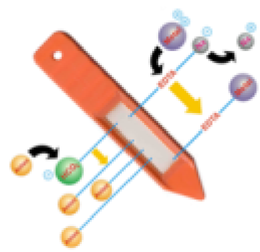
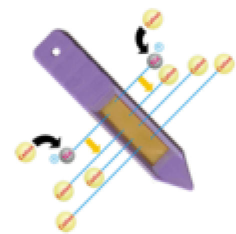
Planning Guide for Plant Root Simulator (PRS®) Probes

December 2018





1. Description

Plant Root Simulator (PRS®) probes are used to monitor soil nutrients in all types of ecosystems:

- Forests, ≈34% of samples
- Agriculture, ≈32% of samples
- Grasslands, ≈16% of samples
- Wetlands, ≈6% of samples
- Arid, ≈5% of samples
- Polar/alpine, ≈5% of samples
- Urban, ≈2% of samples

PRS probes have been used in more than 30 countries and PRS probe data has been used in more than 370 peer-reviewed scientific publications.

PRS probes consist of ion-exchange resin membranes held in plastic supports that are easily inserted into soil for the simultaneous measurement of all plant nutrients with minimal soil disturbance. The resin membranes are a network of polystyrene cross-linked with divinylbenzene, with fixed ionic groups to provide permanent charge.

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Anion probes (orange)
• Positively-charged membrane to attract and adsorb negatively-charged anions: NO_3^-, $H_2PO_4^-$, SO_4^{2-}, etc.
• Fixed ionic group is $R\text{-}NH_4^+$
• Maximum adsorption capacity of 150 meq m^{-2} (sufficient to adsorb 2100 mg NO_3^--N m^{-2} or 2400 mg SO_4^{2-}-S m^{-2})
• Primary counter-ion is HCO_3^-
  ○ Low affinity
  ○ Bio-mimics HCO_3^- produced in the rhizosphere
  ○ Not conserved in soil solution, thus avoiding complementary anion interference
• EDTA added on approximately 30% of exchange sites to increase adsorption of P and micronutrients (Fe, Mn, Cu, and Zn)
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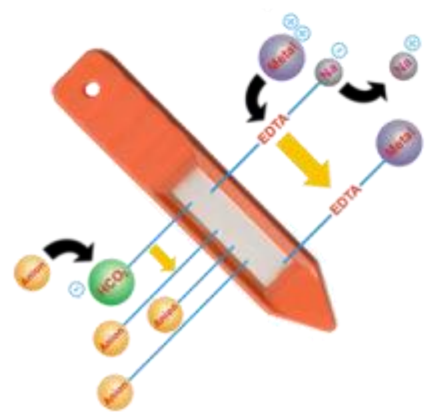

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Cation probes (purple)
• Negatively-charged membrane to attract and adsorb positively-charged cations: NH_4^+, K^+, Ca^{2+}, Mg^{2+}, etc.
• Fixed ionic group is $R\text{-}SO_3^-$
• Maximum adsorption capacity of 240 meq m^{-2} (sufficient to adsorb 3400 mg NH_4^+-N m^{-2} or 4800 mg Ca^{2+} m^{-2})
• Primary counter-ion is Na^+ (low affinity)
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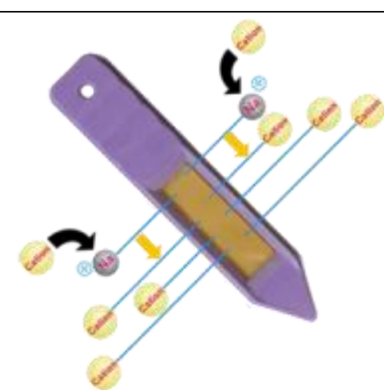
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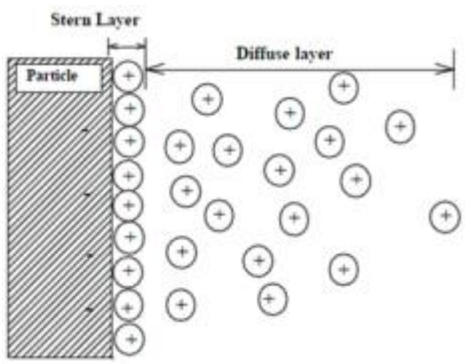
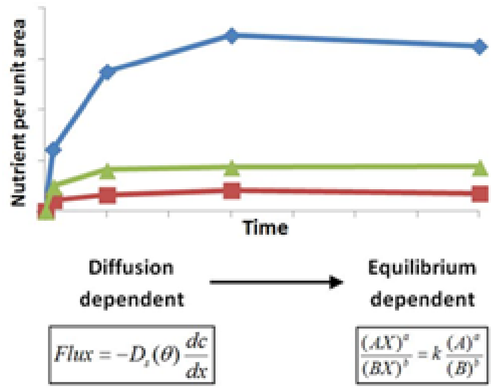
2. Dynamics of Ion Adsorption

