WESTERN AG INNOVATIONS INC.

Applying Research Solutions to Agriculture and the Environment

Plant Root Simulator (PRS™) Operations Manual

Patents have been awarded in Australia (AU673817), Canada (CA2129843), Europe (EP0626066), New Zealand (NZ249068), the United States (US6242261), and by the World Intellectual Property Organization (WO9316382).

WESTERN AG INNOVATIONS INC.

PRS™-Probe Operations Manual

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DISCLAIMER: THE PROCEDURES OUTLINED IN THIS MANUAL HAVE BEEN DESIGNED FOR USE WITH PRS™-PROBES ONLY AND MAY NOT BE SUITABLE FOR USE WITH OTHER ION EXCHANGE RESIN MATERIALS, INCLUDING OTHER TYPES OF ION EXCHANGE MEMBRANES.

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Introduction

Dear Plant Root Simulator (PRS)™-probe user:

The history of the use of chemical extractions for soil testing dates back more than 200 years to the first citric acid extractable tests of soil. The original aim of these historic procedures was to quantify those properties of the soil that contributed to plant growth.

As Soil Scientists, Agronomists, Horticulturists, Ecologists and Foresters, our focus on what these tests mean for plant nutrition and health has somehow shifted over time. Powerful developments in analytical equipment have fostered the thinking that we are ever improving our "accuracy" in measuring soil nutrients. However, even if we can measure sub-parts per trillion in the extracted solution, we may not be seeing an accurate reflection of the *in situ* nutrient supply to a plant. Consequently, chemically-extracted indices of nutrient 'bioavailability' remain a weak link in improving our understanding of nutrient dynamics.

The PRS™-probe heralds a new era in functionally viewing the dynamic chemistry at an adsorbing surface. In simulating the mechanism of nutrient uptake used by plant roots, the PRS™-probe improves the accuracy of monitoring soil nutrient supply. This said - one should not expect "conventional" chemical extraction indices to have anything more than a general relationship to the dynamic flux measured by the PRS™-probe technology.

This procedures manual is a compilation of more than fifteen years of research experience with the PRS™-probe. A careful consideration of the principles contained within this manual will not only improve your experimental design and the data generated using the PRS™-probes, but also contribute to our collective understanding of nutrient supply to plants.

Sincerely,

Kenneth J. Greer, M.Sc. P.Ag.

President

Technology Background

The Plant Root Simulator (PRS)™-probe consists of an ion exchange membrane encapsulated in a plastic probe, which is then inserted into the soil. The membrane is chemically pre-treated so that it exhibits surface characteristics and nutrient sorption phenomena that resemble a plant root surface. When buried in soil, the PRS™-probe can assess nutrient supply rates by continuously adsorbing charged ionic species over the burial period.

The cation and anion PRS™-probes can be used *in situ* to effectively measure forest soil nutrient dynamics.

The System

Pre-treated anion and cation exchange membranes each separately encased in plastic probe form the basis for the PRS™ technology. This highly adaptable technique can be easily used in the field, greenhouse, growth chamber, or the lab. For in-field use, the PRS™-probes can be inserted into field moist or dry soils. When the PRS™-probes are left in the soil under field moist conditions, the ion sink will trap any ions that the soil supplies over the duration of the burial. Once removed from the soil, the PRS™-probes are washed clean and eluted. The resulting eluate is analysed for ion concentration.

Direct insertion of the PRS™-probe into the soil under field conditions allows the many edaphic factors that affect nutrient ion flux to roots to be accounted for. During the burial period, nutrient ions adjacent to the PRS™-probe already in the available form, along with nutrients that are converted to the available form, will be adsorbed onto the membrane surface. The amount of nutrient ions adsorbed on the PRS™-probe at the end of the burial period represents the potential nutrient supply rate to a plant for the duration of the burial. This is expressed in units of micrograms of nutrient adsorbed per 10 cm^2 of membrane surface over the burial time. Burial times of one hour are convenient for "snapshots" of the nutrient ion supply rate, while longer-term burials (i.e., greater than two weeks) integrate more of the factors affecting nutrient availability. Some of these factors include mineralization, dissolution, and ion diffusion from greater distances.

Method of Use

Two types of PRS™-probes are available for use: anion exchange and cation exchange. The anion exchange PRS™-probe (orange) simultaneously adsorbs all nutrient anions, including nitrate, phosphate, sulphate, and borate. Cation exchange PRS™-probes (purple) simultaneously adsorb nutrient cations such as ammonium, potassium, calcium, and magnesium. A chelating pre-treatment of the anion PRS™-probe also permits the adsorption of the micronutrient metals such as copper, zinc, iron, and manganese.

The PRS™-probe can be buried into pre-wetted soil or soil at field wet conditions. In the field, at each PRS™-probe sampling point, a small slot is made in the soil into which the PRS™-probe is inserted. If one is interested in the nutrient supply rate as it exists naturally in the field, as affected by differences in soil water content, then no water is added. On the other hand, to remove differences in nutrient supply rate arising from variation in soil water content, a small amount of water may be added to the slot to bring the soil immediately adjacent to the PRS™-probe to field capacity. The PRS™-probe is inserted into the slot and allowed to remain in the soil for the prescribed period of time. More details on PRS™-probe burials can be found on page 8.

At the end of the burial period, the PRS™-probe is removed from the soil and rinsed free of adhering soil with a jet of de-ionized or distilled water using a backpack sprayer. Ideally, the PRS™-probes should be thoroughly cleaned in the field; however, it may be impractical to haul water to sites with limited access. In these situations, it is acceptable to simply clean off any residual soil from the membrane surface and keep the PRS™-probes cool, in order to minimize microbial activity, until they can be properly rinsed. Likewise, if the field sites are within close proximity of the laboratory and the PRS™-probes will be rinsed within two days - then clean off any residual soil from the membrane surface and keep cool during transport until PRS™-probes are cleaned. Once the PRS™-probes have been thoroughly washed in the lab, they are placed in a dilute acid (or salt) solution to elute the adsorbed ions into solution and measure analytically for nutrient concentration.

The Results

The PRS™-probes are valuable tools for assessing the supply rate of soil nutrients and toxins. Ion uptake by the PRS™-probe is consistently found to relate well to plant uptake which is ultimately the most important measure of soil nutrient supply power. The PRS™-probes has the capability to assess any ion species with a charge that can move to the exchange membrane. As well, PRS™-probes can account for differences in ion mobility which is controlled by the soil type. The PRS™-probes have been used to assess soil supply rates in many environments and soil types.

Measuring Up

For intensive field mapping of soil fertility, a more direct, less labour intensive assessment of soil fertility is necessary. To describe nutrient variation across a field, intensive soil sampling is conducted, usually on a grid, followed by extraction of the samples with a solution such as dilute calcium chloride or sodium bicarbonate. These tests, however, provide limited information on how different locations within the field vary in their ability to supply nutrients in an available form over time under field conditions. In particular, they are unable to measure the nutrients supplied over time through the process of mineralization.

When buried in a grid formation, PRS™-probes provide an efficient, cost effective method to map the soil nutrient supply power of a field. By eliminating the need to collect, handle and process many soil samples, the PRS™ method saves time and labour. In addition, the PRS™ method provides a functional measure of nutrient supplying power under field conditions.

PRS™-probes can be used almost anywhere!

