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ELECTRONIC ACKNOWLEDGEMENT RECEIPT

APPLICATION #	RECEIPT DATE / TIME	ATTORNEY DOCKET #
18/323,490	**05/25/2023 10:32:49 AM ET**	**7028-P71709US00**

Title of Invention

SYSTEM, APPARATUS AND METHOD OF NON-DESTRUCTIVELY DETERMINING PETIOLE NUTRIENT VALUES IN NEAR REAL-TIME USING A PORTABLE SPECTROPHOTOMETER

Application Information

APPLICATION TYPE	Utility - Nonprovisional Application under 35 USC 111(a)	PATENT #	-
CONFIRMATION #	5538	FILED BY	Jennifer Howe
PATENT CENTER #	62152553	FILING DATE	-
CUSTOMER #	1059	FIRST NAMED INVENTOR	Ahmad Al-Mallahi
CORRESPONDENCE ADDRESS	-	AUTHORIZED BY	Nicholas Aitken

Documents

TOTAL DOCUMENTS: 5

DOCUMENT		PAGES	DESCRIPTION	SIZE (KB)
ADS_2023-05-25_P71709US00.pdf		8	Application Data Sheet	83 KB
Warning: This is not a USPTO supplied ADS fillable form. Data in the form cannot be automatically loaded to other USPTO systems.				
Spec_TO_BE_FILED_2023-05-25_P71709US00.pdf		30	-	369 KB
Spec_TO_BE_FILED_2023-05-25_P71709US00-SPEC.pdf	(1-24)	24	Specification	364 KB
Spec_TO_BE_FILED_2023-	(25-29)	5	Claims	136 KB

05-25_P71709US00-CLM.pdf				
Spec_TO_BE_FILED_2023-05-25_P71709US00-ABST.pdf	(30-30)	1	Abstract	125 KB
Drawings_TO_BE_FILED_2023-05-25_P71709US00.pdf		5	Drawings-only black and white line drawings	452 KB

Digest

DOCUMENT	MESSAGE DIGEST(SHA-512)
ADS_2023-05-25_P71709US00.pdf	80AAD23D3C375B6B0669610F1F5F0164FF2D3F135303F730464EB6C724ED9A480F158AC9805EDA316ABDED33C603D1F70B616BB5C7C341300B992112C803367D
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Spec_TO_BE_FILED_2023-05-25_P71709US00-SPEC.pdf	76C7E6DD779C0ABE23A22F491133E9E3268816EB9A298258C5EBF9FA43A02DE0342F9E294FEEBA8DC83D05F5A7C27F7381FC3363F8E32B289558C94564FFD849
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Spec_TO_BE_FILED_2023-05-25_P71709US00-ABST.pdf	41D90131F7316083E3C9AB66821F3ED94268EAC4B7847BF3CB36D74F18B8F77FAE0F33F1BBEC96C501A0CF1D976D9E61D8B1FE0769046A9837A9BF6E99AD4301
Drawings_TO_BE_FILED_2023-05-25_P71709US00.pdf	1AAFD17BD3549AA02ACF7EBF3CE3570C731EC532D27A75A3C4684B3F21F4EF448B86F6E9F7D4C0130936C29A716E82B0CEBE33E73FFFCC5E6FC99CBA24C59307

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If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

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CORRESPONDENCE ADDRESS	-	FIRST NAMED INVENTOR	Ahmad Al-Maliahi

Payment Information

PAYMENT METHOD	PAYMENT TRANSACTION ID	PAYMENT AUTHORIZED BY
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PRE-AUTHORIZED ACCOUNT	PRE-AUTHORIZED CATEGORY
022095	37 CFR 1.16 (National application filing, search, and examination fees); 37 CFR 1.17 (Patent application and reexamination processing fees); 37 CFR 1.19 (Document supply fees); 37 CFR 1.20 (Post Issuance fees); 37 CFR 1.21 (Miscellaneous fees and charges)

FEE CODE	DESCRIPTION	ITEM PRICE($)	QUANTITY	ITEM TOTAL($)
1051	SURCHARGE- LATE FILING FEE, SEARCH FEE, EXAMINATION FEE, INVENTOR'S OATH OR DECLARATION, OR APPLICATION FILED WITHOUT AT LEAST ONE CLAIM OR BY REFERENCE	160.00	1	160.00
1111	UTILITY PATENT APPL. SEARCH FEE	700.00	1	700.00

1011	BASIC FILING FEE - UTILITY (PAPER FILING ALSO REQUIRES NON-ELECTRONIC FILING FEE UNDER 1.16(T))	320.00	1	320.00
1311	PATENT APPL. EXAMINATION FEE	800.00	1	800.00
1202	EACH CLAIM IN EXCESS OF 20	100.00	7	700.00
1201	EACH INDEPENDENT CLAIM IN EXCESS OF THREE	480.00	1	480.00
			TOTAL AMOUNT:	**$3,160.00**

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SYSTEM, APPARATUS AND METHOD OF NON-DESTRUCTIVELY DETERMINING PETIOLE NUTRIENT VALUES IN NEAR REAL-TIME USING A PORTABLE SPECTROPHOTOMETER

FIELD

[0001] This document relates to systems, apparatus, and methods of non-destructively determining petiole nutrient values in near real-time from plant leaves in a crop field using a portable spectrophotometer.

BACKGROUND

[0002] Plants need many nutrients for growth and sustenance. For example, plants may need macronutrients like nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S) in large quantities. Plants may also need micronutrients like manganese (Mn), zinc (Zn), iron (Fe), sodium (Na), copper (Cu), aluminum (Al), and boron (B) in small quantities.

[0003] In agricultural applications, crop yield and/or quality of harvested crops may be affected if the crop plants do not receive a suitable amount of each required nutrient. For example, the crop yield and/or quality may be reduced if the plants do not receive enough nutrients. In some cases, excessive supply of nutrients may also reduce the crop yield and/or quality.

[0004] Determining the nutrient value status of plants can enable corrective actions to be performed to improve crop yield and/or quality. For example, the composition and quantity of fertilizer may be tailored for one or more specific nutrients based on the determined nutrient value status of the plants.

SUMMARY

[0005] The following summary is provided to introduce the reader to the more detailed discussion to follow. The summary is not intended to limit or define any claimed or as yet unclaimed invention. One or more inventions may reside in any combination or sub-

combination of the elements or process steps disclosed in any part of this document including its claims and figures.

[0006] According to some aspects, a method of non-destructively determining petiole nutrient values in near real-time from plant leaves in a crop field using a portable spectrophotometer is provided. The method may comprise: (a) taking non-destructive spectral measurements of a leaf of a plant in the crop field using the portable spectrophotometer to generate leaf spectral data, (b) storing the leaf spectral data in a memory; (c) computing, by a processor, the petiole nutrient values based on the stored leaf spectral data; and (d) providing a near real-time result indicating the petiole nutrient values.

[0007] According to some aspects, an apparatus for non-destructively determining petiole nutrient values in near real-time from plant leaves in a crop field is provided. The apparatus may comprise: a memory storing a machine learning model trained to provide petiole nutrient value outputs based on leaf spectral data inputs; and at least one processor communicatively coupled with the memory. The at least one processor may be configured to collectively: receive leaf spectral data generated by a portable spectrophotometer based on non-destructive spectral measurements of a leaf of a plant in the crop field; store the leaf spectral data in the memory; input the leaf spectral data into the machine learning model; receive an output comprising the petiole nutrient values determined by the machine learning model based on the leaf spectral data; and provide a near real-time result to a mobile device, the near real-time result indicating the petiole nutrient values.

[0008] According to some aspects, a non-transitory computer-readable medium comprising instructions executable by a processor is provided. The instructions when executed may configure the processor to: receive leaf spectral data generated by a portable spectrophotometer based on non-destructive spectral measurements of a leaf of a plant in a crop field; store the leaf spectral data in a memory; input the leaf spectral data into a machine learning model trained to provide petiole nutrient value outputs based on leaf spectral data inputs; receive an output comprising the petiole nutrient values

determined by the machine learning model based on the leaf spectral data; and provide a near real-time result indicating the petiole nutrient values.

[0009] According to some aspects, a system for non-destructively determining petiole nutrient values in near real-time from plant leaves in a crop field is provided. The system may comprise a portable spectrophotometer and a remote server. The portable spectrophotometer may be configured to: generate leaf spectral data based on non-destructive spectral measurements of a leaf of a plant in the crop field; and transmit the leaf spectral data for receipt by the remote server via a network. The remote server may comprise a processor and a memory, the memory storing a machine learning model trained to provide petiole nutrient value outputs based on leaf spectral data inputs. The remote server may be configured to: receive the leaf spectral data; store the leaf spectral data in the memory; input the leaf spectral data into the machine learning model; receive the petiole nutrient values determined by the machine learning model based on the leaf spectral data; and provide a near real-time result indicating the petiole nutrient values to a mobile device.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The drawings included herewith are for illustrating various examples of articles, methods, and apparatuses of the present specification and are not intended to limit the scope of what is taught in any way. In the drawings:

[0011] FIG. 1 is an illustration of a leaf of a plant whose nutrient values may be determined, in accordance with an embodiment;

[0012] FIG. 2 is a schematic illustration of a system for non-destructively determining petiole nutrient values in near real-time from plant leaves in a crop field, in accordance with an embodiment;

[0013] FIG. 3 is a schematic illustration of a result indicating petiole nutrient values provided by the system of FIG. 2 and graphically displayed on a mobile device;

[0014] FIG. 4 is a schematic illustration of an apparatus for non-destructively determining petiole nutrient values in near real-time from plant leaves in a crop field, in accordance with an embodiment; and

[0015] FIG. 5 is a flowchart illustrating an example method of non-destructively determining petiole nutrient values in near real-time from plant leaves in a crop field using a portable spectrophotometer.

DETAILED DESCRIPTION

[0016] Numerous embodiments are described in this application and are presented for illustrative purposes only. The described embodiments are not intended to be limiting in any sense. The invention is widely applicable to numerous embodiments, as is readily apparent from the disclosure herein. Those skilled in the art will recognize that the present invention may be practiced with modification and alteration without departing from the teachings disclosed herein. Although particular features of the present invention may be described with reference to one or more particular embodiments or figures, it should be understood that such features are not limited to usage in the one or more particular embodiments or figures with reference to which they are described.