Ions in soil solution are attracted by ion-exchange membranes of opposite charge and repulsed by those with the same charge. The resulting distribution of ions adjacent to charged surfaces is referred to as a diffuse double layer. Attracted ions are exchangeable, but must be replaced by ions of equivalent charge to maintain electrical neutrality (Donnan exchange principle). Ions with higher valence or smaller hydrated diameter are attracted more strongly than ions with lower valence or larger hydrated diameter. Initially, the counter-ions ions present on PRS probes have low valence and large hydrated diameter, and thus are easily displaced by ions from soil solution.





When PRS probes are first inserted in soil; the rate of exchange is ***Diffusion Dependent***: the flux of ions to the ion exchange membrane is controlled by the activity and diffusivity of ions in soil solution. The process is similar to that occurring in the soil-root system, in which roots adsorb nutrients from soil solution by releasing counter ions such as H^+, OH^-, and HCO_3^-. In both systems, a critical rate-limiting step is ion diffusion through soil.

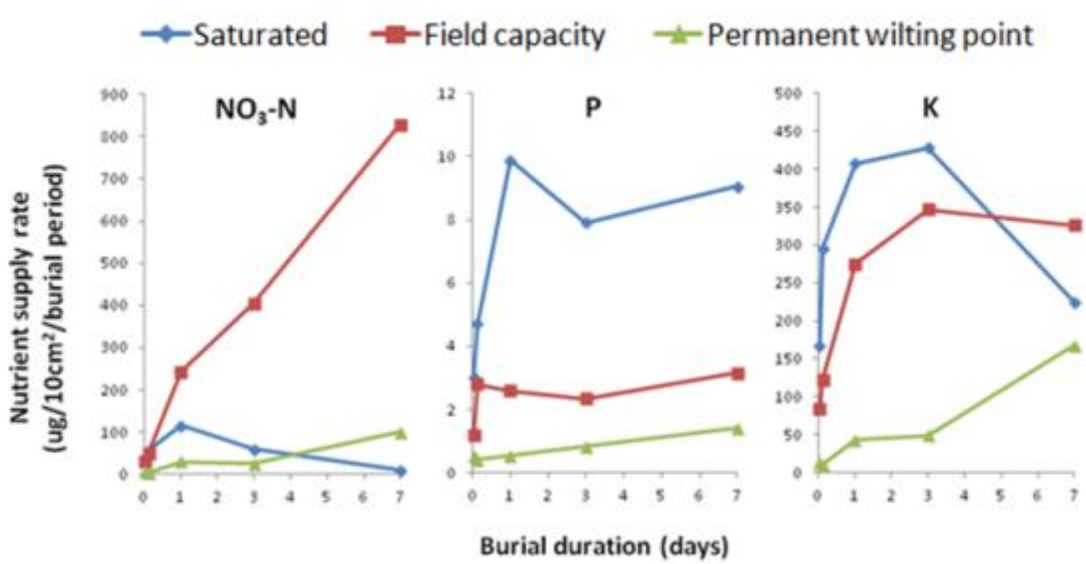
Eventually, the quantity of a specific ion adsorbed on the ion exchange membrane reaches a constant level that is **Equilibrium Dependent:** it depends on the relative ion activity in soil solution and affinity on the membrane of the ion. The affinity of an ion on a resin membrane (or other soil colloids) is most strongly influenced by valence: divalent ions are retained more strongly than monovalent ions, and trivalent ions are retained even more strongly. Within a given valence, ions that have a smaller dehydrated radius are held more strongly.