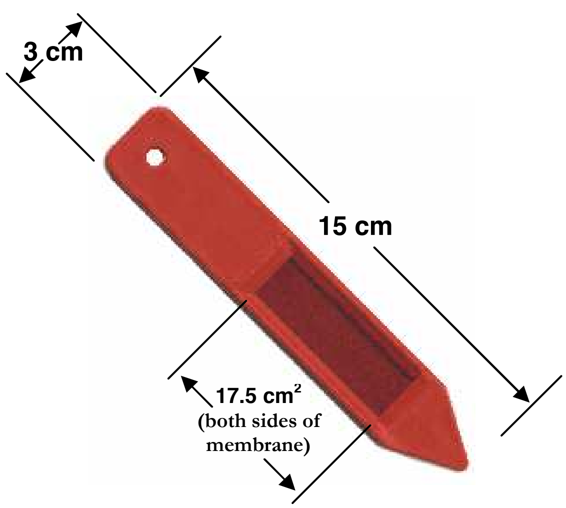
PRS™-Probe Specifications

Anion PRS™-probe = orange encasement

Cation PRS™-probe = purple encasement

Adsorbing surface area = 17.5 cm^2 (includes both sides)

Plastic encasement thickness ~ 0.4 cm



Dimensions of a PRS™-probe.

PRS™-Probe Maximum Ion Capacity*

Units: μg 10 cm^{-2}

Cl^-:	5288	NO_3^--N:	2088	K^+:	9273	Cu^{2+}:	9731	Fe^{3+}:	8552
Na^+:	5455	NH_4^+-N:	3320	Ca^{2+}:	4753	Mn^{2+}:	8412	Al^{3+}:	4131
SO_4^--S:	4782	$H_2PO_4^-$-P:	4620	Mg^{2+}:	2883	Zn^{2+}:	10012	$B(OH)_4^-$-B:	1600

*Cl^- and Na^+ capacities determined empirically in the lab. The remaining ion capacity is determined by calculating meq charge on the membrane surfaces. Keep in mind that these maximums were determined for ***single nutrient ions only*** and, therefore, will decrease depending on the specific ratio (i.e., availability) of that ion in solution relative to the other ions.

Typical nutrient supply rate values encountered during *in situ PRS™-probe burials in A-horizon agricultural and forest soils. Note the difference in burial lengths.**

Nutrient	Agricultural Soil** μg 10 cm^{-2} 2 $weeks^{-1}$	Forest Soil*** μg 10 cm^{-2} 4 $weeks^{-1}$
NO_3-N:	~ 50 to 1200	~ 2 to 260
NH_4-N:	~ 1 to 150	~ 2 to 400
P:	~ 2.5 to 40	~ 0.5 to 20
K:	~ 50 to 400	~ 12 to 900
S:	~ 20 to 800	~ 2 to 300

*In-lab burials will result in larger supply rates than in-field burials.

** Except for saline soils, which may test very high in S.

*** Including values from both disturbed and undisturbed sites.

Contact Information

For more information please contact Western Ag Innovations Inc.:

Address: 3 – 411 Downey Road, Saskatoon, Saskatchewan S7N 4L8, Canada

Phone: (306) 978-1777

Toll Free: (877) 978-1777

Fax: (306) 978-4140

Email: gerneral@westernag.ca

Web: http://www.westernag.ca/innov/index.php

Agreements
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Collaborative Research Agreements

This section reviews the requirements outlined and agreed to in the PRS™-probe analysis collaborative research agreement.

The purpose of the collaborative research agreement is to facilitate the collection and interpretation of high quality nutrient supply rate data. In the past, resin methods have suffered from poor transfer of knowledge as to how and where these dynamic monitoring tools are best used. Western Ag Innovations is committed to sharing our knowledge of such dynamic processes with our collaborative research partners. This allows researchers to benefit from more than fifteen years of research expertise and to maximize the potential for successful results.

A typical research project with the PRS™-probes begins with a consultation with the Western Ag R&D Coordinator about the costs, availability, burial duration and numbers of PRS™-probes that might be required in the study. Once these parameters are established, a research agreement is filled out and signed by both parties. Following this, PRS™-probes, protocols and additional information are sent to the researcher and the study begins. The PRS™-probes are used in the study and then returned to Western Ag Innovations for analysis. Researchers are required to provide Western Ag Innovations with the study proposal, as well as copies of annual and final project reports. It is not necessary to write a special report just for us; we will accept copies of reports generated for other purposes. Depending on the novelty of the study, we may showcase the PRS™-probe related results at scientific meetings and in our Technical Updates. Please note that this is done ONLY after receiving permission from the researcher to do so.

Collaborative Research Agreement: PRS™-probe analyses

Western Ag sends PRS™-probes to the researcher as required, the researcher uses the PRS™ to make the desired measurements, washes and ships them back to Western Ag in appropriately labelled sample bags for analysis. Western Ag then proceeds to elute the PRS™-probes, analyze the eluates, regenerate the PRS™-probes and send the data back to the researcher. In this case, the cost of using the PRS™-probes is included in the cost of the analysis. Specifically, researchers are provided with up to four pairs of PRS™-probes (i.e., four cation and four anion exchange PRS™-

probes) to spread throughout the experimental unit and then combine anion and cations PRS™-probes for analysis much like a composite soil sample. Western Ag currently offers analysis packages for several ions and can analyse other ions for a small additional cost. Please refer to the price list on our website or call us to learn more about the analysis packages.

Responsibilities of Western Ag Innovations

Under the research agreement, Western Ag Innovations provides the researcher with:

- a discount on the cost of analysing the PRS™-probes
- assistance with any questions or concerns relating to use of the PRS™-probes and interpretation of PRS™ nutrient supply rate data
- annual QA/QC check on a representative sample of PRS™-probes
- a guarantee that information supplied to Western Ag Innovations by the researcher will remain confidential unless otherwise authorized

Responsibilities of the Researcher

In return for the above provisions by Western Ag, researchers entering the collaborative research agreement agree to:

- maintain contact with Western Ag for the duration of the agreement and request assistance with any concerns that arise
- provide Western Ag with a copy of the research study proposal outlining how the PRS™ will be used, prior to receiving PRS™-probes
- provide a copy of an annual report from the study, including a summary of the PRS™ results, to Western Ag by March 31st of each year unless an alternative date is agreed
- provide Western Ag with a copy of the study's final report following project completion. The final report can be a thesis, dissertation or published article etc.
- provide a list of all completed or planned projects that contain PRS™-probe data such as published articles, presented posters/papers, field days etc.
- acknowledge the financial support provided by Western Ag Innovations in published or presented reports, papers, posters etc.

- refer to the probes as "PRS™-probes (Western Ag Innovations Inc., Saskatoon, SK, Canada)" in published or presented reports, posters, and papers. ***Please do not refer to the PRS™-probes as resin stakes, resin probes, resin sticks, or similar names***

- respect Western Ag Innovations' ownership of the PRS™ technology

PRS™-Probe Research Price List

Please visit our website for the most up to date PRS™-probe price list (http://www.westernag.ca/innov/pricing_info.php).

If there is a graduate student affiliated with the research project, there is a 10% discount applied to the first year of the Collaborative Research Agreement. Furthermore, FREE shipping is included with orders exceeding 50 PRS™-probe analyses placed two weeks in advance.

Shipping

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Shipping PRS™- Probes

This section outlines the common procedures followed when shipping the PRS™-probes to and from Western Ag Innovations.