[0017] The terms "an embodiment," "embodiment," "embodiments," "the embodiment," "the embodiments," "one or more embodiments," "some embodiments," and "one embodiment" mean "one or more (but not all) embodiments of the present invention(s)," unless expressly specified otherwise.

[0018] The terms "including," "comprising" and variations thereof mean "including but not limited to," unless expressly specified otherwise. A listing of items does not imply that any or all of the items are mutually exclusive, unless expressly specified otherwise. The terms "a," "an" and "the" mean "one or more," unless expressly specified otherwise.

[0019] As used herein and in the claims, two or more parts are said to be "coupled", "connected", "attached", "joined", "affixed", or "fastened" where the parts are joined or operate together either directly or indirectly (i.e., through one or more intermediate parts), so long as a link occurs. As used herein and in the claims, two or more parts are said to

be "directly coupled", "directly connected", "directly attached", "directly joined", "directly affixed", or "directly fastened" where the parts are connected in physical contact with each other. As used herein, two or more parts are said to be "rigidly coupled", "rigidly connected", "rigidly attached", "rigidly joined", "rigidly affixed", or "rigidly fastened" where the parts are coupled so as to move as one while maintaining a constant orientation relative to each other. None of the terms "coupled", "connected", "attached", "joined", "affixed", and "fastened" distinguish the manner in which two or more parts are joined together.

[0020] Further, although method steps may be described (in the disclosure and / or in the claims) in a sequential order, such methods may be configured to work in alternate orders. In other words, any sequence or order of steps that may be described does not necessarily indicate a requirement that the steps be performed in that order. The steps of methods described herein may be performed in any order that is practical. Further, some steps may be performed simultaneously.

[0021] As used herein and in the claims, a group of elements are said to 'collectively' perform an act where that act is performed by any one of the elements in the group, or performed cooperatively by two or more (or all) elements in the group.

[0022] As used herein and in the claims, a first element is said to be "received" in a second element where at least a portion of the first element is received in the second element unless specifically stated otherwise.

[0023] Some elements herein may be identified by a part number, which is composed of a base number followed by an alphabetical or subscript-numerical suffix (e.g., 112a, or 112_1). Multiple elements herein may be identified by part numbers that share a base number in common and that differ by their suffixes (e.g., 112_1, 112_2, and 112_3). All elements with a common base number may be referred to collectively or generically using the base number without a suffix (e.g., 112).

[0024] As used herein and in the claims, "up", "down", "above", "below", "upwardly", "vertical", "elevation", "upper", "lower" and similar terms are in reference to a directionality

generally aligned with (e.g., parallel to) gravity. The terms "distal", "proximal" and similar terms are in reference to a directionality generally that is transverse (e.g., perpendicular) to gravity. However, none of the terms referred to in this paragraph imply any particular alignment between elements. For example, a first element may be said to be "vertically above" a second element, where the first element is at a higher elevation than the second element, and irrespective of whether the first element is vertically aligned with the second element.

[0025] Generally, plant tissue tests for determining plant nutrient value status are destructive and do not provide real-time results. For example, a farmer may harvest petioles from plants in a crop field for measurement. The harvested petioles may be shipped to a laboratory for testing. Depending on the testing to be performed, a large number of petioles may need to be destructively removed.

[0026] The laboratory may then conduct plant tissue testing and provide petiole nutrient values to the farmer. The process of removing the petioles, shipping, testing, and result notification may take weeks to complete. This delay undermines the effectiveness of any corrective action (e.g. adjusting fertilizer composition and quantity) taken based on the results because the nutrient content in the measured plants may have changed in the intervening period.

[0027] The disclosed systems, apparatus and methods can provide non-destructive and near real-time determination of plant nutrient value status using a portable spectrophotometer. Molecules absorb light at frequencies that are characteristic of their structure. The portable spectrophotometer can be used to take non-destructive spectral measurements that indicate the presence and concentration of different molecules (nutrients) in the probed region (e.g., a leaf of a plant). The portable spectrophotometer can generate leaf spectral data (based on the non-destructive spectral measurements) that can be used to determine the nutrient value status of plants. No plant leaves or petioles are required to be removed from the plants for testing. The disclosed system, apparatus and method can provide the plant nutrient value status without destruction of any of the plants used for testing.

[0028] Further, the disclosed system, apparatus and method can conduct the analysis and provide the results in near real-time, for example, within 10-20 seconds. This can enable any required corrective actions (based on the determined plant nutrient value status) to be immediately performed. As used herein and in the claims, an action is said to be performed in "near real-time" where that action is performed in less than 1 minute from when it was initiated.

[0029] In canopy reflectance measurements, ground-based or air-borne platforms are used to determine the ratio of the amount of light leaving the canopy to the amount of incoming light. The canopy reflectance measurement may be used for calculating the crop nutrient value status. However, canopy reflectance measurements are frequently subject to atmospheric and soil interference. The disclosed system, apparatus and method can use a portable spectrophotometer to probe plant leaves which avoids the atmospheric interference and/or soil interference associated with conducting canopy reflectance measurements using ground-based or air-borne platforms.

[0030] Referring now to FIG. 1, shown therein is an illustration of a plant 10 whose nutrient value status may be determined using the disclosed system, apparatus or method. In the illustrated example, plant 10 includes a stem 14, a leaf 18 and a petiole 22 attaching leaf 18 to stem 14. Leaf 18 includes a leaf blade 26 and multiple leaf veins 30.

[0031] The surface area of leaf blade 26 can be much larger compared with petiole 22 and therefore spectral reflectance measurements may be taken from leaf blade 26 instead of petiole 22. Accordingly, the measured nutrient values may be indicative of the nutrient values corresponding to the leaf blade instead of the petiole nutrient values.

[0032] Nutrient values in petioles are not the same as nutrient values measured at other parts of a plant (e.g. the leaf blade). At present and historically, farmers have sent petiole to laboratories, and the laboratories have returned petiole nutrient values. As such, farmers generally understand what corrective actions are required based on laboratory petiole nutrient values but not based on nutrient values associated with other parts of the plant.

[0033] The disclosed system, apparatus and method can take spectral measurements from leaf blades of a plant to produce leaf spectral data and compute petiole nutrient values based on the leaf spectral data. Providing petiole nutrient values (as opposed to nutrient values associated with the leaf) can enable a user to select and apply well known and understood corrective actions.

[0034] Referring now to FIG. 2, shown therein is a schematic illustration of a system 100 for non-destructively determining petiole nutrient values in near real-time from plant leaves 18 in a crop field 34, in accordance with an embodiment. As shown, system 100 may include a portable spectrophotometer 104 and a remote server 108.

[0035] In the illustrated example, portable spectrophotometer 104 and remote server 108 are communicatively coupled using a network 112. Network 112 may include a communication network such as the Internet, a Wide-Area Network (WAN), a Local-Area Network (LAN), or another type of network. In other examples, portable spectrophotometer 104 and remote server 108 may not be connected to a common network and may communicate using intermediary devices and/or communication networks.

[0036] Crop field 34 may include multiple plants 10 (e.g., at least 500 plants). Each plant 10 may have one or more leaves 18. Plants 10 may include any suitable plants grown in agricultural applications. For example, plants 10 may include wheat, corn, soy, potato etc. Crop field 34 may be located in open air or inside a greenhouse.

[0037] Portable spectrophotometer 104 may have any suitable design that is portable and capable of taking non-destructive spectral measurements of leaves of plants 10. Portable spectrophotometer 104 may be sized and designed to be carried by an operator while the operator uses the portable spectrophotometer to take spectral measurements. For example, portable spectrophotometer 104 may be battery-operated and designed to be carried in a backpack by an operator 38.

[0038] A light source within portable spectrophotometer 104 can generate incident light onto a leaf and a detector within portable spectrophotometer 104 can measure the light

reflected from leaves of plants 10. Portable spectrophotometer 104 may generate leaf spectral data based on the reflected spectral measurements.

[0039] In some embodiments, portable spectrophotometer 104 may take spectral measurements and generate leaf spectral data in visible and/or near-infrared wavelength ranges. For example, portable spectrophotometer 104 may generate leaf spectral data in a wavelength range from 400nm-2500nm. In other examples, portable spectrophotometer 104 may generate leaf spectral data in smaller (e.g., 400nm-2000nm) or larger (e.g., 350nm-2500nm) wavelength ranges. Smaller wavelength ranges may enable faster completion of the spectral measurements and/or require fewer resources for computing the petiole nutrient values. Larger wavelength ranges may enable determination of the petiole nutrient values with higher accuracy and/or detection of a larger number of nutrients. The wavelength range may be manually or automatically adjusted based on the nutrient values being measured. For example, operator 38 may manually adjust the wavelength range. In other examples, the wavelength range may be automatically adjusted, for example, by remote server 108.

[0040] Portable spectrophotometer 104 may take the spectral measurements at discrete wavelength intervals within the measured wavelength range. For example, portable spectrophotometer 104 may take the spectral measurements at 0.5nm wavelength intervals within the measured wavelength range. The wavelength intervals used during the measurements may be manually or automatically adjusted based on the nutrient values being determined. For example, operator 38 may manually adjust the wavelength interval. In other examples, the wavelength interval may be automatically adjusted, for example, by remote server 108. Different wavelength intervals ranging from 0.1nm to 10nm may be used. Smaller wavelength intervals may enable determination of nutrient values with higher accuracy and/or determination of a larger number of nutrients. Larger wavelength intervals may enable faster determination of nutrient values and/or require fewer computing resources for determination of the nutrient values.

[0041] In some embodiments, portable spectrophotometer 104 may be a NIRS™ DS2500 Analyzer or an ASD™ FieldSpec 4 spectroradiometer. In other embodiments, portable spectrophotometer 104 may be any other suitable spectrophotometer.

[0042] Portable spectrophotometer 104 may be configured to transmit the generated leaf spectral data for receipt by remote server 108. In the illustrated example, portable spectrophotometer 104 may transmit the generated leaf spectral data to remote server 108 via network 112. In other examples, portable spectrophotometer 104 may transmit the generated leaf spectral data to an intermediary device, for example, a mobile device 42 of operator 38. Portable spectrophotometer 104 may transmit the generated leaf spectral data to mobile device 42 using point-to-point communication or a local-area network (e.g. Bluetooth™) and mobile device 42 may then transmit the leaf spectral data to remote server 108 using a large-area network/internet.