The temporal pattern of ion adsorption to PRS probes is the same for all nutrients, but the maximum quantity and time required to achieve varies widely due to differences in ion diffusivity, activity and soil buffering capacity. Ions diffuse through water-filled pore spaces and interact with the solid phase, and thus the diffusion rate in soil is much slower than in water and much slower for nutrients that strongly interact with the solid phase (e.g., P) those that do not (e.g., NO_3). As soil water content declines from field capacity (30 to 40% moisture) to wilting point (10 to 15% moisture), diffusion slows by about an order of magnitude.

Ion	Diffusion coefficient (cm^2/sec) Water	Diffusion coefficient (cm^2/sec) Moist soil	Movement in soil (mm per day)
NO_3^-	2×10^{-5}	10^{-6}	3
K^+	2×10^{-5}	10^{-7}	0.9
$H_2PO_4^-$	1×10^{-5}	10^{-9}	0.13

As soils are constantly undergoing change, the quantity of ions adsorbed on PRS probes may also change. However, the principles of ion exchange continue to apply. Increasing activity of an ion that is strongly held will increase the quantity of that ion on PRS probes and may reduce the quantity of ions that are weakly held. Declining activities of a strongly-held ion may not reduce the quantity held by PRS probes because other ions are unable to displace the strongly-held ion.

The following figure illustrates several of these principles. At permanent wilting point (dry soil), the quantity of nutrients adsorbed by PRS probes was low for all nutrients. At field capacity (moist soil), the quantity of nutrients adsorbed increased for all nutrients, but with much greater and prolonged adsorption for mobile (NO_3-N) than less mobile nutrients (P and K). At saturation, the quantity of nutrients adsorbed was consistently higher for P, but lower for NO_3-N due to microbial denitrification and lower for K by day 7 due to displacement by more strongly held cations such as Ca.



3. Definition of a PRS Probe Sample

Our standard service provides PRS probes and their analysis as one sample when they are returned to us. A PRS probe sample can consist of one to four anion (orange) and cation probes (purple):

One sample

One sample

One sample

One sample

Ordering and cost is based on the number of samples, not number of probes.

The PRS probes from one sample are distributed throughout the experimental unit and combined prior to analysis, like a composite soil sample. All probes in a sample are analyzed together as **one** sample.

Types of PRS probe samples

1. **Complete**: up to four pairs of PRS probes/sample, analyzed for NO_3-N, NH_4-N, P, K, S, Ca, Mg, Fe, Cu, Zn, B, Mn, Al, Pb, and Cd. Complete analysis is recommended to obtain a more complete description of nutrient dynamics.
2. **Anion**: up to four anion probes/sample, analyzed for NO_3-N, P, S, Fe, Cu, Zn, B, Mn, and Pb.
3. **N-only**: up to four pairs of PRS probes/sample, analyzed for NO_3-N and NH_4-N.

The use of multiple PRS probes per sample is recommended to reduce the impact of micro-scale variability on soil nutrient supply measurements. This is similar to the use of multiple soil cores when sampling soil.

Recommended number of PRS probes per sample

Sampling unit	PRS probes per sample*
Well-mixed soils (lab, greenhouse)	1-2 pairs
Small plots (1 to 10 m^2) with uniform soil and vegetation (e.g., tilled annual cropland, grass on uniform soil type)	2-3 pairs
Small plots (1 to 10 m^2) with heterogeneous soil, fertility amendment or vegetation	3 to 4 pairs
Large plots (>10 m^2) with heterogeneous soil and vegetation	3 to 4 pairs/sample 1 to 4+ samples/plot

*Depends on objectives, experimental design and measurement variation. When possible, evaluate statistical power of proposed experiment based on preliminary evaluation of treatment differences and measurement variability.