From Western Ag Innovations to the Researcher

PRS™-probe requests should be made at least two weeks before the PRS™-probes are needed for deployment to assure availability and allow time for processing. The PRS™-probes are shipped approximately one week before they are required and, depending on the location, can take up to eleven business days to reach the researcher. For orders within Canada, the PRS™-probes are shipped via regular post, bus or courier. International orders are shipped via courier. Please contact a R&D Coordinator in case of unexpected delays in receiving PRS™-probes.

Western Ag Innovations covers the cost of shipping PRS™-probes on orders of more than 50 PRS™-probe analyses placed two weeks in advance. Import customs and/or duties may be charged to the researcher for international orders when probes are shipped.

From the Researcher to Western Ag Innovations

It is very important that PRS™-probes being returned to Western Ag <u>for analysis</u> be shipped by a method that guarantees prompt delivery. If the researcher is in Western Canada, it is possible to ship PRS™-probes via bus. Shipments taking longer than one day to reach Western Ag should be kept cool – this can be done by packing in a disposable cooler or styrofoam-lined box with a couple of blue ice packs. GROUND SHIPPING ACROSS CANADIAN BORDER CAN REQUIRE A CUSTOMS BROKER.

The researcher is responsible for the cost of shipping the PRS™-probes back to Western Ag. FOR PRS™-PROBES BEING RETURNED TO WESTERN AG FROM OUTSIDE OF CANADA, PLEASE INDICATE ON THE INTERNATIONAL WAYBILL THAT **CANADA IS THE ORIGIN OF THE GOODS AND GOODS RETURNING TO CANADA** – this will avoid erroneous customs charges, unnecessary hassle and delay in delivery.

Below is an example of a commercial invoice that can be downloaded off our website (http://www.westernag.ca/innov/forms.php), filled out using Word, and then submitted (**three copies**) with the shipping documents outside the box. Text in red shows an example of how to fill out the form.

COMMERCIAL INVOICE

Date of Exportation	Shipping Label No.	Number of Packages	Currency of Sale
DATE		1	USD

Shipper/Exporter	Consignee	Importer
Jane Smith # Street City, State/Province Zip Code/ Postal Code Country Phone	Western Ag Innovations 3-411 Downey Road Saskatoon, SK S7N 4L8 Canada (306) 978-1777	Same as consignee

Country of Export	Country of Manufacture	Country of Ultimate Destination
COUNTRY	Canada	Canada

Description of Goods	Quantity	Unit of Measure	Unit Value ($)	Weight	Value ($)
Plastic PRS™-probes **Returning to Canada (goods originated in Canada - Code 066)**	100	Probe	0.10	0.01kg	$10.00

Terms of Sale:	Total Weight (kg)	Total Value
Free Carrier (FCA/FOB)	1.0	$10.00

SIGNATURE OF SHIPPER/EXPORTER:

I declare that all of the information contained in this invoice is true and correct.

SIGNATURE	TITLE	DATE

Sample Labelling and Sample Shipping Summary

When preparing samples for analysis by Western Ag, please ***combine the anion and cation PRS™-probes from each plot*** (i.e., that are to be analyzed as one sample) into one clearly labeled, plastic sample bag for analysis. In terms of labeling, please ***use only numeric notations*** (i.e., 1, 2, 3...n). This makes things easier for sample receiving on our end, easier for you to cross-reference our billing invoice with the number of samples you submitted, but most importantly, it keeps the analyses 'blind' on our end.

Example of Sample Label:

Researcher Smith
N Mineralization Study
June 1- 14, 2009
Sample #1

Western Ag requires that a ***Sample Shipping Summary*** be submitted (inside the box) when sending back PRS™-probes for analysis. Without a shipping summary enclosed, our lab staff will not process your samples. See below for an example; a copy is also included with each PRS™-probe order. Please return any broken PRS™-probes because they are re-ground and used to make new ones. Finally, it is important to return any unused/extra PRS™-probes that were included in your shipment. At the end of the project **ALL** PRS™-probes should be returned to Western Ag, charges may apply to any researcher that does not return all the probes at a cost of 15$/probe as a loss of use fee. Please refrain from trading PRS™-probes with other researcher or from using probes in experiments that have not been discussed with a Western Ag R&D Coordinator before hand. If any probes have been lost in the course of your experiment, please notify your R&D Coordinator and make note of the number of lost PRS™-probes on your shipping summary under additional information.

******* THIS FORM MUST BE RETURNED WITH PRS™-PROBE SAMPLES *******

Download additional forms from: http://www.westernag.ca/innov/forms.php

For Office use only

Agreement # ______________
RDOS Shipment #_________
Tracking #_______________

***** THIS FORM MUST BE RETURNED WITH PRS™-PROBE SAMPLES *****
Download additional forms: http://www.westernag.ca/innov/resources/Shipping_Form.pdf.

PRS™-PROBE SAMPLE SHIPPING SUMMARY

Samples will not be processed unless this form is filled in completely and signed[1]. Call 1-877-978-1777 for assistance.

Researcher/Supervisor: ______________________ Date: ____________

Technician/Student: ______________________ Phone #: ____________

Institution: ______________________ Western Ag Contact: (please circle one) Name of R&D Coordinator

Research Project: ______________________

Please make sure to fill out the correct Analysis Type below

Analysis Type (Please Circle)	# Samples for Analysis (in this shipment)	# ANION PRS™-probes per SAMPLE (Please Circle)	# CATION PRS™-probes per SAMPLE (Please Circle)	Sample Label Range[3] (ie: 1-100)	Burial Date (mm/dd/year)	Retrieval Date (mm/dd/year)
Complete	100	1 2 3 4	1 2 3 4	1-100	05/15/2009	05/30/2009
NO_3- & NH_4-N only	25	1 2 3 4	1 2 3 4	101-125	05/15/2009	05/30/2009
Anions only		1 2 3 4	1 2 3 4			
NO_3-N only		1 2 3 4	1 2 3 4			
Other:						

TOTAL BILLABLE SAMPLES = 125 [1]

Extra Unused Anion: 5 | # Extra Unused Cation: 4

Broken Anion: | # Broken Cation:

[1]Approval Signature: ______________________

Additional Notes:

Print Signatory Name: ______________________

Protocols

3

Protocols and Procedures

The most successful means of collecting high quality data from the PRS™-probes is to follow these procedures carefully.

As with any lab procedure, careful use of the PRS™-probes and attention to the methods in this section will help to insure your success with the PRS™ system. The PRS™-probes are a very sensitive monitoring tool of nutrient supply and in order to achieve reproducible results it is important to maintain consistent soil contact. Similarly, being diligent to wash all soil from the PRS™-probes upon removal from soil can make the difference between finding significant treatment effects and creating random numbers.

PRS™-Probe Storage

CAUTIONS: KEEP IN A COOL, MOIST STATE DURING STORAGE (refrigerate where possible, do not place in freezer)

KEEP AWAY FROM FERTILIZERS OR OTHER CONCENTRATED CHEMICALS.

DO NOT EXPOSE TO DIRECT SUNLIGHT OR EXTREME HEAT FOR EXTENDED PERIODS.

Quality Control and PRS™-Probe Blanks

Western Ag Innovations' quality control procedures include two tests in order to ensure that the PRS™-probes you receive are clean and functional. After each batch of PRS™-probes are regenerated; we analyze them to ensure there are no residual ions on the membrane. In addition, we annually test the ion capacity of a representative sample of PRS™-probes to confirm they have maintained maximum capacity. There is a list of maximum ion capacities for the PRS™-probes on page vi.

