Plant Root Simulator™-Probes: An Effective Alternative for Routine Soil Testing

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Abstract

With the current uncertainty facing the agronomic community, it is imperative for producers to have all of the necessary tools available for making informed decisions regarding crop nutrition planning. Considering that there are many indeterminate factors affecting the bottom line at the end of the growing season, it is prudent to manage the risk involved whenever possible. Utilizing a network of over 20 Field Service Representatives throughout Western Canada, Western Ag Labs provides an extensive one-on-one crop nutrition planning service to producers encompassing over 600,000 acres. Preceding any crop nutrition consultation, however, is the soil nutrient supply rate analysis carried out in the lab using Plant Root Simulator (PRS)™ probes. The purpose of this paper is to briefly describe the protocols employed by Western Ag Labs during routine soil analysis, including: soil sample handling and preparation; PRS™-probe analysis; and, the quality assurance QA program. Historical ranges of selected nutrient supply rate data measured in the lab using the PRS™-probes also are presented.

Introduction

Less than 10 % of the fields in Western Canada currently are managed based on annual soil testing practices (Karamanos, 2001). Since the inception of soil testing, grower adoption of annual soil testing has been minimal, with a peak occurring in 1968 followed by a large decline until the late 70's/early 80's, where it has since stabilized (Jones and Kalra, 1992). Such statistics clearly indicate that producers see limited utility in the fertilizer recommendations provided to them by soil test labs (Green et al., 2000). Although the reasons for this stagnant growth in conventional soil testing vary among regions, one common limitation is the decades old yield response curves upon which these fertilizer recommendations are based. In essence, the use of such an antiquated recommendation program results in every grower deemed *average*, with the consequence that many are provided with inappropriate recommendations for their particular field (Karamanos and Henry, 1991). Considering the heterogeneous natures of both edaphic properties and environmental conditions, the use of a mechanistic computer model is essential in determining the fertilization required yielding a positive economic return without conducting a series of calibration field trials for each particular soil type (Barber, 1998).

Building on the principles of Barber (1984), the Plant Root Simulator (PRS)™-probe has proven its utility and descriptive powers in soil science research over the last 10 years (Qian and Schoenau, 2002). Subsequent development of a constrained-resource mechanistic model, known as the PRS™ Nutrient Forecaster, provided the foundation for fertilizer prescriptions based on

the soil nutrient supply rates measured using the PRS^{TM}-probes. Together, the PRS^{TM}-probes and PRS^{TM} Nutrient Forecaster methodology comprise the PRS^{TM} technology. Since the establishment of Western Ag Labs (WAL) in 1998, the number of acres that are fertilized based on recommendations developed by the PRS^{TM} technology have increased steadily. The soil nutrient data measured using the PRS^{TM}-probes provides a nutrient supply rate or nutrient flux per unit surface area per time (i.e., $\mu g/10cm^2/24$ h), and is incomparable to the nutrient availability indices (i.e., ppm) provided by conventional soil tests. Therefore, existing proficiency testing programs for soil testing labs that employ sample exchanges and/or control samples are inapplicable to the routine soil testing practice of WAL. The purpose of this paper, therefore, is to detail the lab protocols and quality assurance (QA) program implemented with the first routine soil testing application of the PRS^{TM}-probes.

Lab Protocols

Western Ag Labs has an established QA program in place assuring that the integrity of each sample is maintained throughout the sample handling and analytical procedures. The ambition of WAL in terms of its lab protocols, is appropriately summated in its mission statement:

The goal of WAL is to handle, prepare, and analyse each soil sample in a consistent and efficient manner, while under the control of an effective QA program, thereby yielding accurate and precise data in a timely manner.

Ultimately, if the data is posted to the WAL server for downloading by the Field Service Representative (FSR) within three days of sample receipt, while maintaining the confidence of both the FSR and customer in terms of the quality of data provided, then WAL has achieved it its objective.

Lab Manager Software

After receiving a batch of soil samples from a FSR, prior to any sample preparation, all of the information regarding each sample is entered into the *Lab Manager* software. Employing a central management tool such as Lab Manager provides an essential foundation for an effective QA program, due to its functionality in terms of storing sample information, tracking samples, data processing, monitoring the quality control data, and the posting of data to the appropriate FSR folder on the WAL server.

