Soil Nutrient Supply Rates as an Indicator of Site Suitability and Seedling Growth Requirements

R.D. Hangs[1], K.J. Greer[1], K.C.J. Van Rees[2]

[1]Western Ag Innovations, 3 - 411 Downey Road, Saskatoon, SK S7N 4L8, Canada
[2]Department of Soil Science, University of Saskatchewan, Saskatoon, SK S7N 5A2, Canada

Introduction

There is a stigma attached to conventional soil testing methodologies within the forest industry and for good reason; the nutrient availability data provided are poorly correlated with seedling nutrient uptake and growth during the early establishment phase (Pritchett and Fisher 1987). A single ‘point-in-time’ extraction only represents a *snapshot* of readily available soil nutrients and, therefore, may not adequately reflect the soil nutrient supply throughout the growing season (Stark and Hart 1997, Driscoll et al. 1999). Conversely, an index of soil *N supplying power* is biologically more meaningful, because it integrates all of the factors affecting nutrient availability over time (Pritchett and Fisher 1987). Unlike conventional soil extractions, *in situ* burials of ion-exchange membrane (IEM) integrate all of the principal edaphic factors affecting nutrient uptake by plants (i.e., soil moisture and temperature, mineralization and immobilization, buffer power, dissolution, ion diffusion from greater distances, free ion activities, etc.) regardless of soil type (Qian and Schoenau 2002). Consequently, IEM are an effective surrogate for *bio-mimicking* nutrient absorption by plant roots as they remove soil nutrients through ion-exchange; therefore, providing the most reliable index of nutrient bioavailability (Yang et al. 1991, Qian et al. 1992, van Raij 1998). The objective of this study then was to measure nutrient supply rates at several hybrid poplar plantations in northern Saskatchewan, using *in situ* burials of IEM, and then relate these data to plantation productivity during the early establishment phase.

Materials and Methods

Study sites

The data for this study were collected from four hybrid poplar plantations in northern Saskatchewan. Two sites are located approximately 25 km southwest of Meadow Lake, Saskatchewan (Cubbon: NW 22 58 19 W3; Culbert: SW 31 57 19 W3). The other two sites are located near Star City and Arborfield (NW 36 45 17 W2 and NE 4 46 12 W2, respectively). Although the topography of all sites is very gently undulating (i.e., slopes less than two percent), the soil and site characteristics are diverse (Table 1). This site diversity is advantageous in that it allows for a greater inference space in terms of providing accurate fertilizer recommendations based on the measured relationship between nutrient supply rates and early growth of hybrid poplar seedlings at each site. All sites underwent mechanical and chemical site preparation prior to planting and throughout each growing season (Table 1).

Experimental design

At the two Meadow Lake sites, the experimental design is a 3 x 2 x 2 factorial, randomized complete block and replicated three times. The treatments include: stock type (cuttings, rooted cuttings, and container seedlings), pruning (pruned lower branches and unpruned), and N fertilization split-plots (0 and 100 kg N/ha). For the fertilization treatment, half of the treatment plots within each block were control plots and the others designated fertilizer plots. Within the fertilizer plots, each plot was split in half (i.e., split-plot design) with one half receiving a broadcast application of NH_4NO_3 fertilizer (100 kg N/ha) on June 4, 2003 (year two of the plantation), while the remaining half will receive a similar application in June, 2005 (year four of the plantation). The remaining two sites had no imposed treatments, but instead were simply clonal studies set-up in a randomized complete block design (12 and 18 different hybrid poplar clones planted at the Star City and Arborfield sites, respectively) and replicated three times. The Meadow Lake and Star City sites were established in the spring of 2002, while the Arborfield site was planted in June 2003.