As a check that PRS™-probes remain uncontaminated once they leave Western Ag Innovations, a researcher can use a few PRS™-probes as blanks. These PRS™-probes should be treated in the same manner as the PRS™-probes used in burials with the exception that they are not buried rather they are placed in sample bags for the duration of the burial. The "blank" PRS™-probes should be kept cool and moist with deionised water, as desiccation will affect the reading from the blanks. These blank PRS™-probes should come out of the same bag or "batch" of PRS™-probes as the ones buried. It is best to remove the blank PRS™-probes prior to doing burials to prevent these clean PRS™-probes from becoming contaminated with soil. After the sample PRS™-probes are retrieved, the blank PRS™-probes should be washed in the same manner as the sample PRS™-probes and sent to Western Ag Innovations to be analyzed along with the sample PRS™-probes. If results from analysis of the blank PRS™-probes detect contamination and it is known that there was no contamination of the blank PRS™-probes by the researcher, it may be necessary to subtract the value of the blank eluate from the sample eluates. Please contact a R&D Coordinator if considering method banks. **NOTE: We charge the same price for the analysis of blanks as for the analysis of PRS™-probe samples.**

Types of Burials

The PRS™-probes can be used effectively in all soil types and geographic regions.

In the field: PRS™-probes can be buried directly in the field to measure nutrient supplies in relatively undisturbed soil conditions. The PRS™-probe is placed vertically in the 0-15 cm soil layer. Soil conditions (temperature, moisture, etc.) are monitored and used to interpret supply rates (Jowkin, 1997; Adderley, 1998; Salisbury, 2000; Hangs, 2004).

In the lab: For in-lab PRS™ burials, we recommend mixing the soil and wetting it with deionized water to field capacity. In-lab PRS™-probe burials are typically performed for a 1 - 24 hour period. The PRS™-probes may also be inserted into intact cores sampled from the field (Qian and Schoenau, 1995).

In the growth chamber: Nutrient release and mineralization can be compared to plant growth and nutrient uptake under growth chamber conditions by using the PRS™-probes. Duplicate pots of soil are prepared – one is seeded and grown with the crop being studied while PRS™- probes are buried in the other. Supply rates are measured by consecutive burials of PRS™-probes into the same soil slot in the pot without plants. Cumulative nutrient supply rates measured using the PRS™-probes are then compared to plant nutrient uptake at the end of the growth period (Sulewski, 1996; Qian and Schoenau, 2000).

In saturated pastes: Saturated pastes are often prepared to measure soil sodium adsorption ratio (SAR) with the PRS™-probe. In this case, the PRS™-probes are regenerated with a solution such as NH_4Cl instead of $NaHCO_3$ since Na^+ is the major ion of interest. Anaerobic conditions will be created in a saturated paste, thus this method is not appropriate for supply rate measurements of N and other nutrients affected by reducing conditions (unless, of course, these are the conditions of interest) (Greer and Schoenau, 1996).

Under crop residues or the LFH layer in forest soils: To measure nutrient release and leaching from crop residues decomposing in the field, PRS™-probes can be placed horizontally on the soil surface below the residue. Similarly, in forestry-related applications, PRS™-probes can be inserted horizontally below the forest floor (LFH layer) or between the organic layers to measure nutrient fluxes over time in 'undisturbed' forest soils or following different management practices. Ions are adsorbed from any leachate that happens to fall on the PRS™ membrane surface (Huang and Schoenau, 1996; MacLeod, 1999).

By horizon: In forestry related applications, soil nutrient supplies are often studied according to genetic horizon. Supply rates can be measured in these different horizons by digging a pit and burying PRS™-probes horizontally in the different layers through the side of the pit. Soil from the pit can be replaced after the PRS™-probes are inserted to maintain more natural soil environmental conditions (Huang, 1996).

Under water: PRS™-probes can be buried underwater to measure nutrient supplies in the peat base of a fen. A stick can be used to push the PRS™-probes down into the peat below the depth that cannot be reached by hand. In order to locate the buried PRS™-probes, fishing line is tied to each PRS™-probe handle, which are attached to a nearby pole secured in the fen (Rask, unpublished data).

Short Duration (1-24 hours) Soil Burial

A short duration burial is often performed to measure a "snapshot" of the soil nutrient ion supply rate at a particular time.

1) Make a slot in the soil to be tested – in mellow or moist soils it may be possible to insert the PRS™-probe directly into the soil without making a slot.

2) Add distilled or deionized water to the slot and soil within a 5 cm radius to bring the soil water content close to field capacity. It is important that the soil be moist because little exchange will take place in a dry soil over a short time period.

3) Insert the PRS™-probe into the slot and pack the soil around it to **ENSURE GOOD CONTACT BETWEEN THE MEMBRANE AND THE SOIL**. You may wish to add more distilled/deionized water after this step.

4) Leave the PRS™-probe in the soil for the desired time, ensuring that PRS™-probes in different treatments are buried for equivalent times. It is very important that PRS™-probes are buried for equal times among treatments that are being compared because ion supply to the soil solution is not linear over time; thus, the supply rate cannot be divided into shorter time segments. See the section on burial duration on page 13.

Extended Duration (multiple weeks) Soil Burial

Long duration burials are often performed when a researcher wishes to measure mineralization or nutrient release from soil and/or soil amendments and/or when nutrient supply rates are being monitored continuously throughout the season.

Long duration burials are most often performed for multiple weeks at a time; however researchers working with soils high in nutrient supply may wish to decrease the burial time to two weeks to avoid the possibility of ion saturation on the PRS™-probe membrane. Likewise, researchers working in nutrient poor soils may wish to increase the burial duration up to 12 weeks.

1) Make a slot in the soil to be tested – it may be possible to insert the PRS™-probe directly into mellow or moist soils without making a slot first.

2) **DO NOT ADD WATER**. When PRS™-probes are buried for long periods to assess ion release; water should not be added as this may alter the mineralization/nutrient release rates being measured. In addition, it is difficult to ensure that all treatments remain at equivalent water contents during a long-duration burial. It is a good idea to monitor soil water content levels during the PRS™-probe burial if possible.

3) Insert the PRS™-probe into the slot and pack the soil around it to **ENSURE GOOD CONTACT BETWEEN THE MEMBRANE AND THE SOIL**. During wetting and drying cycles in strongly expanding and contracting soil types, contact may be disrupted during the burial period. It may be advisable to check PRS™-probes after prolonged dry periods to ensure soil contact with the membrane.

4) Leave the PRS™-probes in the soil for the appropriate length of time ensuring that supply rates being compared have equivalent burial times.

Photo courtesy of T. Wong;
University of Hawaii at Manoa

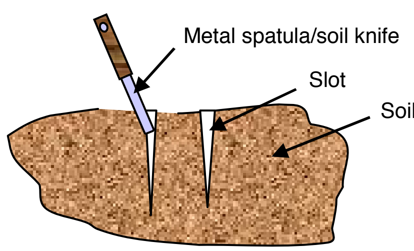
Photo courtesy of R. Harbut;
University of Wisconsin-Madison

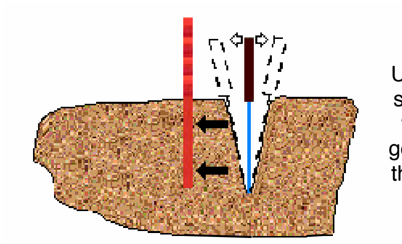
Important Considerations for Field Burials

Soil Contact

It is very important to ensure complete contact between the soil and the resin membrane of the PRS™-probe to achieve accurate results and consistency among PRS™-probe measurements. Nutrient supply rate is determined using a specific surface area of soil. If there is incomplete contact between the membrane and the soil, then the soil surface area actually supplying ions to the membrane is different than that assumed in the calculation of supply rates. For example, if only half of the PRS™ membrane surface area is in contact with the soil, then the supply rate measured will be only half of the value of the true supply rate of the soil.