Upon opening Lab Manager, a new soil sample input page appears (Figure 1). Within this window all of the pertinent soil sample information is entered, such as the FSR identification number and name, legal location, and customer name. Additional comments regarding the prior crop grown, condition of the field during sampling (i.e., summer fallow), or sample position within the landscape are entered into the comment box. This detailed information can facilitate the regional interpretation and aggregation of the subsequent nutrient supply rate data. The values for burial time, soil moisture and temperature are default settings, because the conditions for the PRS^{TM}-probe analysis remain constant. Other additional information to consider includes whether or not the customer requests pH and EC measurement.

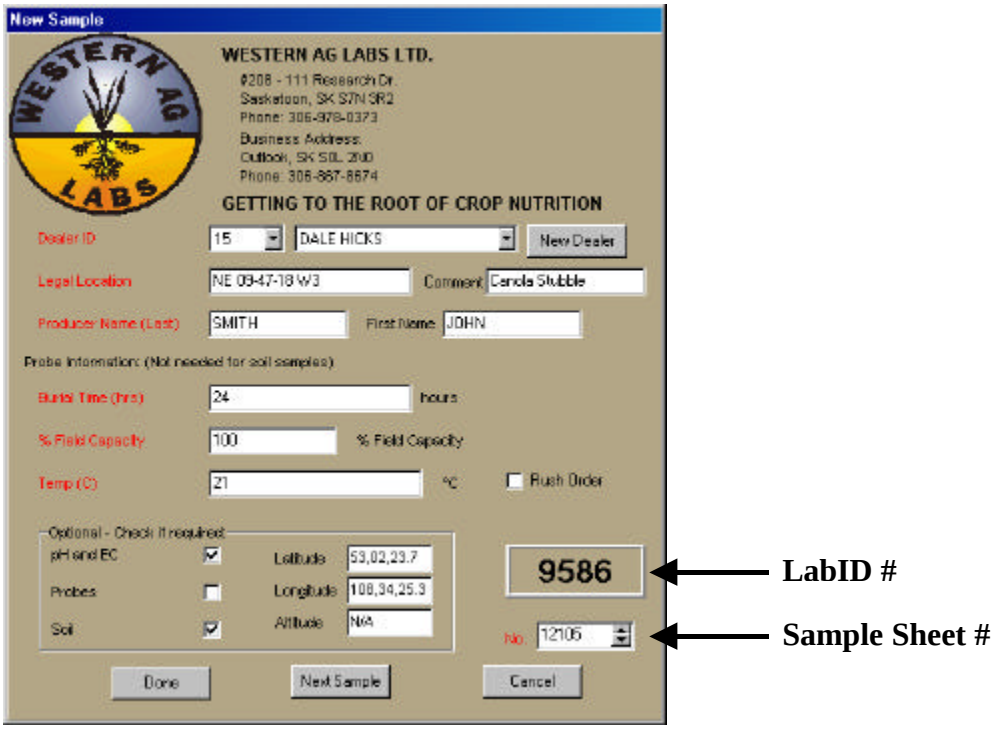

Figure 1. Lab Manager soil sample information input page.

When entering a batch of soil samples into the database, Lab Manager automatically assigns consecutive Lab Identification (LabID) numbers to each new sample; thus, preventing the same LabID from being assigned to two different samples. The LabID is a unique identifier used to track samples as they progress through all of the lab procedures. Finally, the original soil sample sheet number is entered, so that there is a correlation between the LabID numbering system, and the sample sheet numbering system used by the FSR. All of this information can be edited at a later date if necessary.

After a new batch of samples is received into Lab Manager, the user is prompted to print LabID labels and a pH/EC lab sheet for those samples for which these analyses were requested. If you decide not to print the LabID labels immediately, the background of the sample table for those particular samples remains red. Samples with a yellow background indicate that the LabID labels are printed and sample processing is underway. Ultimately, a green background appears when the sample data is posted to the WAL server. This background colour scheme is an intuitive means through which to keep track of the status of each sample throughout all lab procedures.