[0043] Mobile device 42 may be any suitable device that is portable and capable of sending and receiving data over a communication network (e.g., wireless communication networks like cellphone networks and/or wi-fi networks). For example, mobile device 42 may be a laptop, a tablet device, or a smartphone with wireless communication capabilities. Mobile device 42 may be a dedicated companion device designed for use with portable spectrophotometer 104. In some embodiments, mobile device 42 may be a general-purpose device that includes proprietary software for communication with portable spectrophotometer 104 and/or analysis of data received from portable spectrophotometer 104. In some embodiments, the functionality of portable spectrophotometer 104 and mobile device 42 may be provided by a single device.

[0044] In the illustrated example, remote server 108 includes a processor 116 and a memory 120. Processor 116 may control the operation of remote server 108. Processor 116 may be any suitable processor, controller or digital signal processor that can provide sufficient processing power depending on the configuration, purposes and requirements of system 100, as is known by those skilled in the art. For example, processor 116 may be a high-performance general processor. For example, processor 116 may include a standard processor, such as an Intel® processor, or an AMD® processor. Alternatively,

processor 116 may include more than one processor with each processor being configured to perform different dedicated tasks. Alternatively, specialized hardware (e.g., graphical processing units (GPUs)) can be used provide some of the functions provided by processor 116.

[0045] Memory 120 may include one or more of random-access memory (RAM), read-only memory (ROM), a hard drive, and a flash memory (e.g. solid state drive). Remote server 108 may store received leaf spectral data in memory 120. For example, remote server 108 may receive leaf spectral data generated by portable spectrophotometer 104 and store the received leaf spectral data in memory 120.

[0046] Memory 120 may also store a machine learning model trained to provide petiole nutrient value outputs based on leaf spectral data inputs. The machine learning model may be generated and trained by remote server 108. In some embodiments, remote server 108 may receive a machine learning model generated by an external device. Remote server 108 may train the received machine learning model and store the trained machine learning model in memory 120. In other embodiments, the trained machine learning model may be received by remote server 108 from an external device. Remote server 108 may store the received trained machine learning model in memory 120.

[0047] The leaf spectral data inputs provided to the machine learning model may include, for example, leaf spectral data generated by portable spectrophotometer 104 by taking spectral measurements from leaf blades of plants. The petiole nutrient value outputs provided by the machine learning model may include, for example, determined petiole nutrient values for one or more nutrients such as N, P, K, Ca, Mg, S, Mn, Zn, Fe, B, Cu, Al, and Na. The petiole nutrient values for the different nutrients may be expressed as percentage values (of total mass), g/kg, and/or parts per million (ppm).

[0048] The machine learning model may be any suitable machine learning model based on the input data to be analyzed, the output data requirements, the available training data and/or available computing resources. In some embodiments, the machine learning model may be a multiple linear regression (MLR) model. Lasso subset selection methods may be performed for the MLR model to generate a lasso regression model. In other

embodiments, the machine learning model may be a different model, for example, a polynomial regression model.

[0049] The training data for the machine learning model may be generated by taking spectral measurements of plants (e.g., reflectance spectral measurements from leaf blade portions) and generating leaf spectral data that act as predictors (x) for the machine learning model. Corresponding petioles of the plants may be removed and used for laboratory tissue analysis. The laboratory tissue analysis results of the petioles can act as responses (y) for the machine learning model. Models of correlation may be built between the responses (y) and the predictors (x). Equation (1) below, provides an example of a MLR model using correlation coefficients β_i:

$$y = \beta + \sum_{i=1}^{Z_i} x_i \beta_i \qquad \text{Equation (1)}$$

[0050] The number of predictors (x) being larger than the number of responses (y) can result in over-fitting of the MLR model. The accuracy of the MLR model may be improved by using subset selection methods to select a subset of the predictors. In some embodiments, lasso MLR modelling may be used as the subset selection method. In other embodiments, other subset selection methods like stepwise subset selection or Bayesian model averaging may be used.

[0051] Lasso MLR modelling may be used to identify the most informative, least redundant predictors (wavelengths) using a complexity parameter (λ) that controls the amount of shrinkage: the larger that the value of λ is, the greater can be the penalization of the non-zero coefficients in the model, and consequently a greater shrinkage can be imposed on coefficient values. A lasso regression model may be generated by selecting the value of λ that minimizes the root mean squared error (RMSE). The chosen λ parameter can determine the number of coefficients that will compose the lasso regression model, which are selected as the ones with the greatest explanatory power in relation to the target predictor. Model training and performance assessment may be conducted, for example, using 5-fold cross validation, with the value of λ chosen based on the smallest RMSE. Table 1 below shows values for number, range, and first four

significant wavebands resulting from Lasso MLR modelling of different elements for example leaf spectral data obtained from potato plants.

Table 1 Values for number, range, and first four significant wavebands resulting from Lasso MLR modelling of different elements for example leaf spectral data obtained from potato plants.

Element	Number of bands	Range of bands (nm)	First four significant wavebands (nm)
N	13	404-1828	660, 684, 404, 484
P	10	404-1924	708, 404, 540, 700
K	17	404-2300	404, 428, 588, 948
Ca	20	404-2100	404, 444, 588, 540
Mg	14	404-1940	700, 532, 1716, 524
S	18	404-1916	404, 588, 516, 1452
Mn	22	428-2492	660, 628, 428, 492
Zn	12	468-2124	1932, 524, 1852, 532
Fe	19	404-2316	1932, 636, 524, 2308
B	11	412-1932	684, 1932, 412, 460
Cu	23	428-2484	1940, 676, 428, 1716
Al	17	404-2316	1932, 2308, 524, 652
Na	20	548-2148	548, 972, 700, 1028

[0052] Processor 116 may input the received leaf spectral data (e.g., from portable spectrophotometer 104) and/or stored leaf spectral data (e.g., in memory 120) into the trained machine learning model. The machine learning model can determine petiole nutrient values based on the leaf spectral data. For example, the machine learning model can determine petiole nutrient values for N, P, K, Ca, Mg, S, Mn, Zn, Fe, B, Cu, Al, and Na based on leaf spectral data generated by taking spectral measurements of leaf blades

of potato plants. Processor 116 may receive the petiole nutrient values determined by the machine learning model.

[0053] Processor 116 can provide a near real-time result indicating the petiole nutrient values to a mobile device. For example, processor 116 may provide the near real-time result to mobile device 42 of operator 38. For example, processor 116 may provide the near real-time results to mobile device 42 less than 1 minute (e.g., within 0.01 to 30 seconds) from when the portable spectrophotometer sent the spectral measurements. This may enable operator 38 to non-destructively collect near real-time results indicating petiole nutrient values from multiple plants in a crop field.

[0054] Reference is now made to FIGS. 2 and 3. FIG. 3, shows a schematic illustration of a result indicating petiole nutrient values provided by system 100 and graphically displayed on mobile device 42. Mobile device 42 may include a touchscreen display 46 that provides an interactive display to operator 38. Touchscreen display 46 may provide multiple display portions 50a-50c. For example, display portion 50a may provide a graphical display of the determined petiole nutrient values. In the illustrated example, display portion 50a provides bar graphs displaying determined petiole nutrient values for six nutrients. In other embodiments, display 46 may not be configured to detect touch inputs.

[0055] Display portion 50b may provide additional information regarding the determined petiole nutrient values, for example, number of leaf spectral measurements taken, confidence levels associated with the determined petiole nutrient values etc. Display portion 50c may provide recommended corrective actions based on the determined petiole nutrient values. In some examples, one or more of display portions 50 may include other information unrelated to the results indicating the petiole nutrient values.

[0056] Referring now to FIG. 4, shown therein is a schematic illustration of an apparatus 200 for non-destructively determining petiole nutrient values in near real-time from plant leaves in a crop field. In some embodiments, apparatus 200 may be implemented as a server device (e.g., remote server 108 shown in FIG. 2). In other embodiments, apparatus 200 may be implemented using any other suitable hardware components. For example,

apparatus 200 may be implemented as mobile device 42 (FIGS. 2 and 3), integrated with portable spectrophotometer 104 (FIG. 2), or implemented as a companion apparatus usable with portable spectrophotometer 104 (FIG. 2).

[0057] For the example embodiment illustrated in FIG. 4, apparatus 200 includes a memory 208, an application 212, an output device 216, a display device 220, a secondary storage device 224, a processor 228, an input device 232, and a communication device 236. One or more (or all) of memory 208, application 212, output device 216, display device 220, secondary storage device 224, processor 228, input device 232, and communication device 236 may be communicatively coupled by wire and/or wirelessly.

[0058] In some embodiments, apparatus 200 includes multiple of any one or more of memory 208, application 212, output device 216, display device 220, secondary storage device 224, processor 228, input device 232, and communication device 236. In some embodiments, apparatus 200 does not include one or more of applications 212, secondary storage devices 224, network connections, input devices 232, output devices 216, display devices 220, and communication devices 236.

[0059] In at least one embodiment, apparatus 200 includes a connection with a network 204 such as a wired or wireless connection to the Internet or to a private network. In some cases, network 204 includes other types of computer or telecommunication networks. Apparatus 200 may receive, over network 204, leaf spectra data generated by a portable spectrophotometer (e.g., portable spectrophotometer 104 of FIG. 2) based on non-destructive spectral measurements of a leaf of a plant (e.g., a potato plant) in the crop field (e.g., crop field 34 of FIG. 2).

[0060] In some embodiments, apparatus 200 may receive the leaf spectral data directly from the portable spectrophotometer by wire or wirelessly. In other embodiments, apparatus 200 may receive the leaf spectral data generated by the portable spectrophotometer from an intermediary device (e.g., mobile device 42 of FIG. 2).

[0061] Memory 208 can include one or more of random-access memory (RAM) and read-only memory (ROM). In some embodiments, memory 208 stores one or more applications

212 for execution by processor 228. Applications 212 correspond with software modules including computer executable instructions to perform processing for the functions and methods described herein.

[0062] Memory 208 may store a machine learning model trained to provide petiole nutrient value outputs based on leaf spectral data inputs. The machine learning model may be generated and trained by apparatus 200. In some embodiments, apparatus 200 may receive a generated machine learning model from an external device (e.g., over network 204) and may train the received machine learning model. In some embodiments, apparatus 200 may receive a trained machine learning model from an external device (e.g., over network 204) and store the trained machine learning model in memory 208. The machine learning model may be any suitable model, e.g., a lasso regression model.