Good soil to PRS™-probe contact can be achieved by gently pushing the soil against the PRS™-probe after inserting it into the soil. If a PRS™-probe is removed from the soil and any significant portion of the membrane appears too clean, there was likely poor contact between the PRS™ membrane and the soil. If the complete surface area of the PRS™-probe was not in contact with the soil, but it is known what portion of the surface was in contact, then calculate this area and add it to the notes on the shipping summary so that we can correctly calculate the supply rate.





Use either a spade or soil knife and apply a 'back-cut' to ensure good contact between the PRS™-probe and the soil.

Temperature

When burying PRS™-probes, particularly in the field, it is important to account for the effects of soil temperature on ion diffusion and mineralization. Ions move more slowly through soil at lower temperatures, consequently their movement to the PRS™-probes will also be slower. Microbial activity, and therefore mineralization/immobilization processes, will also be reduced at lower soil temperatures. Soil temperature data should be reported along with nutrient supply rate data where possible. ***Visit the following page on our website to view a poster with data on how soil temperature affects soil nutrient supply rates:***
http://www.westernag.ca/innov/resources/posters/Sulewskietal2001_Poster.pdf

Soil Water Content

Soil water content has a significant effect on ion movement and mineralization in the soil. Drier soil has slower the ion movement. This results in a lower ion supply rate to a plant root and to the PRS™-probe. Microbial activity is also restricted in dry soils which will impact mineralization and/or immobilization processes. Mineralization may also be reduced in very wet soils because

mineralizing microorganisms may not be able to survive the anaerobic conditions created. In very saturated soils, denitrification may occur, causing reduced N supply rates. For short-duration burials, soils should be moistened to field capacity. For long-duration, in-field burials, soil moisture levels should be continuously monitored where possible and reported as interpretative data along with nutrient supply rates. ***Visit the following page on our website to view a poster with data on how soil water content affects soil nutrient supply rates:***
http://www.westernag.ca/innov/resources/posters/Sulewskietal2001_Poster.pdf

Root Competition

For extended duration burials, burying the PRS™-probes near plant roots will result in a measure of the difference between total nutrient supply and plant uptake (nutrient surpluses rather than net mineralization). Net mineralization without root competition can be assessed by inserting a root exclusion cylinder (Fig. 1) such as a PVC or aluminium pipe into the ground and burying the PRS™-probes within the soil area isolated by the cylinder. Care should be taken to remove plants growing within the cylinder over the course of the experiment.

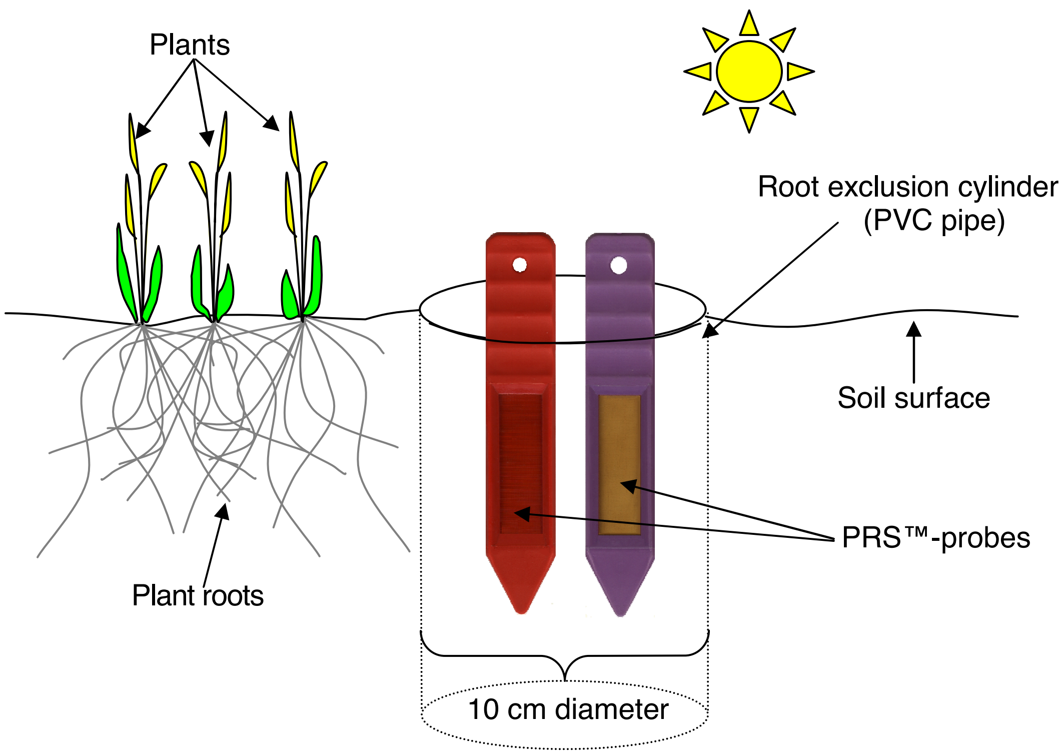


Figure 1. Root exclusion cylinder used for isolating PRS™-probes from plant root competition during long burial durations in the field.

An alternative method to control root competition is to cut a deep slit (approximately 30 cm) around the PRS™-probes in a radius of at least 20 cm. This procedure will need to be repeated at least once a month.

Some researchers have used a combination of PRS™ burials within root competition and those isolated from roots to gain a more complete understanding of total nutrient supply, plant uptake and nutrient surpluses. The difference between supply rates within a root exclusion cylinder and those outside the cylinder can be used as an indicator of plant nutrient uptake. However, the presence of a root system may have secondary effects on nutrient supplies by altering soil moisture content, microbial dynamics and incorporation of nutrients into the microbial biomass. Following a heavy rain, runoff will be reduced inside the root exclusion cylinder, which may result in ponding of water within the cylinder. This in turn may lead to denitrification within the cylinder and therefore lower supply rates measured. To avoid this, try to insert the root exclusion cylinder so that its rim is with the level of the soil surface and/or drainage holes can be drilled in the PVC just above the soil line. When N-fixing plants are being studied, the additional N fixed by plants outside of the cylinder will affect the relationship between N supplies measured inside and outside the root exclusion cylinder.

Other Competing Sinks

Plant roots act as ion sinks. Likewise, any other factor responsible for removing ions from the available soil nutrient pool can compete with the PRS™-probes for ions and can result in reduced nutrient supply rates. For example, if the soil has a large organic carbon source, with a wide C:N, C:P or C:S ratio, microorganisms may compete with the PRS™-probes for ions and immobilize N, P and/or S. Nutrient immobilization is one process within the whole cycle of mineralization, immobilization transformation (MIT) that can affect the supply rates measured. For a more complete discussion of these nutrient dynamics with reference to N, see "Mineralization and immobilization of soil nitrogen." *In:* Nitrogen in Agricultural Soils. Jansson, S.L., Persson, J. and Stevenson, F.J. (ed). 1982. Pp. 229-252.