Soil Sample Preparation and PRS^{TM}-Probe Analysis

Complete reviews of the utility of the PRS^{TM}-probes and related ion-exchange membranes for studying soil nutrient dynamics have been reported elsewhere (Qian and Schoenau, 2002). The

PRS^{TM}-probes have provided the soil science research community with a convenient and valuable descriptive tool for nearly ten years (Schoenau et al., 1993). Therefore, justification for using the PRS^{TM}-probes to measure soil nutrient supply rates in this paper would be superfluous. However, considering the PRS^{TM}-probe methodology within a routine lab setting differs somewhat from its *in situ* research applications, a brief description of the lab protocols employed by WAL is warranted.

Prior to insertion of the PRS^{TM}-probes, soil samples are moistened to field capacity (FC) by spraying the soil sample with an adequate amount of deionized water and kneading the sample until it is of uniform consistency. This subjective determination of FC is based on the 'appearance and feel' technique traditionally used in the field. Depending on the soil moisture level of the sample when it is received, along with soil texture, the amount of water added to the sample and time needed to bring the entire soil sample to FC can range anywhere from two minutes for sandy soils to two days for heavy clay soils. However, the average length of time required to reach FC is approximately 10 minutes. This estimation of FC, although subjective, does not significantly affect the measured nutrient supply rates, because there is no difference in nutrient supply rates measured using the PRS^{TM}-probes in the range of 70 to 120 % FC for a variety of soil textures (Schoenau et al., 1993). Once the soil sample is brought to FC, four PRS^{TM}-probes (i.e., two cation- and two anion-exchange probes) are inserted. Before incubating the soil samples for 24 h, the soil sample bag is pressed firmly on each side to ensure good contact between the ion-exchange membranes and the soil.

Given WAL's commitment to quality assurance, a new sample wetting process currently is under development. A "wetting" table that is comprised of a micro-porous polyethylene material under a suction head, will allow many hundreds of soil samples to be uniformly wetted by wicking up water under matric suctions of greater than $^{1}/_{3}$ bar. A wetting table also will effectively remove technician subjectivity from the wetting process, thereby increasing wetting accuracy and precision among samples.

After removing the PRS^{TM}-probes from the soil, they are scrubbed and washed thoroughly with high-pressure deionized water. Methodically washing the PRS^{TM}-probes is critical, as even a minute quantity of residual soil on a PRS^{TM}-probe will significantly increase the nutrient supply rates above the true values. After the PRS^{TM}-probes have been washed thoroughly, they are eluted with 0.5 *N* HCl for 1 h and the eluate analysed for nutrient concentrations using automated colorimetry and inductively-coupled plasma spectrometry (ICP). Knowing the total volume of eluent used and the nutrient concentrations (i.e., µg/mL) in the eluate, the nutrient supply rates are calculated by Lab Manager and expressed in terms of the mass of nutrient ion per unit ion-exchange surface area over a 24 h burial period (i.e., µg 10 cm^{-2} 24 h^{-1}). This data then is processed through Lab Manager, posted to the WAL server, and used (together with additional soil and climatic information) in the PRS^{TM} Nutrient Forecaster software to develop a crop nutrition plan for the field in question.

After each use, the regeneration of the PRS^{TM}-probes involves a multi-step washing procedure including an HCl wash followed by three washes with $NaHCO_3$ for the cation- and anion-exchange PRS^{TM}-probes, plus an extra EDTA wash for the anion-exchange PRS^{TM}-probes. The HCl wash removes 95 % of the ions from the ion-exchange membrane, and also provides a

disinfecting cleaning. The $NaHCO_3$ wash removes additional ions, and recharges the cation-exchange membrane surfaces with Na^+, and the anion-exchange membrane surfaces with HCO_3^-. The final EDTA wash for the anion-exchange PRS^{TM}-probes will exchange a maximum of 30 % of the ion-exchange sites with EDTA. The EDTA acts as a chelating agent allowing the anion-exchange membrane to adsorb micronutrients, particularly, polyvalent metal cations such as Mn, Zn, Cu, and Pb. Full saturation of the anion-exchange membrane with EDTA is impossible given the size of the EDTA molecule and repulsive forces between them.

Quality Assurance Program

Now that the procedural flow of soil samples through WAL has been described, a discussion of the established QA program is necessary. An effective QA program allows for: the integrity of each sample to be maintained throughout the sample handling and analytical procedures; the comparability between samples (i.e., year after year); and, maintaining the confidence of FSR and customers in the data provided. As mentioned, fundamental to this QA program is the use of the Lab Manager software, which is essential for the administration of routine internal operations of WAL.

