Factors Affecting Nutrient Supply Rate Measurements with PRS™-Probes.

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Abstract

This poster includes background information about how PRS™-probes are used to measure soil nutrient supply rates and how factors of the soil environment influence nutrient supply rate measurements. The discussion contains research examples of the effects of soil moisture, soil temperature, and competing sinks as well as the effect of the duration of PRS™-probe burial. These effects are important to consider when interpreting supply rate data.

What is a PRS™-Probe?

Plant Root Simulator (PRS™) probes are comprised of an anion or cation exchange resin membrane encapsulated in a plastic holding device (Figure 1). A high concentration of ion adsorption sites on the resin surface allows the PRS™ membrane to act as an ion sink when buried in soil, similar to a plant root surface (Schoenau *et al*., 1993). The PRS™ assesses nutrient supply rates by continuously adsorbing charged ionic species from the soil during the burial period.

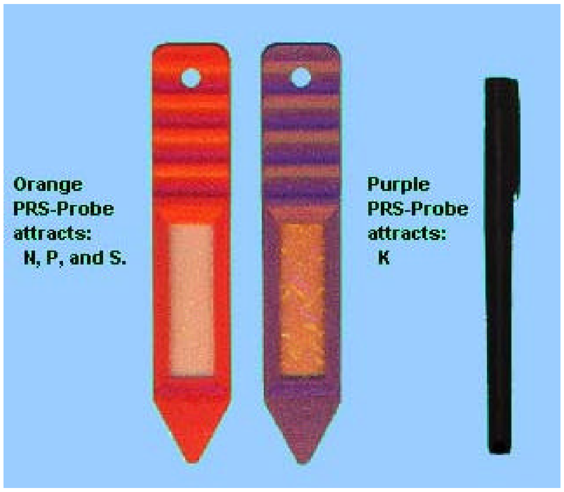

Figure 1. Anion (on the left) and cation (on the right) PRS™-probes.

PRS™-probes are buried *in situ* under conditions similar to those in which plant roots grow and absorb nutrients. This provides an integrated measure of supply as affected by all of the factors that affect nutrient supply to plant roots (free ion activities, buffer capacity, mineralization, immobilization, temperature, moisture, crop uptake, diffusion etc.).

What are PRS™ Ion Supply Rates?

Ion supply rates are reported as amount of ion adsorbed per unit surface area ion exchange membrane per entire time of PRS™-probe burial, conventionally “μg 10cm^{-2} duration of burial^{-1}”. PRS™ supply rates represent ion fluxes adsorbed from both the soil labile ion pool as well as ions replenished by more slowly supplying pools. They are a function of soil ion pool sizes as well as soil physical, chemical and biological conditions, meaning all factors of the soil environment must be considered when interpreting PRS™ supply rate data. PRS™ supply rates are well correlated with plant nutrient uptake (Table 1).

Table 1. Relationship between PRS™ Supply Rates, Soil Ion Concentrations Determined by Conventional Chemical Extraction and Plant Ion Uptake.

Chemical Species	PRS™ Type	Correlation (R^2) with		References
		Conventional Extraction Method	Plant Uptake	
Nitrate	Anion	0.69	0.86	Qian & Schoenau, 1995
Phosphate	Anion	0.57	0.71	Schoenau *et al*., 1993
Sulfate	Anion	0.73	0.98	Greer & Schoenau, 1994
Borate	Anion	0.79	n/a	Greer & Schoenau, 1994
Chloride	Anion	0.81	n/a	Greer & Schoenau, 1994
Potassium	Cation	0.87	0.68	Qian *et al*., 1996
SAR	Cation	0.95	n/a	Greer & Schoenau, 1995
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 & Schoenau, 1995
Nickel	DTPA-Anion	1.00[‡]	1.00[‡]	Liang & 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 & Schoenau, 1995
Lead	DTPA-Anion	0.97[‡]	0.98[‡]	Liang & Schoenau, 1995
2,4-D amine	Anion	0.98[‡]	n/a	Szmigielska & Schoenau, 1994
Metsulfuron	Anion	n/a	0.98	Szmigielska *et al*., 1998
Glucosinolates	Anion	0.98	n/a	Szmigielska *et al*., 2000

[‡] Experiments using soils spiked at increasing rates.