Burial Duration

It is vital that the duration of PRS™ burials be equivalent for all treatments that researchers wish to compare. Burial duration will affect the amount of ion adsorbed. The longer a PRS™-probe is buried, the greater the opportunity to adsorb ions released from the soil, the larger the supply rates that will be measured. The time of burial is particularly important when measuring ions that are being mineralized and/or immobilized. Since ion adsorption is not linear, generally following first order kinetics over time, supply rates cannot be divided into time units smaller than the entire duration of soil burial. For example, supply rates determined using a 2-week burial cannot be divided by 14 to be reported as supply rate per day.

It is also important that the PRS™-probes not be buried for so long that the membrane becomes saturated with ions from the soil. If this occurs, the PRS™-probe will underestimate the continuously supplied ions such as N and S. See pages 8 and 9 for guidelines on PRS™-probe burial lengths, and page vi for the maximum amounts of various ions that the PRS™-probe can adsorb.

Insect and Animal Damage

During short-term burials, damage to the PRS™-probe from insects or animals is unlikely; however, for long-term burials it may be a problem. Although these situations are rare, researchers have experienced PRS™-probe damage from soil microfauna, seagulls, rodents, cattle, wild boars, birds and bears. To minimize damage, bury the PRS™-probes deep enough or conceal the handles in a manner as to minimize the attention drawn to the PRS™-probes. Often after an animal pulls out and chews on the first one they quickly realize that the nutritional value is not worth the effort. In our experience, in those rare situations where PRS™-probes are removed by wildlife (or humans), typically one or two PRS™-probes are removed early on and then never again.

Even from a plant's perspective there is more to life!

Washing the PRS™-Probes

It is very important to **WASH, WASH, and WASH** the PRS™-probes as thoroughly as possible. If it is not possible to get the PRS™-probes completely clean in the field, it is necessary to RE-WASH the PRS™-probes in the lab under a distilled/deionized water tap. **If soil is visible anywhere on the PRS™-probe plastic, membrane or in any cracks, the PRS™-probe is not clean enough!** Incomplete washing will result in contamination of the eluant, causing cloudy eluate samples and resulting in erroneous numbers. Furthermore, the cloudy eluate samples may cause problems with analytical equipment. **ABSOLUTELY ALL SOIL MUST BE WASHED OFF OF THE PRS™-PROBES PRIOR TO ELUTION**.

Pull the PRS™-probe from the soil and immediately wash off **ALL** residual material by spraying the PRS™-probes with de-ionized water, paying special attention to where the membrane meets the plastic. Hand scrubbing the adhering soil with a scrub brush and/or toothbrush while washing is usually necessary to remove sticky soil. It is extremely important to ENSURE THAT THE PRS™ MEMBRANE, PLASTIC CASING AND ANY CRACKS ARE ABSOLUTELY CLEAN – because contamination with soil will alter results during the elution process.

1) Re-inspect the cleanliness of the PRS™-probes once they are brought back to the lab and re-wash under a deionized/distilled water tap if necessary. It may also be necessary to transfer the PRS™-probes to a new bag at this time.

2) Shake excess water off of each washed PRS™-probe and place in a heavy-duty (one that will not leak or be easily punctured) zipseal freezer bag (18 cm x 20 cm size (945 mL) works well) and label appropriately. Excess water left on the PRS™-probes will dilute the concentration of ions in the eluate, introducing error in the results. Cation and anion PRS™-probes from one sample should be combined in the same bag.

3) If you would like to have a Method Blank PRS™-probe sample analyzed as well, place one unused cation and one unused anion into a heavy-duty zipseal freezer bag and label as a "Blank PRS™-probe". The blank PRS™-probe samples will be used to account for ions that may not have been properly cleaned in the wash/recharge step. Please note that the cost to analyze a Blank sample is the same as the cost of analyzing a regular PRS™-probe sample.

Note: A high-pressure backpack style hand pump sprayer filled with deionized water is a particularly effective tool for washing the PRS™-probes in the field.

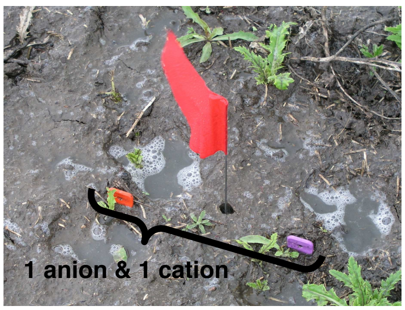
Labelling and Bagging the PRS™-Probes

When preparing samples for analysis by Western Ag, please ***combine the anion and cation PRS™-probes from each plot*** (i.e., that are to be analyzed as one sample) into one clearly labeled sample bag for analysis. All PRS™-probes combined in one bag will only yield one number value for each nutrient of interest. In other words, each PRS™-probe within a bag acts as an individual component within a composite sample. ***Do not combine PRS™-probes within a bag if a measured value is desired for each PRS™-probe***. The sample identification should be printed on a label sticker and placed on the bag. Waterproof marker can also be used. In terms of labeling, please ***use only numeric notations*** (i.e., 1, 2, 3...n). This makes things easier for sample receiving on our end, easier for you to cross-reference our billing invoice with the number of samples you submitted, but most importantly, it keeps the analyses 'blind' on our end.

Please do not directly mark the PRS™-probes. Any identification marks on the plastic handle of the PRS™-probes should be removed prior to returning to Western Ag, otherwise a fee for cleaning the PRS™-probes may be charged. Alcohol can be used to remove waterproof marker from the plastic and will not harm the membrane if it comes in contact with it. After washing and bagging, ship the PRS™-probes to Western Ag Innovations for analysis (see page 4).

PRS™ Sampling

Procedures for **PRS™-probes**



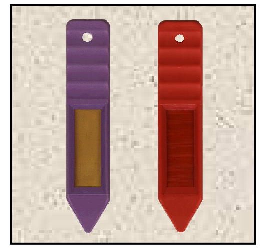
How our Service Works:

1) We charge based on the number of PRS™-probe analyses (samples) you'd like rather than on each individual PRS™- probe:

*A single analysis can include the use of up to 4 PRS probe **PAIRS** (4 anions + 4 cations).*

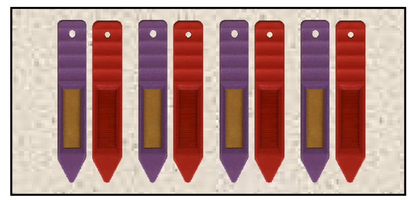
One Sample Can:

Consist of 1 cation and 1 anion PRS™-probe pair



Up to:

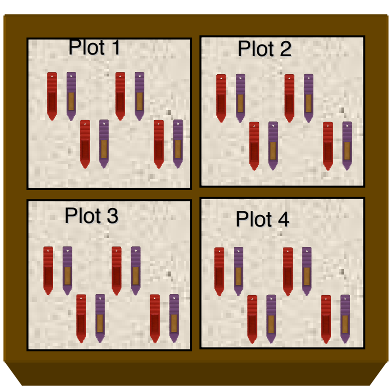
4 cation and 4 anion PRS™-probe pairs



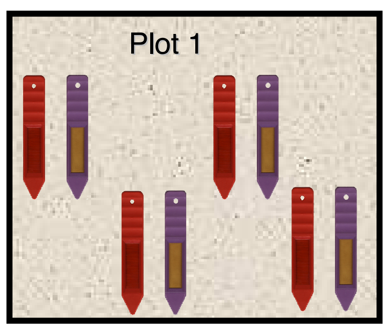
**Number of PRS™-probes per sample will usually depend on experimental design and should be discussed with an R&D Coordinator.*

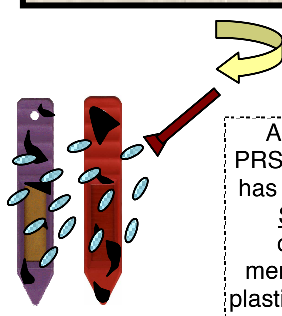
2) A PRS™-probe analysis sample works much like a composite soil sample, where you would distribute the pairs of PRS™-probes within a single experimental treatment

Example: This shows an experiment - using 4 pairs of PRS™-probes, total of 4 cation and 4 anion PRS™-probes.