[0063] In some embodiments, memory 208 may also store received leaf spectral data, determined petiole nutrient values, and/or results derived from the petiole nutrient values (e.g. a graphical representation of the petiole nutrient values). The stored data may be retrieved by a user for historical data analysis.

[0064] Secondary storage device 224 may include any suitable non-transitory computer-readable medium including instructions executable by a processor (e.g., processor 228). For example, secondary storage device 224 can include a hard drive, floppy drive, CD drive, DVD drive, Blu-ray drive, solid state drive, flash memory or other types of non-volatile data storage. Processor 228 may execute instructions included on secondary storage device 224 to perform processing for the functions and methods described herein.

[0065] In some embodiments, apparatus 200 stores information in a remote storage device, such as cloud storage, accessible across a network, such as network 204 or another network. In some embodiments, apparatus 200 stores information distributed across multiple storage devices, such as memory 208 and secondary storage device 224 (i.e., each of the multiple storage devices stores a portion of the information and collectively the multiple storage devices store all of the information). Accordingly, storing data on a storage device as used herein and in the claims, means storing that data in a

local storage device, storing that data in a remote storage device, or storing that data distributed across multiple storage devices, each of which can be local or remote.

[0066] Input device 232 can include any device for entering information into apparatus 200. For example, input device 232 can be a keyboard, keypad, cursor-device, touchscreen, camera, or microphone. Input device 232 can also include input ports and wireless radios (e.g., Bluetooth®, or 802.11x) for making wired and wireless connections to external devices.

[0067] Display device 220 can include any type of device for presenting visual information. For example, display device 220 can be a computer monitor, a flat-screen display, a projector or a display panel.

[0068] Output device 216 can include any type of device for presenting a hard copy of information, such as a printer for example. Output device 216 can also include other types of output devices such as speakers, for example. In at least one embodiment, output device 216 includes one or more of output ports and wireless radios (e.g., Bluetooth®, or 802.11x) for making wired and wireless connections to external devices.

[0069] Communication device 236 can have any design suitable to receive analog and/or digital inputs from, and to provide analog and/or digital outputs. In some embodiments, communication device 236 may include separate modules for analog and digital signals.

[0070] Processor 228 may be any device that can execute applications, computer readable instructions or programs. The applications, computer readable instructions or programs can be stored in memory 208 or in secondary storage device 224, or can be received from remote storage accessible through network 204, for example. Processor 228 may be a high-performance general processor, a standard processor (e.g., an Intel® processor or an AMD® processor), specialized hardware (e.g., GPUs), or multiple processing devices that collectively perform the functions provided by processor 228.

[0071] Processor 228 may input leaf spectral data (e.g., leaf spectral data stored in memory 208) into a trained machine learning model (e.g., trained machine learning model stored in memory 208). The machine learning model can determine petiole nutrient values

based on the leaf spectral data. Processor 228 may receive an output from the machine learning model that includes the petiole nutrient values determined by the machine learning model.

[0072] In some embodiments, processor 228 can provide a near real-time result indicating the petiole nutrient values to a mobile device (e.g., mobile device 42 of FIG. 2). The petiole nutrient values may be graphically displayed on the mobile device. In other embodiments, processor 228 may provide the results to display device 220 and the petiole nutrient values may be graphically displayed on display device 220.

[0073] FIG. 4 illustrates one example hardware schematic of an apparatus 200. In alternative embodiments, apparatus 200 contains fewer, additional or different components. In addition, although aspects of an implementation of apparatus 200 are described as being stored in memory, one skilled in the art will appreciate that these aspects can also be stored on or read from other types of computer program products or computer-readable media, such as secondary storage devices, including hard disks, floppy disks, CDs, or DVDs; a carrier wave from the Internet or other network; or other forms of RAM or ROM. For example, apparatus 200 may include a non-transitory computer readable medium storing computer-readable instructions that when executed by processor 228, configure processor 228 to perform method(s) described herein.

[0074] Referring now to FIG. 5, shown therein is a flowchart illustrating an example method 300 of non-destructively determining petiole nutrient values in near real-time from plant leaves in a crop field using a portable spectrophotometer. Method 300 may be performed, for example, using system 100 (FIG. 2) or apparatus 200 (FIG. 4) and reference is also made below to FIGS. 2 and 4.

[0075] Method 300 may be performed while carrying the portable spectrophotometer in the crop field. For example, portable spectrophotometer 104 may be carried in crop field 34 on a person or vehicle.

[0076] At 308, non-destructive spectral measurements may be taken of a leaf of a plant in the crop field using the carried spectrophotometer to generate leaf spectral data. For

example, non-destructive spectral measurements may be taken of a leaf of a potato plant using portable spectrophotometer 104. Portable spectrophotometer 104 can generate leaf spectral data based on the spectral measurements.

[0077] At 312, the leaf spectral data may be stored in a memory. In some embodiments, the generated leaf spectral data may be sent to a remote server over a network and stored in a memory of the remote server. For example, portable spectrophotometer 104 may send the generated leaf spectral data to remote server 108 over network 112 and remote server 108 may store the leaf spectral data in memory 120.

[0078] In other embodiments, the generated leaf spectral data may be sent to a mobile device and the mobile device may send the leaf spectral data to a remote server over a network. The leaf spectral data may be stored in a memory of the remote server. For example, portable spectrophotometer 104 may send the generated leaf spectral data to mobile device 42 and mobile device 42 may send the leaf spectral data to remote server 108 over network 112. Remote server 108 may store the leaf spectral data in memory 120.

[0079] At 316, a processor may compute the petiole nutrient values based on the stored leaf spectral data. The processor may compute the petiole nutrient values by inputting the leaf spectral data into a machine learning model trained to provide petiole nutrient value outputs based on leaf spectral data inputs. In response, the machine learning model may output the petiole nutrient values to the processor. For example, processor 116 (or processor 228) may input the leaf spectral data into a trained machine learning model stored in memory 120 (or memory 208). The machine learning model may be a lasso regression model.

[0080] At 320, a near real-time result indicating the petiole nutrient values may be provided. In some embodiments, the near real-time result may be provided by sending the petiole nutrient values to a mobile device. The petiole nutrient values may then be graphically displayed on the mobile device. For example, remote server 108 or apparatus 200 may provide the near real-time result by sending the petiole nutrient values to mobile device 42. Mobile device 42 may graphically display the petiole nutrient values.

[0081] In some embodiments, method 300 may proceed to 308 if there are additional leaves for measurement. For example, method 300 may loop through 308 to 320 for at least five other plant leaves in the crop field within ten minutes. This may enable near real-time results to be obtained indicating the petiole nutrient values corresponding to non-destructive spectral measurements from multiple leaves in a short time period. In turn this will allow the farm to contemporaneously react to the returned petiole nutrient values (e.g., by adjusting the composition and/or quantity of fertilizer) before the nutrient content of the measured plants has had time to change. This may improve the effectiveness of the corrective actions, whereby the crop yield and/or quantity may be improved.

[0082] While the above description provides examples of the embodiments, it will be appreciated that some features and/or functions of the described embodiments are susceptible to modification without departing from the spirit and principles of operation of the described embodiments. Accordingly, what has been described above has been intended to be illustrative of the invention and non-limiting and it will be understood by persons skilled in the art that other variants and modifications may be made without departing from the scope of the invention as defined in the claims appended hereto. The scope of the claims should not be limited by the preferred embodiments and examples, but should be given the broadest interpretation consistent with the description as a whole.

ITEMS

[0083] Item 1: A method of non-destructively determining petiole nutrient values in near real-time from plant leaves in a crop field using a portable spectrophotometer, the method comprising: (a) taking non-destructive spectral measurements of a leaf of a plant in the crop field using the portable spectrophotometer to generate leaf spectral data, (b) storing the leaf spectral data in a memory; (c) computing, by a processor, the petiole nutrient values based on the stored leaf spectral data; and (d) providing a near real-time result indicating the petiole nutrient values.

[0084] Item 2: The method of any preceding item, wherein said providing comprises sending the petiole nutrient values to a mobile device.

[0085] Item 3: The method of any preceding item, wherein said providing further comprises graphically displaying the petiole nutrient values on the mobile device.

[0086] Item 4: The method of any preceding item, wherein said storing comprises sending the leaf spectral data to a remote server over a network, wherein the remote server comprises the memory and the processor.

[0087] Item 5: The method of any preceding item, wherein said storing comprises a mobile device receiving the leaf spectral data and the mobile device sending the leaf spectral data over a network to a remote server, wherein the remote server comprises the memory and the processor.

[0088] Item 6: The method of any preceding item, wherein said providing comprises sending the petiole nutrient values from the remote server to the mobile device and graphically displaying the petiole nutrient values on the mobile device.

[0089] Item 7: The method of any preceding item, further comprising repeating steps (a) to (d) for at least five other plant leaves in the crop field within ten minutes.

[0090] Item 8: The method of any preceding item, wherein the plant is a potato plant.

[0091] Item 9: The method of any preceding item, wherein said computing comprises inputting the leaf spectral data into a machine learning model trained to provide petiole nutrient value outputs based on leaf spectral data inputs, the machine learning model outputting the petiole nutrient values.

[0092] Item 10: The method of any preceding item, wherein the machine learning model is a lasso regression model.

[0093] Item 11: An apparatus for non-destructively determining petiole nutrient values in near real-time from plant leaves in a crop field, the apparatus comprising: a memory storing a machine learning model trained to provide petiole nutrient value outputs based on leaf spectral data inputs; and at least one processor communicatively coupled with the memory, the at least one processor configured to collectively: receive leaf spectral data generated by a portable spectrophotometer based on non-destructive spectral

measurements of a leaf of a plant in the crop field; store the leaf spectral data in the memory; input the leaf spectral data into the machine learning model; receive an output comprising the petiole nutrient values determined by the machine learning model based on the leaf spectral data; and provide a near real-time result to a mobile device, the near real-time result indicating the petiole nutrient values.

[0094] Item 12: The apparatus of any preceding item, wherein the petiole nutrient values are graphically displayed on the mobile device.

[0095] Item 13: The apparatus of any preceding item, wherein the leaf spectral data generated by the portable spectrophotometer is received over a network from the mobile device.

[0096] Item 14: The apparatus of any preceding item, wherein the plant is a potato plant.

[0097] Item 15: The apparatus of any preceding item, wherein the machine learning model is a lasso regression model.