Lab Manager Utilities

Several Lab Manager functions can be accessed from the utility icon bar within the sample data table window (Figure 2). Most of these functions are self-explanatory, therefore, only the key operational Lab Manager functions will be discussed.

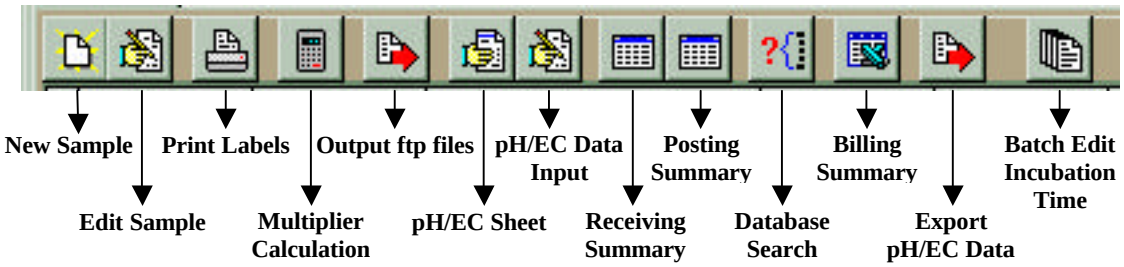

Figure 2. Lab Manager utility icons accessible from the sample data table window.

As mentioned, the soil nutrient supply rate data (i.e., µg nutrient 10 cm^{-2} 24 h^{-1}) measured using the PRS^{TM}-probes provide the basis for developing a crop nutrition plan using the PRS^{TM} Nutrient Forecaster. Consequently, it is imperative to assure the quality of the nutrient supply rate data. Therefore, any deviation from standard protocols affecting subsequent nutrient supply rate calculations by Lab Manager, require correction to the default settings using the *Multiplier Calculation* window (not shown). Occasionally, the ion-exchange membrane inside the PRS^{TM}-probe is damaged during insertion into a soil sample, resulting in a reduction of total adsorptive surface area. Given that nutrient supply rates measured using the PRS^{TM}-probe are expressed on a unit surface area basis, it is prudent to account for these losses during subsequent nutrient supply rate calculations. Similarly, corrections to the quantity of eluent used can be made in the

Multiplier Calculation window. When calculating a nutrient supply rate, Lab Manager incorporates both the volume of eluent used and the nutrient concentration within the eluate. Entering the appropriate eluent volume corrects for the relative dilution of ions in the eluate, thereby allowing for accurate calculations to be made. Adjustments to the number of PRS^{TM}-probes used during the 24 h incubation also can be made in the Multiplier Calculation window. For instance, to minimize the effects of micro-scale variability within a soil matrix, each soil sample is probed with two cation- and two anion-exchange PRS^{TM}-probes. However, if there is insufficient soil provided, only a single pair of PRS^{TM}-probes is used during the analysis, which needs to be corrected for prior to the nutrient supply rate calculations.

The PRS^{TM} Nutrient Forecaster requires that the PRS^{TM}-probe nutrient supply rate data be expressed over a 24 h period. If a batch of probed soil samples are incubated for a time other than 24 h, then the *Batch Edit Incubation Time* utility (not shown) is used to make the appropriate changes prior to the Lab Manager calculations.

Another important function of the Lab Manager is to ensure that the integrity of the sample data is preserved until it is posted to the appropriate FSR folder on the WAL server. When importing raw sample data from the autoanalyzer and ICP analyses into the database using the *Data Input and Verification* utility (not shown), the data remains in the digital domain, thereby preventing errors during manual data recording. Furthermore, Lab Manager automatically matches LabID numbers and imports the data into the correct sample row, thus, preventing a mix up of data between samples during data entry.