[*] Unpublished data.

What Factors Influence PRS™ Supply Rates?

Duration of Burial in Soil

The longer a PRS™-probe is buried in the soil, the greater the opportunity to adsorb ions, the higher the ion supplies measured. The effect of PRS™ burial time on nutrient supply rates measured in three soils is shown in Table 2. Supply rates of all nutrients are visibly higher after 24-hour *versus* 1-hour burial. Supply rates would be even higher following a 2-week PRS™ burial, particularly for ions such as N and S that are released through mineralization processes.

Table 2. PRS™ Nutrient Supplies Determined during Two Burial Periods in Three Soils under Controlled Environmental Conditions. (Schoenau *et al*., 1993)

Soil	Burial Time	NO_3-N	PO_4-P	K	SO_4-S
		µg cm^{-2} burial $time^{-1}$			
1	1 hr 24 hr	20.9 142.9	0.66 1.60	35.5 72.0	3.6 15.5
2	1 hr 24 hr	4.7 84.1	0.07 0.23	17.6 28.3	10.1 106.6
3	1 hr 24 hr	5.9 21.6	0.14 0.25	20.9 30.6	2.3 5.4

PRS™-probes should be buried for equivalent time periods among treatments to be compared. Supply rates can not be divided into smaller time units, as ion adsorption may not be linear over time. However, measurements made by repeated burial of PRS™-probes in the same soil slot over time can be added together to achieve cumulative supplies (i.e. over the growing season as in Table 6). "Snapshots" of soil nutrient supplying power are obtained by 1 - 24 hour burial of PRS™-probes, while 1 - 4 week burials are used to measure release of soil ions over time.

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. Microbial activity, and therefore mineralization/immobilization processes, will be reduced at lower soil temperatures, which will affect measurements of mineralizable nutrients such as N and S in particular. This is demonstrated in Table 3 in which microbial respiration progressively increases as soil temperature increases. At the same time, N supply rates measured by PRS™-probes also increase. Alternatively, higher temperatures could result in reduced supply rates as increased microbial activity causes ion immobilization (see Competing Sinks section).

Table 3. Microbial Activity and Nutrient Supplies in Triplicate Samples of a Loamy Sand Soil (O.M.= 1.8%) Incubated for One Week at Three Temperatures. ($P>F = 0.02$)

Incubation Temperature (°C)	$(NO_3 + NH_4)$-N	PO_4-P	Cumulative Respiration (µg CO_2-C kg^{-1} O.D. soil)
	µg $10cm^{-2}$ $week^{-1}$		
5	62	2.2	37 a
23	90	2.1	189 b
32	300	2.4	337 c

Although differences may be greater following long duration burials, there is also an effect of temperature on ion movement to the PRS™ during short-term burials (Table 4). At reduced soil temperatures, ions diffusion decreases and thus, movement of ion diffusion limited nutrients such as PO_4-P to the PRS™-probes will be reduced. For these reasons, soil temperature data should be reported along with nutrient supply rate data where possible.

Table 4. Nutrient Supply Rates Measured in Triplicate Soil Samples over Two Time Periods at Four Soil Temperatures. ($P <= 0.05$)

Incubation Temperature (°C)	Nutrient Supply Rate (μg 10cm^{-2} time of burial^{-1})							
	$(NO_3 + NH_4)$-N		PO_4-P		K		SO_4-S	
	1 hr	24 hr	1 hr	24 hr	1 hr	24 hr	1 hr	24 hr
4	63 b	244 b	2.3 b	7.8 b	217 c	221 b	17 c	61 b
10	74 ab	296 ab	2.7 ab	8.1 b	248 bc	195 ab	21 c	72 ab
20	86 a	290 ab	3.0 a	12.1 a	275 ab	175 a	25 a	82 a
30	90 a	352 a	3.0 a	10.3 ab	292 a	186 a	25 a	85 a

Soil Moisture

Soil moisture content has a large influence on physical movement, biological uptake and chemical reaction of ions in the soil, which in turn influence ion supplies to plant roots. An example of how moisture affects PRS™ nutrient supply rates is provided in Table 5 in which the PRS™-probes were buried in soils incubated for 1 hour at 5 moisture contents (values represent means of 3 replicates).