Soil nutrient analysis

Plant Root Simulator™-probes (Western Ag Innovations Inc., Saskatoon, SK) were used to measure soil nutrient availability at each site. Plant Root Simulator™-probes provide a basis for determining fertilizer recommendations for different cereal, oil seed, pulse, and forage crops in western Canada (Qian and Schoenau 2002) and have been used to study forest soil nutrient dynamics in both undisturbed and disturbed sites (Huang and Schoenau 1996,1997; Johnson et al. 2001; Duarte 2002; Hangs et al. 2004). The PRS™-probe consists of either cation- or anion-exchange resin membrane

Table 1. *Selected characteristics of four hybrid poplar study sites located in northern Saskatchewan.*

Site	Soil Characteristics				Site Characteristics				Vegetation Management Practices			
									Pre-planting		Post-planting	
	Association	Soil Type	Texture	PH	EC (mS/cm)	Prior Crop	ACC*	Rainfall† (mm)	Mechanical	Chemical	Mechanical	Chemical
Cubbon‡	Loon River	Orthic Gray Luvisol	sandy-loam to loam	6.5	0.8	alfalfa	3-4	190	- Deep till - Light cultivation	- Glyphosate (2.5 L/ha) - Linuron (4 kg/ha)	-Tandem disc -Mowing	- Glyphosate (2.5 L/ha) - Linuron (4 kg/ha)
Culbert‡	Bittern Lake	Brunisolic Gray Luvisol	sandy-loam to loam	5.4	0.7	pasture	4-5	190	Deep till (x2)	- Glyphosate (2.5 L/ha) - Linuron (4 kg/ha)	Tandem disc	- Glyphosate (2.5 L/ha) - Linuron (4 kg/ha)
Star City§	Melfort-Hoey	Orthic Black Chernozem	clay-loam to loam	5.1	0.8	canola	1-2	250	Tandem disc (x 2)	- Treflan (5 L/ha) - Sencor (395 g/ha)	-Tandem disc -Mowing	- Glyphosate (2.5 L/ha) - Linuron (4 kg/ha)
Arborfield¶	Eldersley	Orthic Gray Luvisol	clay-loam to loam	6.3	0.6	wheat	1-2	350	Tandem disc (x 2)	- Treflan (5 L/ha) - Sencor (395 g/ha)	-Tandem disc -Mowing	- Glyphosate (2.5 L/ha) - Linuron (4 kg/ha)

* Agriculture capability classification (Class 1: no significant limitations; Class 2: moderate limitations; Class 3: moderately severe limitations; Class 4: severe limitations; Class 5: very severe limitations).
† During the period of PRS™-probe burials.
‡ For a complete description (i.e., map unit, parent material, stoniness, drainage, etc.) see SCSR (1995).
§ For a complete description see SCSR (1989).
¶ For a complete description see Stonehouse and Ellis (1983).

encased in a plastic holding device and is inserted into soil to measure nutrient supply rates *in situ* with minimal disturbance (Fig. 1). At the Meadow Lake sites, four pairs of PRS™-probes (i.e., four cation- and four anion-exchange) were installed within each treatment plot, for a total of 288 PRS™-probes (12 treatment plots x 3 reps x 4 PRS™-probes x 2 types) per burial period at each site. At the other two sites, two pairs of PRS™-probes were installed within each clone plot, for a total of 144 (12 clone plots x 3 reps x 2 PRS™-probes x 2 types) and 216 (18 clone plots x 3 reps x 2 PRS™-probes x 2 types) PRS™-probes per burial period at the Star City and Arborfield sites, respectively. The PRS™-probes were inserted vertically into the Ap horizon (Fig. 2); thereby having the ion-exchange membrane effectively measure soil nutrient supply rates in the zone having the largest concentration of hybrid poplar roots (Block, 2004). The PRS™-probes were left in the soil for five weeks and then replaced with fresh PRS™-probes twice more during the growing season for a total of 15 weeks. Replacing fresh PRS™-probes in the same soil slot provides a true *in situ* measure of temporal nutrient availability and yields the most accurate index of nutrient availability to correlate with seedling growth. Consequently, continuously measuring soil solution nutrient availability should provide a basis for accurately predicting nutrient supply-limited uptake or growth, because it is an integral part of the mechanisms governing nutrient supply and uptake (Lajtha et al. 1999, Smethurst 2000).