Quality Control Practices

The QA program also implements a series of *quality control* (QC) practices that assures data accuracy and precision. The QC practices involve the use of a *control check* sample every 10 samples (during eluate analysis) with known nutrient concentrations, for ensuring that the automated colorimetry and ICP analyses are acceptable. A *method blank* is run every 20 samples, which are clean cation- and anion-exchange PRS^{TM}-probes (which are washed, eluted, and analysed in the same manner as the routine soil sample PRS^{TM}-probes) for checking background nutrient levels. A *reagent blank* is run at the beginning of each sample set, which is a subsample of the stock 0.5 *N* HCl, which is analysed for possible contamination. Furthermore, the identical lot # of the acid is used for all analyses. A d*uplicate* sample (i.e., original soil sample is split into two distinct samples) is run every 20 samples to test the precision of the analytical preparation and instrumental measurement system, along with testing the precision of the PRS^{TM}-probes in measuring nutrient supply rates on the same sample. One of the samples is assigned the original LabID number, while the other is given a *LabLink* number, so that it is traceable back to its duplicate for subsequent comparison using Lab Manager. The duplicate samples are prepared and analysed in the same manner as the routine samples. Once per year, an *ion-exchange capacity check* is performed on 10 % of the PRS^{TM}-probe stock, and discarding any cation- or anion-exchange PRS^{TM}-probe having lost more than 15 % of its maximum ion-exchange capacity.

A recently initiated QC practice at WAL is to run a *standard reference soil* every 20 samples. A standard reference soil provides a more accurate evaluation of the level of precision (i.e., reproducibility) the PRS^{TM}-probes have in measuring soil nutrient supply rates. The standard reference soil is well-sorted, wind-deposited topsoil, sampled from along an old fence line. A tonne of this soil was collected, dried, ground, sieved, and thoroughly mixed. Only 55 of these standard reference soil samples have been run to date. However, despite this small sample number, the sample-to-sample variability is low (i.e., < 1 standard deviation for most nutrients) (Figure 3) and, therefore, should make an excellent contribution to the current QC practices. Considering the inherent variability within biological systems and micro-scale variability in a soil matrix, such variability is acceptable for a standard reference soil. Moreover, with increasing analyses of standard reference soil samples, this apparent variability in nutrient supply rates surely will decrease.

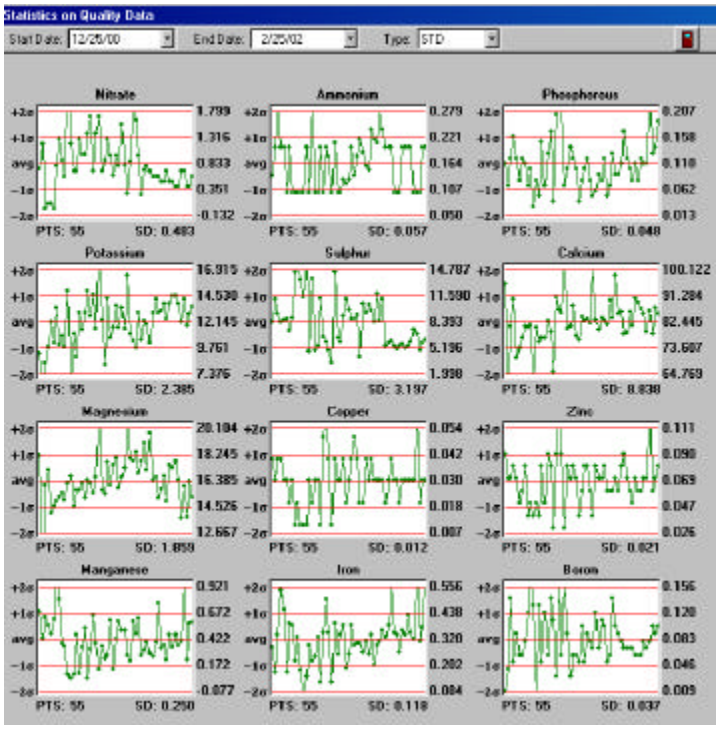

Figure 3. Descriptive statistics of selected nutrient concentrations (µg/mL) for the standard reference soil measured using PRS^{TM}-probes. *Note:* multiply by 20 to convert data to µg nutrient 10 cm^{-2} 24 h^{-1}.