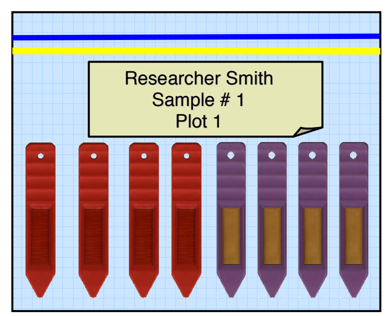
3) Remove the PRS™-probes from the soil; clean the PRS™-probes with deionized water:





A clean PRS™-probe has NO SOIL on its membrane, plastic handle, or in any cracks.

4) Combine ALL **PRS™-probe** pairs per experimental unit/plot into **one** sample Ziploc bag and label:



Bag cations and anions TOGETHER

5) Send back PRS™-probes to Western Ag for analysis:

Fill out a ***Shipping Form*** and ***Commercial Invoices*** (three copies; indicating that the **GOODS RETURNING and ORIGINATED in CANADA; Code 066**) and include with the shipping documents. *Note: documents are sent with PRS™-probes and are available on our website.*

Eluating the PRS™-probes

PRS™-probes are eluted using a 0.5N HCl solution for 1 hour, following which the eluate is analyzed colourimetrically or with an ICP.

Colourimetric Analysis of PRS™-Probe Eluate

Western Ag analyzes the PRS™ eluate for NO_3^--N and NH_4^+-N by colourimetry using an automated flow injection analysis (FIA) system. The current method detection limits are $0.1\,\mu g \cdot mL^{-1}$ for NO_3^--N and $0.1\,\mu g \cdot mL^{-1}$ for NH_4^+-N in the PRS™-probe eluate. These are the lowest numbers that can be read with reasonable accuracy using our equipment and procedures.

ICP Analysis of PRS™-Probe Eluate

Western Ag currently uses an ICP (Inductively Coupled Plasma) to analyse the P, K, S, Ca, Mg, Mn, Fe, Cu, Zn, B, Al and Pb content of the PRS™ eluate. The method detection limits ($\mu g \cdot mL^{-1}$) for each ion are:

P:	0.01	K:	0.2	S:	0.1
Ca:	0.2	Mg:	0.2	Mn:	0.01
Fe:	0.02	Cu:	0.01	Zn:	0.01
B:	0.01	Al:	0.01	Pb:	0.01

HPLC Analysis of PRS™-Probe Eluate

High Pressure Liquid Chromatography has been used to measure herbicide and glucosinolate contents of PRS™ eluates. For detailed explanations of the procedures used, refer to:

Szmigielska and Schoenau, 2000
Szmigielska and Schoenau, 1999
Szmigielska and Schoenau, 1994
Szmigielska *et al.*, 2000
Szmigielska *et al.*, 1998

Data

4

Data Interpretation

The data generated with the PRS™-probes is unlike data generated from a conventional soil extraction for nutrient concentrations. It is a dynamic rate measure, based on sorption to a specific surface area, and varies in response to changing soil conditions. Therefore, it is very important that these conditions be considered when interpreting supply rate data.

What are Ion Supply Rates?

Ion supply rate is defined as the amount of ion adsorbed per amount of ion exchange surface area per time of duration of direct burial in a medium as specified by given temperature and moisture conditions. The PRS™-probe will act as an ion sink, based on the principle of Donnan exchange, which describes the primary mechanism of ion absorption by plant roots. The permanently charged amine/sulfoic acid groups on the PRS™ resin membrane adsorb oppositely charged ions from the labile nutrient pool and soil solution. This can cause further release of ions from more slowly supplying ion pools in an attempt to maintain the ion concentration in solution. The membrane continues to adsorb ions from these pools as long as it remains in contact with the soil and/or until the buffering capacity of the soil is reached.

How Do Supply Rates Compare with Conventional Nutrient Extractions?

No direct calibration can be made between supply rate data and soil nutrient concentrations determined by conventional extractions. An extraction is used to measure the "available" ion pool at a certain point in time. Many chemical extractions provide a nutrient index that is only meaningfully related to plant uptake when soil pH conditions exist within a certain range. Functionally, this means that a basic soil may require one type of extraction chemical while an acidic soil requires a different one. Supply rate data includes a measure of ions adsorbed from the soil solution and labile pool as well as those replenished into the labile pool by the more slowly supplying pools over time. Resin membranes can be used in any type of soil to measure nutrient supplies.

The supply of nutrients or toxins from the soil over time as measured by the PRS™-probes is often more biologically meaningful than the levels which can be extracted by a given chemical solution.

The PRS™ system uses an ion sink, in direct contact with undisturbed soil, to attract and hold the "charged" or ionic species that are supplied from the soil over time. This patented system has been found to be very useful in tracking the dynamic behaviour of soil nutrient and toxin supply to plants. Relationships between PRS™ supply rates and conventional soil extractions and plant uptake are shown in Table 1.

Table 1. Chemical species detected using PRS™-probes in soils or other heterogeneous media.

Chemical Species	PRS™ Type	Correlation (R^2) With		References
		Conventional Extraction Method	Plant Uptake	
Nitrate	Anion	0.69	0.86	Qian and Schoenau, 1995
Phosphate	Anion	0.57	0.71	Schoenau *et al.*, 1993
Sulphate	Anion	0.73	0.98	Greer and Schoenau, 1994
Borate	Anion	0.79	N/A	Greer and Schoenau, 1994
Chloride	Anion	0.81	N/A	Greer and Schoenau, 1994
Potassium	Cation	0.87	0.68	Qian *et al.*, 1996
SAR	Cation	0.95	N/A	Greer and Schoenau, 1996
Sodium	Cation	0.86	N/A	*
Calcium	Cation	0.68	N/A	*
Magnesium	Cation	0.68	N/A	*
Ammonium	Cation	N/A	N/A	*
Chromium	DTPA-Anion	0.98	0.99	Tejowulan *et al.*, 1994
Manganese	DTPA-Anion	0.50	0.68	Tejowulan *et al.*, 1994
Iron	DTPA-Anion	0.61	0.71	Liang and Schoenau, 1995
Nickel	DTPA-Anion	1.00	1.00	Liang and Schoenau, 1995
Copper	DTPA-Anion	0.78	0.75	Tejowulan *et al.*, 1994
Zinc	DTPA-Anion	0.83	0.74	Tejowulan *et al.*, 1994
Cadmium	DTPA-Anion	0.98	0.98	Liang and Schoenau, 1995
Lead	DTPA-Anion	0.97	0.98	Liang and Schoenau, 1995
2,4-D amine	Anion	0.98	N/A	Szmigielska and Schoenau, 1994
Metsulfuron	Anion	N/A	0.98	Szmigielska *et al.*, 1998
Glucosinolates	Anion	0.98	N/A	Szmigielska *et al.*, 2000