[0098] Item 16: The apparatus of any preceding item, wherein the memory comprises one or more of random-access memory (RAM), read-only memory (ROM), a hard drive, and a flash memory.

[0099] Item 17: A non-transitory computer-readable medium comprising instructions executable by a processor, wherein the instructions when executed configure the processor to: receive leaf spectral data generated by a portable spectrophotometer based on non-destructive spectral measurements of a leaf of a plant in a crop field; store the leaf spectral data in a memory; input the leaf spectral data into a machine learning model trained to provide petiole nutrient value outputs based on leaf spectral data inputs; receive an output comprising the petiole nutrient values determined by the machine learning model based on the leaf spectral data; and provide a near real-time result indicating the petiole nutrient values.

[0100] Item 18: The non-transitory computer-readable medium of any preceding item, wherein the leaf spectral data generated by the portable spectrophotometer is received over a network from a mobile device.

[0101] Item 19: The non-transitory computer-readable medium of any preceding item, wherein the plant is a potato plant.

[0102] Item 20: The non-transitory computer-readable medium of any preceding item, wherein the machine learning model is a lasso regression model.

[0103] Item 21: The non-transitory computer-readable medium of any preceding item, wherein the memory comprises one or more of random-access memory (RAM), read-only memory (ROM), a hard drive, and a flash memory.

[0104] Item 22: A system for non-destructively determining petiole nutrient values in near real-time from plant leaves in a crop field, the system comprising: a portable spectrophotometer configured to: generate leaf spectral data based on non-destructive spectral measurements of a leaf of a plant in the crop field; and transmit the leaf spectral data for receipt by a remote server via a network; and the remote server comprising a processor and a memory, the memory storing a machine learning model trained to provide petiole nutrient value outputs based on leaf spectral data inputs, the remote server configured to: receive the leaf spectral data; store the leaf spectral data in the memory; input the leaf spectral data into the machine learning model; receive the petiole nutrient values determined by the machine learning model based on the leaf spectral data; and provide a near real-time result indicating the petiole nutrient values to a mobile device.

[0105] Item 23: The system of any preceding item, wherein the petiole nutrient values are graphically displayed on the mobile device.

[0106] Item 24: The system of any preceding item, wherein the portable spectrophotometer is configured to transmit the leaf spectral data to the mobile device and the mobile device transmits the leaf spectral data to the remote server.

[0107] Item 25: The system of any preceding item, wherein the plant is a potato plant.

[0108] Item 26: The system of any preceding item, wherein the machine learning model is a lasso regression model.

[0109] Item 27: The system of any preceding item, wherein the memory comprises one or more of random-access memory (RAM), read-only memory (ROM), a hard drive, and a flash memory.

WE CLAIM:

1. A method of non-destructively determining petiole nutrient values in near real-time from plant leaves in a crop field using a portable spectrophotometer, the method comprising:

(a) taking non-destructive spectral measurements of a leaf of a plant in the crop field using the portable spectrophotometer to generate leaf spectral data,

(b) storing the leaf spectral data in a memory;

(c) computing, by a processor, the petiole nutrient values based on the stored leaf spectral data; and

(d) providing a near real-time result indicating the petiole nutrient values.

2. The method of claim 1, wherein said providing comprises sending the petiole nutrient values to a mobile device.

3. The method of claim 2, wherein said providing further comprises graphically displaying the petiole nutrient values on the mobile device.

4. The method of claim 1, wherein said storing comprises sending the leaf spectral data to a remote server over a network, wherein the remote server comprises the memory and the processor.

5. The method of claim 1, wherein said storing comprises a mobile device receiving the leaf spectral data and the mobile device sending the leaf spectral data over a network to a remote server, wherein the remote server comprises the memory and the processor.

6. The method of claim 5, wherein said providing comprises sending the petiole nutrient values from the remote server to the mobile device and graphically displaying the petiole nutrient values on the mobile device.

7. The method of claim 1, further comprising repeating steps (a) to (d) for at least five other plant leaves in the crop field within ten minutes.

8. The method of claim 1, wherein the plant is a potato plant.

9. The method of claim 1, wherein said computing comprises inputting the leaf spectral data into a machine learning model trained to provide petiole nutrient value outputs based on leaf spectral data inputs, the machine learning model outputting the petiole nutrient values.

10. The method of claim 9, wherein the machine learning model is a lasso regression model.

11. An apparatus for non-destructively determining petiole nutrient values in near real-time from plant leaves in a crop field, the apparatus comprising:

a memory storing a machine learning model trained to provide petiole nutrient value outputs based on leaf spectral data inputs; and

at least one processor communicatively coupled with the memory, the at least one processor configured to collectively:

receive leaf spectral data generated by a portable spectrophotometer based on non-destructive spectral measurements of a leaf of a plant in the crop field;

store the leaf spectral data in the memory;

input the leaf spectral data into the machine learning model;

receive an output comprising the petiole nutrient values determined by the machine learning model based on the leaf spectral data; and

provide a near real-time result to a mobile device, the near real-time result indicating the petiole nutrient values.

12. The apparatus of claim 11, wherein the petiole nutrient values are graphically displayed on the mobile device.

13. The apparatus of claim 11, wherein the leaf spectral data generated by the portable spectrophotometer is received over a network from the mobile device.

14. The apparatus of claim 11, wherein the plant is a potato plant.

15. The apparatus of claim 11, wherein the machine learning model is a lasso regression model.

16. The apparatus of claim 11, wherein the memory comprises one or more of random-access memory (RAM), read-only memory (ROM), a hard drive, and a flash memory.

17. A non-transitory computer-readable medium comprising instructions executable by a processor, wherein the instructions when executed configure the processor to:

receive leaf spectral data generated by a portable spectrophotometer based on non-destructive spectral measurements of a leaf of a plant in a crop field;

store the leaf spectral data in a memory;

input the leaf spectral data into a machine learning model trained to provide petiole nutrient value outputs based on leaf spectral data inputs;

receive an output comprising the petiole nutrient values determined by the machine learning model based on the leaf spectral data; and

provide a near real-time result indicating the petiole nutrient values.

18. The non-transitory computer-readable medium of claim 17, wherein the leaf spectral data generated by the portable spectrophotometer is received over a network from a mobile device.

19. The non-transitory computer-readable medium of claim 17, wherein the plant is a potato plant.

20. The non-transitory computer-readable medium of claim 17, wherein the machine learning model is a lasso regression model.

21. The non-transitory computer-readable medium of claim 17, wherein the memory comprises one or more of random-access memory (RAM), read-only memory (ROM), a hard drive, and a flash memory.

22. A system for non-destructively determining petiole nutrient values in near real-time from plant leaves in a crop field, the system comprising:

a portable spectrophotometer configured to:

generate leaf spectral data based on non-destructive spectral measurements of a leaf of a plant in the crop field; and

transmit the leaf spectral data for receipt by a remote server via a network; and

the remote server comprising a processor and a memory, the memory storing a machine learning model trained to provide petiole nutrient value outputs based on leaf spectral data inputs, the remote server configured to:

receive the leaf spectral data;

store the leaf spectral data in the memory;

input the leaf spectral data into the machine learning model;

receive the petiole nutrient values determined by the machine learning model based on the leaf spectral data; and

provide a near real-time result indicating the petiole nutrient values to a mobile device.

23. The system of claim 22, wherein the petiole nutrient values are graphically displayed on the mobile device.

24. The system of claim 22, wherein the portable spectrophotometer is configured to transmit the leaf spectral data to the mobile device and the mobile device transmits the leaf spectral data to the remote server.

25. The system of claim 22, wherein the plant is a potato plant.

26. The system of claim 22, wherein the machine learning model is a lasso regression model.

27. The system of claim 22, wherein the memory comprises one or more of random-access memory (RAM), read-only memory (ROM), a hard drive, and a flash memory.

ABSTRACT

A system, an apparatus and a method of non-destructively determining petiole nutrient values in near real-time from plant leaves in a crop field using a portable spectrophotometer are provided. The method may comprise: (a) taking non-destructive spectral measurements of a leaf of a plant in the crop field using the portable spectrophotometer to generate leaf spectral data, (b) storing the leaf spectral data in a memory; (c) computing, by a processor, the petiole nutrient values based on the stored leaf spectral data; and (d) providing a near real-time result indicating the petiole nutrient values.