The PRS™-probes within each treatment plot were combined for analysis, much like a composite soil sample, and this helped to account for any microscale variability. After removal, the PRS™-probes were washed free of soil and then thoroughly scrubbed and re-washed back in the lab prior to the analysis to ensure complete removal of any residual soil. Inorganic N as ammonium (NH_4^+-N) and nitrate (NO_3^--N) was determined colourimetrically and the remaining nutrients (P, K, S, Ca, Mg, Cu, Zn, Mn, Al, Fe, B, and Pb) measured using inductively-coupled plasma spectrometry. Unused PRS™-probe method blanks also were analysed to test for contamination during the regeneration and handling steps.

Seedling survival and growth

At the end of the growing season, seedling establishment and growth were assessed at each site by measuring seedling survival, ground-line diameter (GLD), and height. Determining the relationship between soil nutrient supply rate at both time of planting and throughout each growing season and subsequent seedling growth should help support effective management strategies, in terms of proper site selection and effectively managing fertilizer requirements.

Statistical analyses

The soil nutrient availability and seedling growth data were analysed independently by site using the GLM procedure in SAS (Version 8.0, SAS Institute Inc. Cary, NC). Mean comparisons were performed using least significant differences (LSD) at a significance level of 0.05. The LSD option was used to carry out pair-wise *t* tests (equivalent to Fisher's protected LSD) of the different means between treatments and clones. All data were tested for homogeneity of variances and normality. Simple linear regressions were performed using the

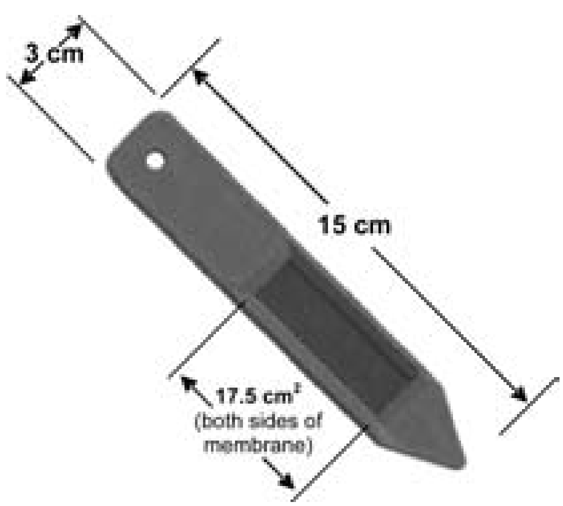

Figure 1. *Dimensions of a PRS™-probe.*

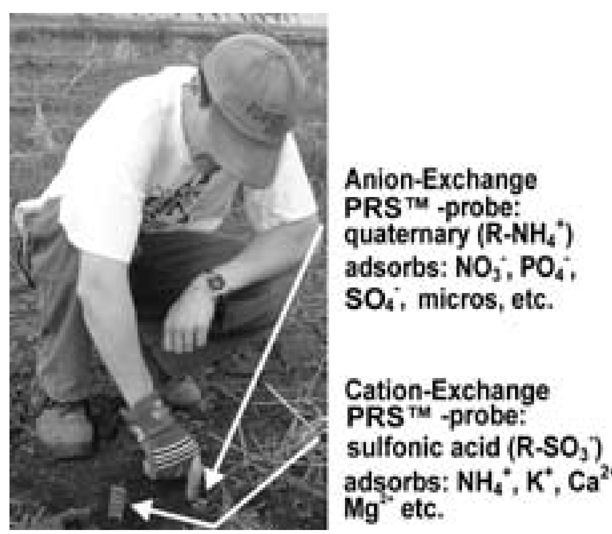

Figure 2. *PRS™-probes used to measure soil nutrient availability in situ.*

REG procedure in SAS (Version 8.0, SAS Institute Inc. Cary, NC) using pooled data (i.e., all sites) to quantify the relationship between the nutrient supply rate data during the growing season and growth of hybrid poplar seedlings over that same period. Residuals from the analyses were examined to the test the assumptions of equal variance and no data transformations were necessary.