Range of Nutrient Supply Rates Measured Using PRS^{TM}-Probes

As mentioned, the nutrient supply rate data measured using the PRS^{TM}-probes provide the basis for developing a crop nutrition plan using the PRS^{TM} Nutrient Forecaster. Therefore, it is imperative that the method detection limit of the PRS^{TM}-probe methodology be below the sensitive range or *threshold nutrient supply rate*, where relevant fertilizer recommendations are made by the PRS^{TM} Nutrient Forecaster. Historical ranges of selected nutrient supply rates measured using the PRS^{TM}-probes are presented in Figure 4. The *critical nutrient supply rate* for

a growing crop clearly depends on the specific nutrient involved, the crop being grown, and the growing season climatic conditions. However, based on a 40-bu/ac-wheat crop as a reference, the nutrient supply rate where the PRS^{TM} Nutrient Forecaster will predict a crop response to the added fertilizer (i.e., threshold nutrient supply rate) is much larger than the method detection limit for most nutrients (Figure 3). The important fertilizer decisions made by the PRS^{TM} Nutrient Forecaster, therefore, are based on nutrient supply rate data measured within a sensitive analytical range. Consequently, the accuracy and precision of the PRS^{TM}-probe nutrient supply rate data provide a legitimate basis for developing a crop nutrition plan using the PRS^{TM} Nutrient Forecaster. The validity of the PRS^{TM} technology is evidenced by an exceptional track record of *back-casting*, which involves using the PRS^{TM} Nutrient Forecaster *a posteriori*, given the growing season climatic conditions, to predict crop yield. In fact, historically, when back-casting a field, a FSR can predict crop yield to within 10 %, over 95 % of the time.

Copper appears to be the only nutrient element that may pose a problem in accurately predicting fertilizer recommendations, because the threshold copper supply rate overlaps the method detection limit (Figure 3). However, a general lack of knowledge as to the shape of the fertilizer response curves for micronutrients preclude an exact forecast of fertilizer requirements anyway.

Despite the abundance of available literature concerning the utility of the PRS^{TM}-probes, the efficacy of the PRS^{TM} technology ultimately is validated by subsequent customer satisfaction (i.e., **http://www.producer.com/articles/20010517/production/20010517prod01.html**). This effective alternative for routine soil testing provides the basis for crop nutrition planning that supersedes the need for costly calibration field trials, which have an inference space possessing both geographical and temporal limitations over which they effectively can be applied.

Conclusion

Numerous research studies have detailed the utility and sensitivity of the PRS^{TM}-probes for monitoring soil nutrient supply *in situ*. Over the past 10 years, the use of PRS^{TM}- probes has advanced from strictly a soil science research tool into an effective alternative for routine soil testing. This detailed description of the lab protocols and QA program employed by WAL clearly shows that the PRS^{TM}-probes have evolved into a legitimate routine soil testing tool. Since the establishment of WAL in 1998, the number of acres that are fertilized based on recommendations developed using the PRS^{TM} technology have increased steadily. As the PRS^{TM} technology gains credence as an effective tool for crop nutrition planning, the number of soil samples coming through WAL will continue to increase. ***Notwithstanding past empirical achievements with the PRS^{TM}-probes, ultimately it is up to the customers validating the PRS^{TM} technology each year who determine the success of this soil testing alternative***.

