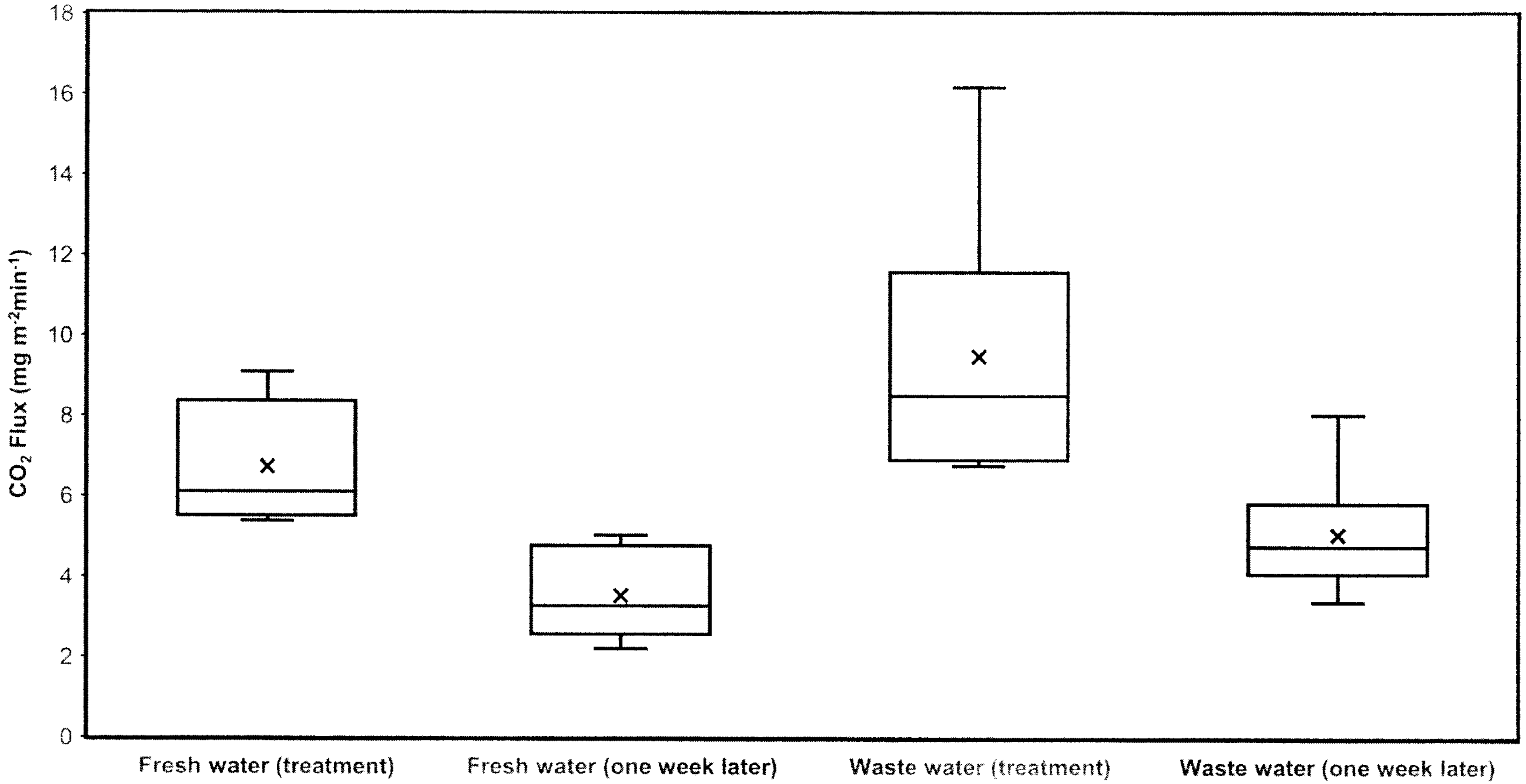
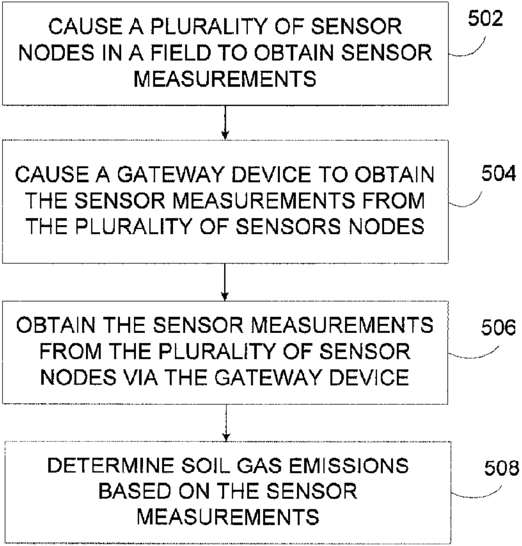

18
16
14
12
10
8
6
4
2
0
CO2 Flux (mg m-2min-1)
Fresh water (treatment)
Fresh water (one week later)
Waste water (treatment)
Waste water (one week later)

FIGURE 9

500


CAUSE A PLURALITY OF SENSOR NODES IN A FIELD TO OBTAIN SENSOR MEASUREMENTS
502
CAUSE A GATEWAY DEVICE TO OBTAIN THE SENSOR MEASUREMENTS FROM THE PLURALITY OF SENSORS NODES
504
OBTAIN THE SENSOR MEASUREMENTS FROM THE PLURALITY OF SENSOR NODES VIA THE GATEWAY DEVICE
506
DETERMINE SOIL GAS EMISSIONS BASED ON THE SENSOR MEASUREMENTS
508