Results and Discussion

Nutrient availability among sites

Within each site, there was relatively low variability in nutrient supply rate for most nutrients (i.e., CV < 20%; data not shown), which is not surprising considering that agricultural soils historically have less microscale variability compared with forest soils (Pritchett and Fisher, 1987). For all sites in this study, NO_3^--N was the predominant inorganic N source available for seedling uptake (Table 2), and is expected considering that NH_4^+-N often is rapidly nitrified in agricultural soils (Brady, 1990). The total N supply rates (i.e., NH_4^+-N + NO_3^--N) varied among the sites with Star City having the largest values. The Chernozemic soils at the Star City site clearly have greater N fertility compared with the Luvisols of the other sites, of which the Culbert soils had the smallest total N supply rate. The smallest supply rate at Culbert is probably attributable in part to increased N immobilization that is common to recently broken pasture having a wide C:N (Ellert and Gregorich, 1996; Kristensen et al., 2000; Parfitt et al., 2003). Of the Luvisols, the Cubbon site had the largest total N supply rates (Table 2) and this is due to the prolonged alfalfa production on this site, which resulted in significant N-fixation in these soils.

In terms of the remaining macro- and micronutrients, there was a wide range in supply rates among the four sites in this study (Table 2) and this can be attributed to a number of factors, including differences in past management practices (i.e., crop, fertilization, site preparation technique, etc.), soil type, and growing season conditions. Such variability in nutrient variability among these different sites is essential, for subsequently relating them to seedling growth, if accurate recommendations are to be made across a large inference space. Of particular interest though, is the extremely large manganese supply rate measured at the Cubbon site compared with the other sites (Table 2). One possible mechanism for this could have been the mixing of the acidic subsoil with the calcareous topsoil, during the deep tillage of this site prior to planting, which would have lowered the soil pH and increased manganese availability. Typically, with decreased soil pH and increased manganese availability, there is a concomitant decrease in magnesium availability (Havlin et al., 1999), and was measured using PRS™-probes (Table 2). In addition, while in sustained forage production this field had a balanced fertility package applied annually with both macro and micronutrients, including Mn (Dave Cubbon, personal communication), which also helps to explain the larger Mn supply rates at the Cubbon site.

Nutrient availability following fertilizer N treatment

At both Meadow Lake sites, the addition of fertilizer N resulted in increased NH_4^+-N, NO_3^--N, and total N supply rates, relative to plots having no fertilizer N added, with no marked effect on the supply rates of other nutrients (Table 3). Specifically, following fertilizer N addition, there was increased NH_4^+-N availability from June to July at both the Cubbon and Culbert sites relative to the plots without

Table 2. *Mean cumulative nutrient supply rates, measured using in situ burials of PRS™-probes, at four hybrid poplar sites from early June to late August 2003*.*

Site	n	NH_4^+	NO_3^-	Total N	P	K	S	Ca	Mg	Cu	Zn	Mn	Al	Fe	B	Pb
		µg/10cm²/12 weeks														
Cubbon	18	6b†	813b	819b	9.7a	281a	129b	3735a	367d	<mdl‡	3.0a	109.9a	52.5a	23.6b	1.0b	0.2a
Culbert	18	10a	568d	578d	3.4b	260a	81c	3393b	611c	0.5a	1.9c	10.7b	43.3b	44.4a	2.9a	0.5a
Star City	54	6b	1153a	1159a	1.7c	125b	140ab	2956b	1275a	0.5a	2.6b	11.4b	31.3c	43.5a	1.1b	0.5a
Arborfield	54	4c	651c	656c	1.8c	52c	174a	3847a	798b	0.5a	1.7c	6.5b	27.3c	35.8a	0.7c	0.7a

* Arborfield site planted early June, so for comparison purposes only June to August data is shown.
† Means within a column followed by the same letter are not significantly different (P >0.05) using LSD.
‡ Method detection limit (0.1 µg/10cm2/12 weeks).

fertilizer N applied (Fig. 3). Subsequent nitrification of this NH_4^+-N resulted in a corresponding pulse of soil NO_3^--N from July to August. This measured increase in soil N supply rate following a single fertilizer application, together with the ability to quantify the nitrification of added fertilizer NH_4^+-N to NO_3^--N, demonstrates the sensitivity of the PRS™-probes to measure treatment effects and their efficacy in determining soil nutrient availability. Unlike the Cubbon site, the plots without fertilizer N at the Culbert site had a marked increase in NH_4^+-N supply rate as the season progressed, and can be attributed to the effect of tillage on increased N mineralization in this former pasture soil.