* Unpublished data

Cumulative Supply Rates

The PRS™-probes may be re-inserted into the same slot in the soil (perhaps within a root exclusion cylinder; page 12) to determine changes in nutrient supply as affected by the time of year and changing environmental conditions. This simulates the constant sink of a plant root. Adding supply rates from these repeated burials together can be used to assess the cumulative nutrient supplies over a growing season. The first PRS™-probe in a soil slot adsorbs ions from the readily available nutrients in the soil solution and labile pool and any ions released from more slowly supplying pools. Subsequent PRS™-probes inserted into the same soil slot continue to adsorb ions released from slowly supplying pools because, due to the constant sink of the PRS™-probe, there would be little labile pool. Supply rate measurements made in different soil slots should not be added together as the size of the initial labile ion pool included in the supply rate measure might vary.

Reporting Units

Ion supply rates generated with the PRS™-probes, or other types of ion exchange membranes, should be reported as the ***amount of nutrient adsorbed per amount of adsorbing surface area per entire time of burial*** in the soil. The conventional PRS™-probe nutrient supply rate unit of measure reported in the literature is ***μg ion/10 cm^2/length of burial***. It is also acceptable to report the number per cm^2 membrane surface area instead of per 10 cm^2. The units may be reported as μg ion/ PRS™-probe/length of burial providing that the surface area of the PRS™-probe (accounting for both sides = 17.5 cm^2) is mentioned somewhere within the document.

When researchers receive data from Western Ag Innovations, Inc. the supply rates have already been calculated and are reported as μg ion/10cm^2. The following discussion describes how we calculated the supply rate. The calculation of a supply rate from the μg/mL ion concentration measured analytically in the eluate is straightforward, but requires the consideration of a number of factors, including the number and type of PRS™-probes eluted at one time, total ion exchange membrane surface area eluted, the volume of eluent used, and the length of PRS™-probe burial in the soil. Data generated by the analytical instrument will be reported in units of μg nutrient ion per mL eluate solution (i.e., ppm). All that is required is to:

i) multiply the ion concentration in the eluate solution by the volume of eluent used to elute the PRS™-probes to obtain a total weight of ions eluted,

ii) divide this value by the total membrane surface area of the PRS™-probes to obtain the weight of ions adsorbed per unit surface area of ion exchange membrane. If calculating supply rate for an anion or the polyvalent metal, divide by the total number of anion PRS™-probes eluted in the sample. If calculating supply rates for a cation, divide by the number of cation PRS™-probes eluted in that sample,

iii) multiply by 10 in order to yield whole numbers for nutrients typically having small numbers (i.e., P and micros),

iv) report data in terms of the length of time the PRS™-probes were left in soil (i.e., 24 hours, 2 weeks, etc.), thereby yielding the standard unit of μg nutrient/10 cm^2/length of burial.. Once again, <u>it is invalid to divide the burial duration into smaller time units since adsorption is not linear over time</u>, particularly when there is a large initial labile nutrient pool. The following three examples demonstrate how to convert the concentration value within the eluate to a PRS™-probe nutrient supply rate value given various sample elution scenarios.

Calculations

Overall equation for determining PRS™-probe nutrient supply rates from eluate ppm data:

$$\frac{\mu g\ nutrient}{mL\ of\ eluate} * \frac{17.5\ mL\ eluent}{probe} * \frac{total\ \#\ of\ probes}{bag} * \frac{bag}{\#\ of\ relevant\ probe\ type} * \frac{probe}{17.5\ cm^2} * 10 = \frac{\mu g\ nutrient}{10\ cm^2}$$

Example Calculation: Uneven numbers of both types of PRS™-probes eluted simultaneously:

The eluted sample consisted of four anion and three cation PRS™-probes that were spread throughout the experimental unit, left in soil for four weeks, removed, and then combined for the analysis. There were seven PRS™-probes placed in the zipseal bag, so a total of 122.5 mL of eluent was used (i.e., seven PRS™-probes x 17.5 mL eluent added per probe). After the one-hour extraction, the resultant NO_3^--N concentration of the eluate was 19.4 ppm.

$$\frac{19.4\ \mu g\ NO_3^- - N}{mL\ of\ eluate} * \frac{17.5\ mL\ eluent}{probe} * \frac{7\ total\ probes}{bag} * \frac{bag}{4\ anion\ probes} * \frac{probe}{17.5\ cm^2} * 10 = \frac{340\ \mu g\ NO_3^- - N}{10\ cm^2}$$

When reported in terms of the length of PRS™-probe burial, it yields <u>340 μg NO_3^--N/10 cm^2/four weeks</u>.

Missing Ion Exchange Membrane

The above example illustrates how to account for differences in dilution factors when varying numbers/types of PRS™-probes are eluted in the same sample. These are the most commonly expected scenarios when analyzing the PRS™-probes and resulting calculations to determine nutrient supply rates. However, sometimes PRS™-probes are returned for analysis with pieces of membrane missing which leaves less surface area for ion adsorption and this is accounted for in the ion supply rate calculation.

For example, if one of the PRS™-probes is missing a portion of the ion exchange membrane, the surface area of the missing membrane is measured prior to elution and then factored into the calculated nutrient supply rate values. The correction factor is then multiplied by the original nutrient supply rate values to yield more accurate data.

$$\frac{\frac{17.5\ cm^2\ membrane}{anion\ probe} * total\ \#\ of\ anion\ probes}{\left(\left(\frac{17.5\ cm^2\ membrane}{anion\ probe} * total\ \#\ of\ anion\ probes\right) - cm^2\ anion\ membrane\ lost\right)} = \textbf{Missing Membrane Correction Factor}$$

Additional Info

5

Additional Information

Additional information, including FAQ's, Technical Updates, Posters and Journal Articles can be found by visiting our website: http://www.westernag.ca/innov

FAQ's: Please recommend any additional FAQs to us if you feel they would be helpful to others (http://www.westernag.ca/innov/faqs.php).

Technical Updates are used to highlight past PRS™-probe related research, to demonstrate the unique ways that they can be used to enhance research, and to gain a more complete understanding of soil nutrient dynamics. These updates are sent out three times a year (e.g. spring, summer, and fall and also review the factors to consider when using the PRS™-probes, along with the services offered by Western Ag Innovations. Feel free to forward them onto any interested colleagues. Please let us know if you would like to include some of your results in a future issue (http://www.westernag.ca/innov/tech_updates.php).

Other Information Sources: There are many sources of information available on use of the PRS™-probes as well as other methods employing ion exchange techniques. The Western Ag Innovations website offers access to the abstracts of numerous scientific papers in which PRS™-probes have been utilized. These papers are available in full form via download from the website. In addition, the website provides some background information about the PRS™ technology and development (http://www.westernag.ca/innov/papers.php).

If you would like a list of published research papers involving the PRS™-probes and their application, a list of related theses where the PRS™-probes were used as part of a larger study, and a list of related papers in which other ion exchange techniques and principles were employed, please contact us at: http://www.westernag.ca/innov/contact_us.php.