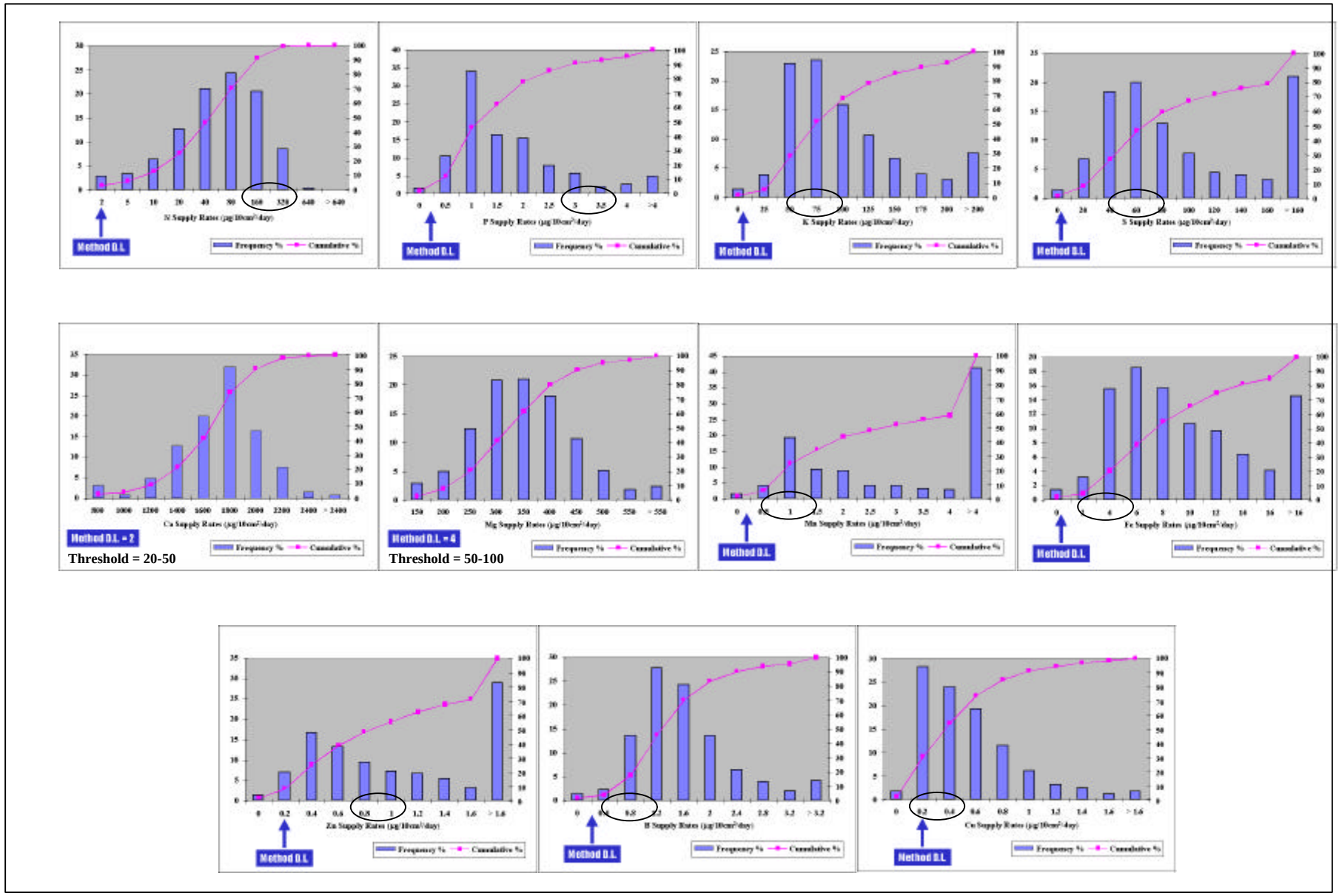

Figure 4. Selected nutrient supply rates, method detection limits, and threshold nutrient supply rates (circles) measured using PRS^{TM}-probes.

References

Barber, S.A. 1984. Soil Nutrient Bioavailability. Wiley. New York.

Barber, S.A. 1998. Chemistry of Soil-Nutrient Interactions and Future Agricultural Sustainability. *In* Future Prospects for Soil Chemistry. SSSA Special Publication no. 55. Madison, WI, USA.

Green, B., Flaten, P., and Routledge, P. 2000. The Beginning of a New Generation of Soil and Plant Analysis Recommendation Software. *In* Proceedings of Soils and Crops Workshop 2000, University of Saskatchewan, Saskatoon, SK.

Jones, J., and Kalra, Y.P. 1992. Soil testing and plant analysis activities-the United States and Canada. Commun. Soil Sci. Plant Anal. 23: 2015-2027.

Karamanos, R. E. 2001. Virtual Soil Testing^{TM}. Is it Possible? *In* Program and Abstracts. (*eds*.) Y.P. Kalra, J.A. Crumbaugh, and I.K. Edwards. 7th International Symposium on Soil and Plant Analysis. July 21-27, 2001. Edmonton, AB, Canada.

Karamanos, R. E., and Henry, J.L. 1991. Criteria for Targeting Yields in Saskatchewan. *In* Proceedings of Soils and Crops Workshop 1991, University of Saskatchewan, Saskatoon, SK.

Schoenau, J.J., Qian, P., and Huang, W.Z. 1993. Ion Exchange Resin Strips as Plant Root Simulators. *In* Proceedings of Soils and Crops Workshop 1993, University of Saskatchewan, Saskatoon, SK.

Qian, P., and Schoenau, J.J. 2002. Practical application of ion exchange resins in agricultural and environmental soil research. Can. J. Soil Sci. 82: (in press).