Table 5. Influence of Soil Moisture Content on PRS™ Soil Nutrient Supply Rates. (Schoenau *et al.*, 1993)

Soil Moisture Content	PRS™ Soil Nutrient Supply Rate (μg 10cm^{-2} hour^{-1})			
	NO_3-N + NH_4-N	PO_4-P	K	SO_4-S
Saturated	282	4.5	218	50
100% F.C.	200	2.7	181	39
70% F.C.	196	1.4	155	37
45% F.C.	113	0.9	93	26
15% F.C.	24	0.3	48	12

At lower soil moisture contents, lower supply rates are measured as microbial activity (and therefore mineralization) is limited and physical ion movement is restricted by greater tortuousity in the path the ions must travel to reach the PRS™ membrane. Microbial activity may also be limited in very wet soils due to anaerobic soil conditions and N supply rates may be reduced in saturated soils as a result of denitrification. Increased microbial activity at higher soil moisture contents could also result in reduced supply rates due to microbial immobilization of ions (see Competing Sinks section).

As a result of limited ion movement in dry conditions, researchers often moisten the soil in the vicinity of the PRS™-probe during short-duration burials to obtain a “snapshot” of soil nutrient supply. For long-duration, in-field burials, soil moisture levels should be continuously monitored and reported as interpretive data along with nutrient supply rates.

Competing Sinks

Any factor responsible for removing ions from the available soil nutrient pool can compete with the PRS™-probes for ions and can be responsible for reduced nutrient supply rate measurements. For example, if there is a large organic carbon source present in the soil with a wide C:N, C:P or C:S ratio, micro-organisms may compete with the PRS™ for ions. This process, known as nutrient immobilization, is one process within the whole cycle of mineralization/immobilization transformations that can affect the supply rates measured.

Plant roots can also compete with the PRS™ for ions. In studies extending over days or weeks, burying the PRS™ near plant roots results in a measure of the difference between net mineralization and plant uptake (nutrient surpluses rather than net mineralization). Net mineralization without root competition can be assessed by inserting a “root exclusion cylinder” (Figure 2) into the ground, removing plants, and burying the PRS™ within the soil area isolated by the cylinder. By burying PRS™ both inside and outside of the cylinders, a more complete picture of the soil NO_3-N dynamics can be obtained. The impact of plant root competition on soil nutrient supplies measured over a growing season is shown in Table 6.

Figure 2. Root exclusion cylinder consisting of a PVC pipe inserted to a 10” depth from which plants were removed to isolate the PRS™-probe from plant root competition.

Table 6. Impact of Plant Roots on NO_3-N Ion Adsorption by PRS™-Probes Buried in Different Pasture Systems Biweekly (12 times) over a Growing Season at Lacombe, Alberta, 1999. (Dr. V.S. Baron, unpublished data)

Pasture Type	No Roots	Roots	N Uptake
	$\mu g\ NO_3$-N $10cm^{-2}$ 24 wk^{-1}		
Old Perennial	1713	237	140
Alfalfa	2686	1328	330
Mixed Brome/Alfalfa	2446	895	320
Annual Rye Grass	2955	2007	200
Low Input	1349	262	140
Significant F	**	**	*
SE LSMeans	185	165	40

Nitrate-N supplies were much lower in the presence of roots than where the PRS™-probes isolated from root competition. The influence of N fixation is also apparent in that N uptake is greatest in the treatments containing alfalfa while PRS™ cumulative supply rates measured in the absence of roots indicate greatest N supply in the annual rye grass treatment. When N-fixing plants are being studied, it is important to remember that N uptake is influenced by both N supply as measured within the root exclusion cylinder as well as N fixation by plants growing outside of the cylinder.

Conclusions

The sensitivity of PRS™-probes to soil environmental conditions makes them a powerful tool for measuring soil nutrient supplies under field conditions similar to those in which plants grow. This sensitivity also means that care must be taken in planning experiments with the PRS™ and when interpreting PRS™ supply rate data. If possible, it is recommended that soil moisture and temperature be measured during the duration of PRS™ burial and that competition from plant roots be accounted for.

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