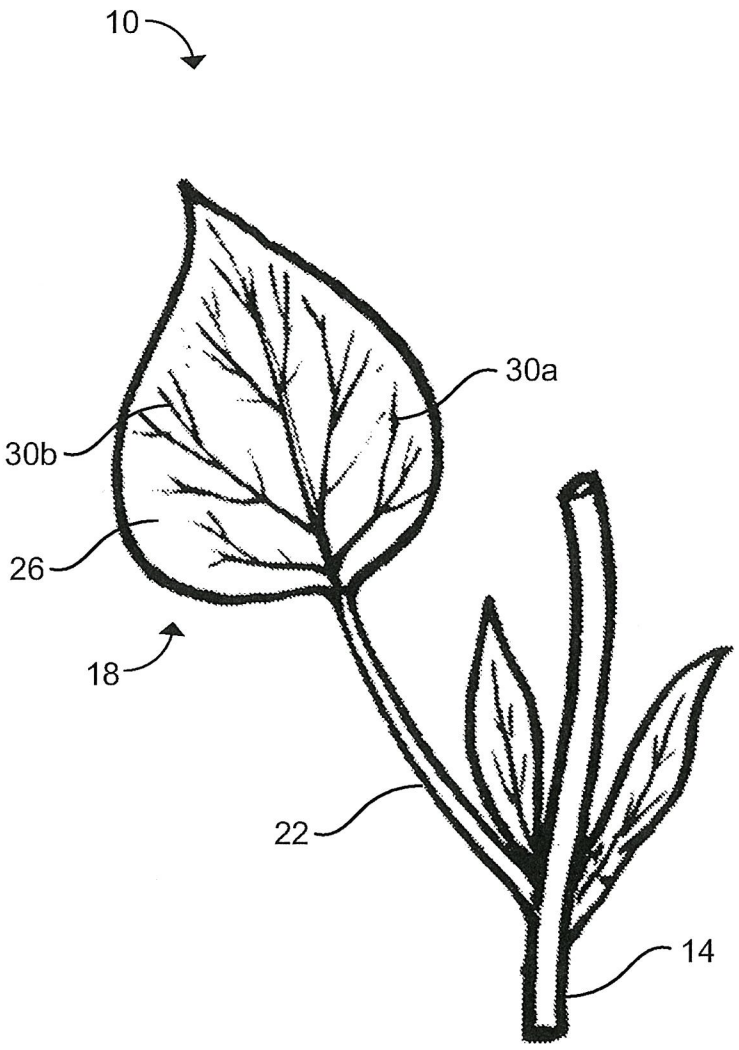


FIG. 1

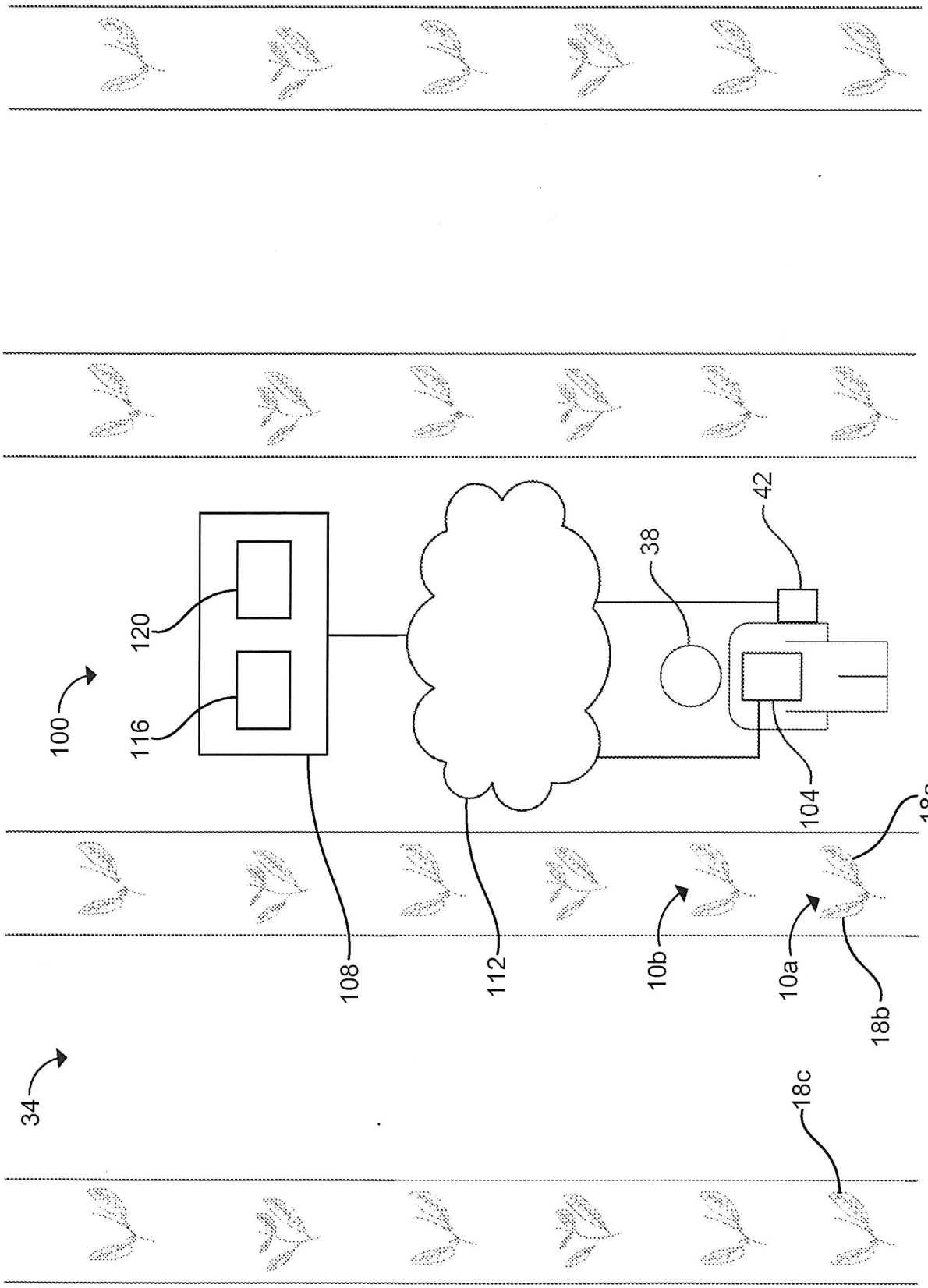


FIG. 2

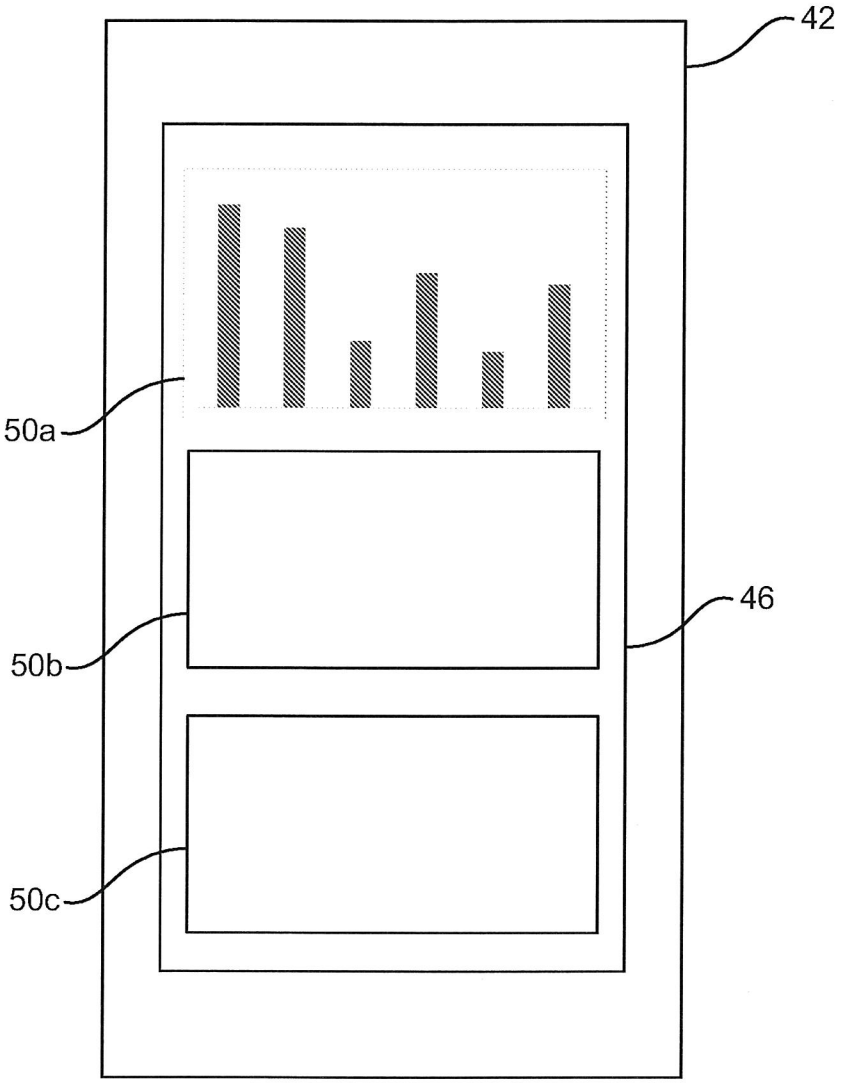


FIG. 3

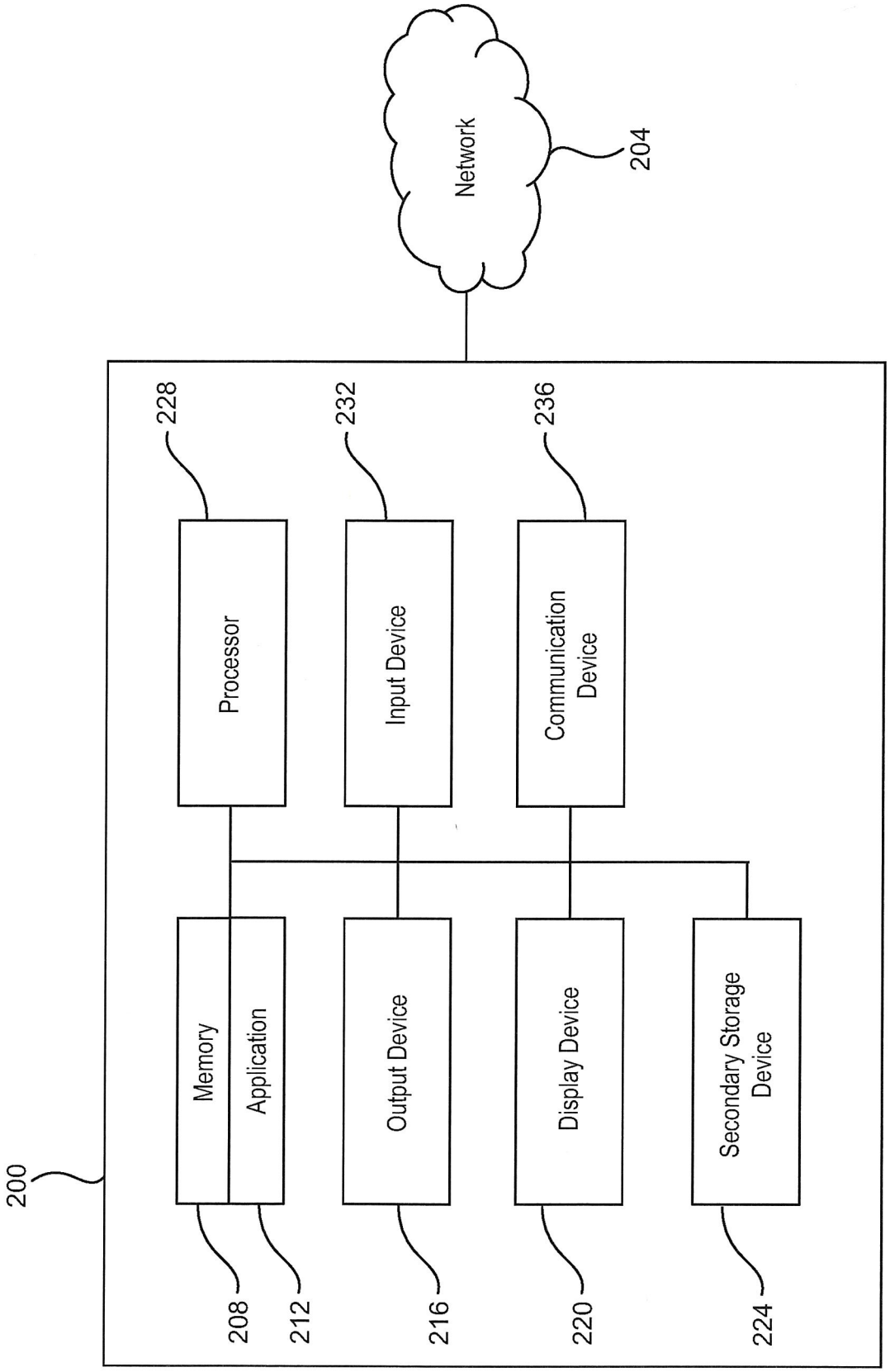

Network
204
200
228
232
236
Processor
Input Device
Communication Device
Memory
Application
Output Device
Display Device
Secondary Storage Device
208
212
216
220
224