4. Duration of Burial Period

Ecosystem	Recommended burial period
Agriculture	1 to 4 weeks
Grassland, forest	2 to 8 weeks
Arid	2 to 12 weeks
Wetland	1 day to 4 weeks

- Most research has utilized burial periods of one to eight weeks. This period is sufficient to ensure that impacts of disturbance due to installation are minimal and provides a sensitive indicator of soil nutrient activity.
- Burial periods of as little as one hour can be used in wetted soil.
- Burial periods greater than eight weeks may be required if soils are consistently dry or frozen.
- A standard burial period under laboratory conditions is one day, but shorter and longer periods have been used.

A consistent burial period is required to reliably compare treatment effects on soil nutrient supply due to non-linear adsorption of nutrients by PRS probes.

Nutrient supply to PRS probes following oats or clover determined with eight one-week burial periods vs. one eight-week burial period (Salisbury, 2000).

Preceding crop	Burial treatment	Nutrient supply (mg/m^2 of membrane/burial period)					
		NO_3-N	NH_4-N	P	K	Ca	Mg
Oats	1 wk * 8	162	8	51	177	1879	127
	8 wk * 1	515	7	73	181	3091	183
	Ratio 8 wk:1 wk	3.2	0.9	1.4	1.0	1.6	1.4
Clover	1 wk * 8	252	9	42	260	1659	119
	8 wk * 1	685	10	64	259	3108	180
	Ratio 8 wk: 1 wk	2.7	1.0	1.5	1.0	1.9	1.5

- One- week burials were deployed sequentially (same slots). Measurements are expressed per burial period (per one week or per eight weeks).
- Compared to one-week burial, eight-week burial period measurements were 3-fold greater (NO_3-N), 40-90% greater (P, Ca and Mg) or the same (NH_4-N, K).
- **Thus, soil nutrient supply was not linear for any of these nutrients**: eight-week burial measurements were not eight times higher than one-week burials.
- Relative impact of preceding crop was similar for burial treatments except for a greater relative increase with eight one-week burials than one eight-week burial for NO_3-N following clover.
- Weekly measurements for NO_3-N tended to decrease with time and were most strongly affected by preceding crop during initial few weeks.
- Eight-week measurements were similar to maximum weekly measurements for Ca, Mg and P.

5. Burial Options

Typical field burials: PRS probes were designed to be inserted vertically into the uppermost soil layer because this is where most soil nutrients are released and roots are most active. Probes may be deployed consecutively or periodically to determine seasonal variations in nutrient supply rates. Consecutive probe burials may be made in same slots or in adjacent areas.

Field burials with root exclusion: PRS probes can be inserted into root-exclusion cylinders to minimize competition from plant roots and thereby determine total plant nutrient supply (Huang and Schoenau, 1997; Quaye et al. 2015). This option may be necessary for nutrients such as nitrogen, which are effectively depleted from soil solution by plants. The supply of other nutrients may be unaffected or increased by plants (Johnson et al., 2007).

Shallow burials: PRS probes can be installed horizontally or at an angle to determine nutrient release at a narrow depth interval or at shallow depths. This technique is also useful to minimize exposure of the PRS probe in situations with high risk of trampling.

Deep burials: PRS probes can be used to monitor nutrient supply rates in subsoil layers by burying PRS probes horizontally in the side of an excavated soil pit or at the bottom of a soil core or access tube.

Under water: PRS probes can be buried underwater to measure nutrient supply in sediments. The probes can be retrieved using a fishing line tied to each PRS probe handle.

Lab incubations: PRS probes can be used in short-term burials (e.g., 24 hours) with soil samples to obtain standardized measurements of soil nutrient supply. Long-term incubations can be used for mineralization studies.