FIG. 4

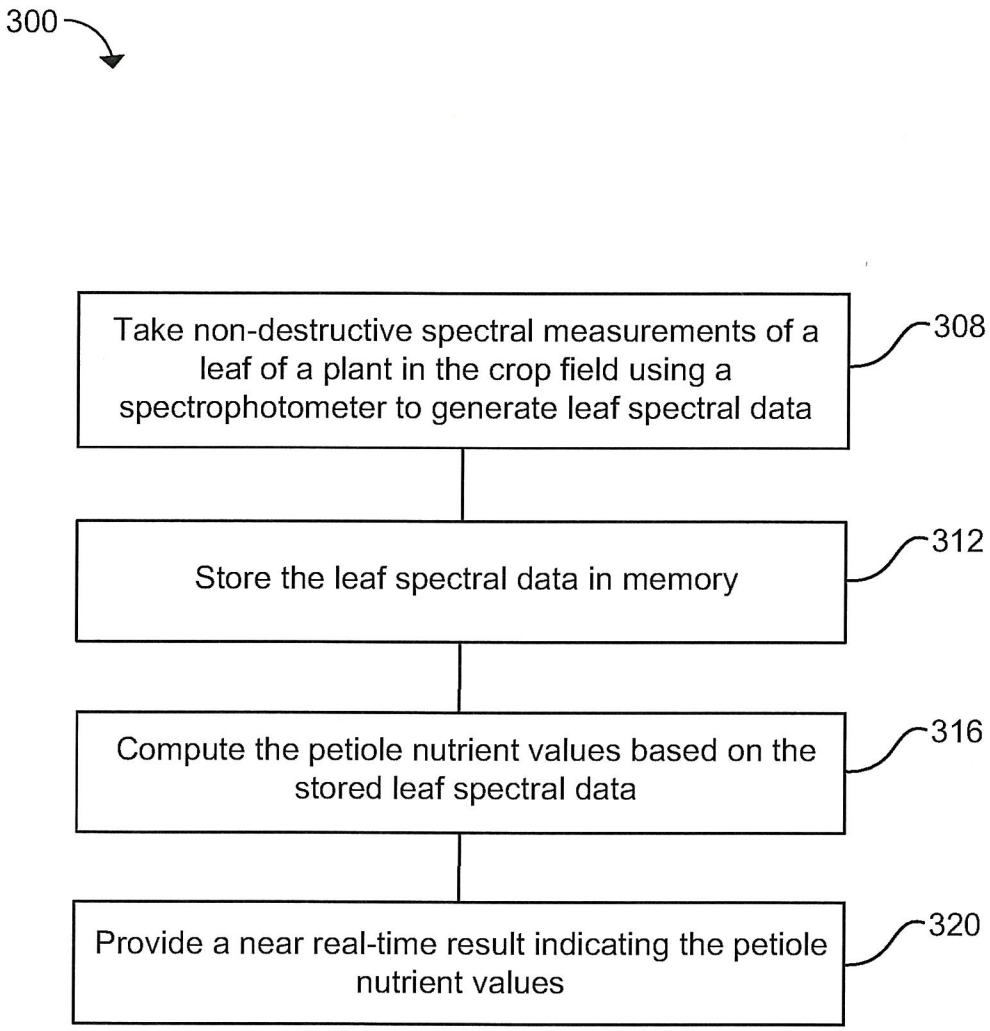

300
Take non-destructive spectral measurements of a leaf of a plant in the crop field using a spectrophotometer to generate leaf spectral data
308
Store the leaf spectral data in memory
312
Compute the petiole nutrient values based on the stored leaf spectral data
316
Provide a near real-time result indicating the petiole nutrient values
320

FIG. 5

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U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	7028-P71709US00
	Application Number	
Title of Invention	SYSTEM, APPARATUS AND METHOD OF NON-DESTRUCTIVELY DETERMINING PETIOLE NUTRIENT VALUES IN NEAR REAL-TIME USING A PORTABLE SPECTROPHOTOMETER	

The application data sheet is part of the provisional or nonprovisional application for which it is being submitted. The following form contains the bibliographic data arranged in a format specified by the United States Patent and Trademark Office as outlined in 37 CFR 1.76.
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Inventor Information:

Inventor 1 Remove

Legal Name

Prefix	Given Name	Middle Name	Family Name	Suffix
Dr.	Ahmad		Al-Mallahi	

Residence Information (Select One) ○ US Residency ◉ Non US Residency ○ Active US Military Service

City	Truro	Country of Residence ⓘ	CA

Mailing Address of Inventor:

Address 1	Dalhousie University Faculty of Agriculture
Address 2	Banting Building, 39 Cox Road, PO Box 550

City	Truro	State/Province	NS
Postal Code	B2N 5E3	**Country** ⓘ	CA

Inventor 2 Remove

Legal Name

Prefix	Given Name	Middle Name	Family Name	Suffix
	Reem		Abukmeil	

Residence Information (Select One) ○ US Residency ◉ Non US Residency ○ Active US Military Service

City	Truro	Country of Residence ⓘ	CA

Mailing Address of Inventor:

Address 1	Dalhousie University Faculty of Agriculture
Address 2	Banting Building, 39 Cox Road, PO Box 550

City	Truro	State/Province	NS
Postal Code	B2N 5E3	**Country** ⓘ	CA

All Inventors Must Be Listed - Additional Inventor Information blocks may be generated within this form by selecting the **Add** button. Add

Correspondence Information:

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	7028-P71709US00
	Application Number	
Title of Invention	SYSTEM, APPARATUS AND METHOD OF NON-DESTRUCTIVELY DETERMINING PETIOLE NUTRIENT VALUES IN NEAR REAL-TIME USING A PORTABLE SPECTROPHOTOMETER	

Enter either Customer Number or complete the Correspondence Information section below.
For further information see 37 CFR 1.33(a).

☐ **An Address is being provided for the correspondence Information of this application.**

Customer Number	1059		
Email Address	ipprocessingcentre@bereskinparr.com	Add Email	Remove Email
Email Address	naitken@bereskinparr.com	Add Email	Remove Email

Application Information:

Title of the Invention	SYSTEM, APPARATUS AND METHOD OF NON-DESTRUCTIVELY DETERMINING PETIOLE NUTRIENT VALUES IN NEAR REAL-TIME USING A PORTABLE SPECTROPHOTOMETER		
Attorney Docket Number	7028-P71709US00	**Small Entity Status Claimed**	☐
Application Type	Nonprovisional		
Subject Matter	Utility		
Total Number of Drawing Sheets (if any)	5	**Suggested Figure for Publication (if any)**	2

Filing By Reference:

Only complete this section when filing an application by reference under 35 U.S.C. 111(c) and 37 CFR 1.57(a). Do not complete this section if application papers including a specification and any drawings are being filed. Any domestic benefit or foreign priority information must be provided in the appropriate section(s) below (i.e., "Domestic Benefit/National Stage Information" and "Foreign Priority Information").

For the purposes of a filing date under 37 CFR 1.53(b), the description and any drawings of the present application are replaced by this reference to the previously filed application, subject to conditions and requirements of 37 CFR 1.57(a).

Application number of the previously filed application	Filing date (YYYY-MM-DD)	Intellectual Property Authority or Country

Publication Information:

☐ Request Early Publication (Fee required at time of Request 37 CFR 1.219)

☐ **Request Not to Publish.** I hereby request that the attached application not be published under 35 U.S.C. 122(b) and certify that the invention disclosed in the attached application **has not and will not** be the subject of an application filed in another country, or under a multilateral international agreement, that requires publication at eighteen months after filing.

Representative Information:

Representative information should be provided for all practitioners having a power of attorney in the application. Providing this information in the Application Data Sheet does not constitute a power of attorney in the application (see 37 CFR 1.32). Either enter Customer Number or complete the Representative Name section below. If both sections are completed the customer Number will be used for the Representative Information during processing.

Please Select One:	◉ Customer Number	○ US Patent Practitioner	○ Limited Recognition (37 CFR 11.9)

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Customer Number	1059

Domestic Benefit/National Stage Information:

This section allows for the applicant to either claim benefit under 35 U.S.C. 119(e), 120, 121, 365(c), or 386(c) or indicate National Stage entry from a PCT application. Providing benefit claim information in the Application Data Sheet constitutes the specific reference required by 35 U.S.C. 119(e) or 120, and 37 CFR 1.78.
When referring to the current application, please leave the "Application Number" field blank.

Prior Application Status		Remove	
Application Number	Continuity Type	Prior Application Number	Filing or 371(c) Date (YYYY-MM-DD)

Additional Domestic Benefit/National Stage Data may be generated within this form by selecting the **Add** button.

Foreign Priority Information:

This section allows for the applicant to claim priority to a foreign application. Providing this information in the application data sheet constitutes the claim for priority as required by 35 U.S.C. 119(b) and 37 CFR 1.55. When priority is claimed to a foreign application that is eligible for retrieval under the priority document exchange program (PDX)[i] the information will be used by the Office to automatically attempt retrieval pursuant to 37 CFR 1.55(i)(1) and (2). Under the PDX program, applicant bears the ultimate responsibility for ensuring that a copy of the foreign application is received by the Office from the participating foreign intellectual property office, or a certified copy of the foreign priority application is filed, within the time period specified in 37 CFR 1.55(g)(1).

			Remove
Application Number	Country[i]	Filing Date (YYYY-MM-DD)	Access Code[i] (if applicable)

Additional Foreign Priority Data may be generated within this form by selecting the **Add** button.

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications

☐ This application (1) claims priority to or the benefit of an application filed before March 16, 2013 and (2) also contains, or contained at any time, a claim to a claimed invention that has an effective filing date on or after March 16, 2013.
NOTE: By providing this statement under 37 CFR 1.55 or 1.78, this application, with a filing date on or after March 16, 2013, will be examined under the first inventor to file provisions of the AIA.

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	Application Number	
Title of Invention	SYSTEM, APPARATUS AND METHOD OF NON-DESTRUCTIVELY DETERMINING PETIOLE NUTRIENT VALUES IN NEAR REAL-TIME USING A PORTABLE SPECTROPHOTOMETER	

Authorization or Opt-Out of Authorization to Permit Access:

When this Application Data Sheet is properly signed and filed with the application, applicant has provided written authority to permit a participating foreign intellectual property (IP) office access to the instant application-as-filed (see paragraph A in subsection 1 below) and the European Patent Office (EPO) access to any search results from the instant application (see paragraph B in subsection 1 below).

Should applicant choose not to provide an authorization identified in subsection 1 below, applicant **must opt-out** of the authorization by checking the corresponding box A or B or both in subsection 2 below.

NOTE: This section of the Application Data Sheet is **ONLY** reviewed and processed with the **INITIAL** filing of an application. After the initial filing of an application, an Application Data Sheet cannot be used to provide or rescind authorization for access by a foreign IP office(s). Instead, Form PTO/SB/39 or PTO/SB/69 must be used as appropriate.

1. Authorization to Permit Access by a Foreign Intellectual Property Office(s)

A. Priority Document Exchange (PDX) - Unless box A in subsection 2 (opt-out of authorization) is checked, the undersigned hereby **grants the USPTO authority** to provide the European Patent Office (EPO), the Japan Patent Office (JPO), the Korean Intellectual Property Office (KIPO), the State Intellectual Property Office of the People's Republic of China (SIPO), the World Intellectual Property Organization (WIPO), and any other foreign intellectual property office participating with the USPTO in a bilateral or multilateral priority document exchange agreement in which a foreign application claiming priority to the instant patent application is filed, access to: (1) the instant patent application-as-filed and its related bibliographic data, (2) any foreign or domestic application to which priority or benefit is claimed by the instant application and its related bibliographic data, and (3) the date of filing of this Authorization. See 37 CFR 1.14(h)(1).

B. Search Results from U.S. Application to EPO - Unless box B in subsection 2 (opt-out of authorization) is checked, the undersigned hereby **grants the USPTO authority** to provide the EPO access to the bibliographic data and search results from the instant patent application when a European patent application claiming priority to the instant patent application is filed. See 37 CFR 1.14(h)(2).

The applicant is reminded that the EPO's Rule 141(1) EPC (European Patent Convention) requires applicants to submit a copy of search results from the instant application without delay in a European patent application that claims priority to the instant application.

2. Opt-Out of Authorizations to Permit Access by a Foreign Intellectual Property Office(s)

☐ A. Applicant **DOES NOT** authorize the USPTO to permit a participating foreign IP office access to the instant application-as-filed. If this box is checked, the USPTO will not be providing a participating foreign IP office with any documents and information identified in subsection 1A above.

☐ B. Applicant **DOES NOT** authorize the USPTO to transmit to the EPO any search results from the instant patent application. If this box is checked, the USPTO will not be providing the EPO with search results from the instant application.

NOTE: Once the application has published or is otherwise publicly available, the USPTO may provide access to the application in accordance with 37 CFR 1.14.

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Title of Invention	SYSTEM, APPARATUS AND METHOD OF NON-DESTRUCTIVELY DETERMINING PETIOLE NUTRIENT VALUES IN NEAR REAL-TIME USING A PORTABLE SPECTROPHOTOMETER	

Applicant Information:

Providing assignment information in this section does not substitute for compliance with any requirement of part 3 of Title 37 of CFR to have an assignment recorded by the Office.

Applicant 1

If the applicant is the inventor (or the remaining joint inventor or inventors under 37 CFR 1.45), this section should not be completed. The information to be provided in this section is the name and address of the legal representative who is the applicant under 37 CFR 1.43; or the name and address of the assignee, person to whom the inventor is under an obligation to assign the invention, or person who otherwise shows sufficient proprietary interest in the matter who is the applicant under 37 CFR 1.46. If the applicant is an applicant under 37 CFR 1.46 (assignee, person to whom the inventor is obligated to assign, or person who otherwise shows sufficient proprietary interest) together with one or more joint inventors, then the joint inventor or inventors who are also the applicant should be identified in this section.

Clear

○ Assignee	○ Legal Representative under 35 U.S.C. 117	○ Joint Inventor
◉ Person to whom the inventor is obligated to assign.	○ Person who shows sufficient proprietary interest	

If applicant is the legal representative, indicate the authority to file the patent application, the inventor is:

Name of the Deceased or Legally Incapacitated Inventor:

If the Applicant is an Organization check here. ☒

Organization Name	Dalhousie University

Mailing Address Information For Applicant:

Address 1	6299 South Street		
Address 2			
City	Halifax	**State/Province**	NS
Country	CA	Postal Code	B3H 4H6
Phone Number		Fax Number	
Email Address			

Additional Applicant Data may be generated within this form by selecting the Add button.

Assignee Information including Non-Applicant Assignee Information:

Providing assignment information in this section does not substitute for compliance with any requirement of part 3 of Title 37 of CFR to have an assignment recorded by the Office.

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Assignee 1

Complete this section if assignee information, including non-applicant assignee information, is desired to be included on the patent application publication. An assignee-applicant identified in the "Applicant Information" section will appear on the patent application publication as an applicant. For an assignee-applicant, complete this section only if identification as an assignee is also desired on the patent application publication.

If the Assignee or Non-Applicant Assignee is an Organization check here. ☐

Prefix	**Given Name**	Middle Name	**Family Name**	Suffix

Mailing Address Information For Assignee including Non-Applicant Assignee:

Address 1			
Address 2			
City		**State/Province**	
Country		Postal Code	
Phone Number		Fax Number	
Email Address			

Additional Assignee or Non-Applicant Assignee Data may be generated within this form by selecting the Add button.

Signature:

NOTE: This Application Data Sheet must be signed in accordance with 37 CFR 1.33(b). **However, if this Application Data Sheet is submitted with the INITIAL filing of the application and either box A or B is not checked in subsection 2 of the "Authorization or Opt-Out of Authorization to Permit Access" section, then this form must also be signed in accordance with 37 CFR 1.14(c).**

This Application Data Sheet **must** be signed by a patent practitioner if one or more of the applicants is a **juristic entity** (e.g., corporation or association). If the applicant is two or more joint inventors, this form must be signed by a patent practitioner, **all** joint inventors who are the applicant, or one or more joint inventor-applicants who have been given power of attorney (e.g., see USPTO Form PTO/AIA/81) on behalf of **all** joint inventor-applicants.

See 37 CFR 1.4(d) for the manner of making signatures and certifications.

Signature	/Nicholas Aitken/			Date (YYYY-MM-DD)	2023-05-25
First Name	Nicholas	Last Name	Aitken	Registration Number	73,004

Additional Signature may be generated within this form by selecting the Add button.

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This collection of information is required by 37 CFR 1.76. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 23 minutes to complete, including gathering, preparing, and submitting the completed application data sheet form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

Privacy Act Statement

The Privacy Act of 1974 (P.L. 93-579) requires that you be given certain information in connection with your submission of the attached form related to a patent application or patent. Accordingly, pursuant to the requirements of the Act, please be advised that: (1) the general authority for the collection of this information is 35 U.S.C. 2(b)(2); (2) furnishing of the information solicited is voluntary; and (3) the principal purpose for which the information is used by the U.S. Patent and Trademark Office is to process and/or examine your submission related to a patent application or patent. If you do not furnish the requested information, the U.S. Patent and Trademark Office may not be able to process and/or examine your submission, which may result in termination of proceedings or abandonment of the application or expiration of the patent.

The information provided by you in this form will be subject to the following routine uses:

1 The information on this form will be treated confidentially to the extent allowed under the Freedom of Information Act (5 U.S.C. 552) and the Privacy Act (5 U.S.C. 552a). Records from this system of records may be disclosed to the Department of Justice to determine whether the Freedom of Information Act requires disclosure of these records.

2. A record from this system of records may be disclosed, as a routine use, in the course of presenting evidence to a court, magistrate, or administrative tribunal, including disclosures to opposing counsel in the course of settlement negotiations.

3 A record in this system of records may be disclosed, as a routine use, to a Member of Congress submitting a request involving an individual, to whom the record pertains, when the individual has requested assistance from the Member with respect to the subject matter of the record.

4. A record in this system of records may be disclosed, as a routine use, to a contractor of the Agency having need for the information in order to perform a contract. Recipients of information shall be required to comply with the requirements of the Privacy Act of 1974, as amended, pursuant to 5 U.S.C. 552a(m).

5. A record related to an International Application filed under the Patent Cooperation Treaty in this system of records may be disclosed, as a routine use, to the International Bureau of the World Intellectual Property Organization, pursuant to the Patent CooperationTreaty.

6. A record in this system of records may be disclosed, as a routine use, to another federal agency for purposes of National Security review (35 U.S.C. 181) and for review pursuant to the Atomic Energy Act (42 U.S.C. 218(c)).

7. A record from this system of records may be disclosed, as a routine use, to the Administrator, General Services, or his/her designee, during an inspection of records conducted by GSA as part of that agency's responsibility to recommend improvements in records management practices and programs, under authority of 44 U.S.C. 2904 and 2906. Such disclosure shall be made in accordance with the GSA regulations governing inspection of records for this purpose, and any other relevant (i.e., GSA or Commerce) directive. Such disclosure shall not be used to make determinations about individuals.

8. A record from this system of records may be disclosed, as a routine use, to the public after either publication of the application pursuant to 35 U.S.C. 122(b) or issuance of a patent pursuant to 35 U.S.C. 151. Further, a record may be disclosed, subject to the limitations of 37 CFR 1.14, as a routine use, to the public if the record was filed in an application which became abandoned or in which the proceedings were terminated and which application is referenced by either a published application, an application open to public inspections or an issued patent.

9. A record from this system of records may be disclosed, as a routine use, to a Federal, State, or local law enforcement agency, if the USPTO becomes aware of a violation or potential violation of law or regulation.

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