6. Timing of Burial Period

The time period selected for PRS probe burial depends on research objectives:

- Burial prior to the period of rapid nutrient uptake by plants provides a measure of nutrient supply likely to influence plant growth without requiring root exclusion. This is particularly important for nutrients such as nitrogen.
- Burial during active plant growth period provides a measure of nutrient supply experienced by plants. Plants influence soil nutrient supply by depleting or competing for nutrients, rhizosphere impacts (±), and by influencing soil moisture and aeration.
- Burial during periods when plants have completed growth or are inactive provides a measure of nutrients that are in excess of plant requirements and may be susceptible to loss.
- PRS probes can be deployed over the winter when soils are frozen, but nutrient adsorption will only occur during periods when soils are unfrozen.
- PRS probes can be deployed when soils are dry, but nutrient adsorption will only occur during periods when soils are moist. Burial periods in arid regions should include at least one period when precipitation is sufficient to wet soil below depth of membrane.
- Long-term burial provides a measure of equilibrium nutrient activity in soil and may reflect total supply of intermittently-released nutrients (e.g., nitrate supply in an arid region). Most nutrients will remain relatively stable once equilibrium has been reached (one day to several weeks or more, depending on nutrient and soil conditions). Weakly-held ions may decline with time in soils with high nutrient activity due to displacement by more strongly held ions.

7. Additional Considerations

- **Equipment requirements:** a soil knife and flagging tape is all that is usually required to install probes, while deionized water, brush and labelled Ziploc bags are required to retrieve probes.
- The **maximum adsorption** for NO_3-N is 2100 mg N/m^2 of membrane, but adsorption is slowed when membranes are more than 50% saturated (>1000 mg N/m^2). This is rare, but may occur in heavily fertilized or saline soils. For example, placement in fertilizer bands should be limited to a period of three to five days.
- **Blank samples** consisting of PRS probes that have not been buried can be used to test for contamination. Blanks indicate if contamination from wash water or other sources is significant, but cannot be used to correct sample values because blank probes are saturated with easily-desorbed counter-ions and thus more likely to adsorb contaminants than sample probes. Decide at the beginning of the study if and how many blank samples will be needed, and include the number of blanks in your overall sample number. The pricing for blank samples is the same as other samples.

8. Ordering

- Contact us for information, price lists and estimates
  - Email: general@westernag.ca
  - Phone: 877-978-1777 ext. 2211 or 2213
  - Website: https://www.westernag.ca/innov/
  - Pre-order form: https://rdos.westernag.ca/orders/new_order.php

- Information required to obtain an estimate (*required)
  - Contact information*: name, organization, phone number, email
  - Principal Investigator (PI) of project*
  - Title for project*
  - Research objective for PRS probe data
  - Study location
  - Dominant vegetation
  - Description of experimental unit
  - Anticipated burial dates
  - Number of PRS probe samples*
  - Number of PRS probes per sample*
  - Type of analysis*
    - Complete: NO_3^--N, NH_4^+-N, P, K, S, Ca, Mg, Fe, Mn, Cu, Zn, B, Al, Pb, Cd
    - Anion: NO_3^--N, P, S, Fe, Mn, Cu, Zn, B, and Pb
  - Selection of 10% collaborative discount* if PRS probe data is intended for publication in a scientific paper and the PI agrees to provide a short final report highlighting PRS probe results within six months of data being provided. Collaborative discounts are provided to improve feedback on PRS probe use and data interpretation. Over 95% of our research clients select to receive collaborative discounts.
  - Delivery address (courier) and date. Free basic shipping of PRS probes to researcher is included with all orders exceeding $2000 to a maximum of 4% of the value of samples booked. The basic shipping cost to North American destinations for orders below $2000 is $40. Allow two weeks for delivery.

- Initiating a PRS probe project
  - The order is not final until we have received the estimate form with the signature of Principal Investigator and payment information (Purchase Order, Visa or Mastercard, bank transfer).