The added fertilizer N had minimal effects on the supply rates of most other nutrients, with the exception of potassium, calcium, manganese, and aluminium at Cubbon and sulphur at Culbert (Table 3). Specifically, the increased NH_4^+-N levels at Cubbon acted to displace the interlayer potassium within the clay minerals, thereby increasing the potassium in soil solution and availability for plant uptake. Furthermore, the increased availability of calcium, manganese and aluminium can be attributed to the net decrease in soil pH following the nitrification of the NH_4^+-N in soil. At Culbert, the decreased sulphur supply rate in fertilized plots at Culbert probably is due to microbial immobilization, in order to maintain an N:S required for their metabolic processes, as N immobilization increased at that site throughout the year. This immobilization-induced decrease in NO_3^--N supply rate as the season progressed is apparent when comparing the Culbert NO_3^--N data with Cubbon, where sustained alfalfa production prior to plantation establishment resulted in larger NO_3^--N pools that remained relatively consistent throughout the growing season (Fig. 3). The measured residual soil N supply rate following a single fertilizer application and its effect on the availability of other nutrients, together with the ability to quantify the nitrification of added fertilizer NH_4^+-N to NO_3^--N, demonstrates the sensitivity of the PRS™-probes to measure treatment effects and efficacy in measuring soil nutrient availability.

Relationship between soil nutrient availability and hybrid poplar seedling growth

Across all sites, the total N supply rate often was better correlated with seedling height, GLD, and stem volume growth than other nutrients (data not shown). In addition, the total N supply rate had a stronger correlation (R^2 0.54 to 0.98, P <0.01) with seedling growth when calculated on an individual treatment combination basis instead of using pooled data including more than one stock type, pruning method, fertilizer rate, and clone. This is not surprising considering that each treatment has a varied influence on seedling growth rate and form, cold hardiness, mortality, etc. and adds considerable variability to the seedling growth data and, therefore, weakens the resultant correlation with the PRS™-probe nutrient supply rate data. Indeed, such variability is not representative of typical operational practices. Consequently, Fig. 4 illustrates the strong relationship between total N supply rate measured over the 2003 growing season and the stem volume growth increment (believed to be the most accurate indicator of overall seedling vigour and growth) of outplanted seedlings each year from a single hybrid poplar clone (var. Walker), planted as rooted cuttings with no fertilizer N applied and ranging in age from 1 to 2 years depending on the site.

Table 3. *Mean (n=18) cumulative nutrient supply rates, measured using in situ burials of PRS™-probes, at two Meadow Lake hybrid poplar sites from early May to late August 2003 in plots with and without fertilizer N application.*

		NH_4^+	NO_3^-	Total N	P	K	S	Ca	Mg	Cu	Zn	Mn	Al	Fe	B	Pb
Site	Treatment	µg/10cm²/15 weeks														
Cubbon	Fertilizer*	58a†	1396a	1455a	26.9a	957a	158a	3966a	420a	0.5a	5.0a	386.7a	80.2a	78.7a	2.6a	0.4a
	No Fertilizer	33b	972b	1004b	25.4a	638b	189a	3651b	416a	0.5a	4.0a	192.5b	68.8b	77.6a	3.2a	0.4a
Culbert	Fertilizer	26a	717a	742a	11.9a	746a	50b	3704a	611a	0.6a	4.0a	32.8a	40.2a	46.1a	3.6a	0.5a
	No Fertilizer	30a	489b	519b	10.0a	656a	68a	3740a	666a	0.6a	3.9a	25.7a	38.5a	47.0a	4.0a	0.5a

* 100 kg/ha NH4NO3 fertilizer broadcast applied on June 4, 2003.
† For each site, means within a column followed by the same letter are not significantly different (P >0.05) using LSD.

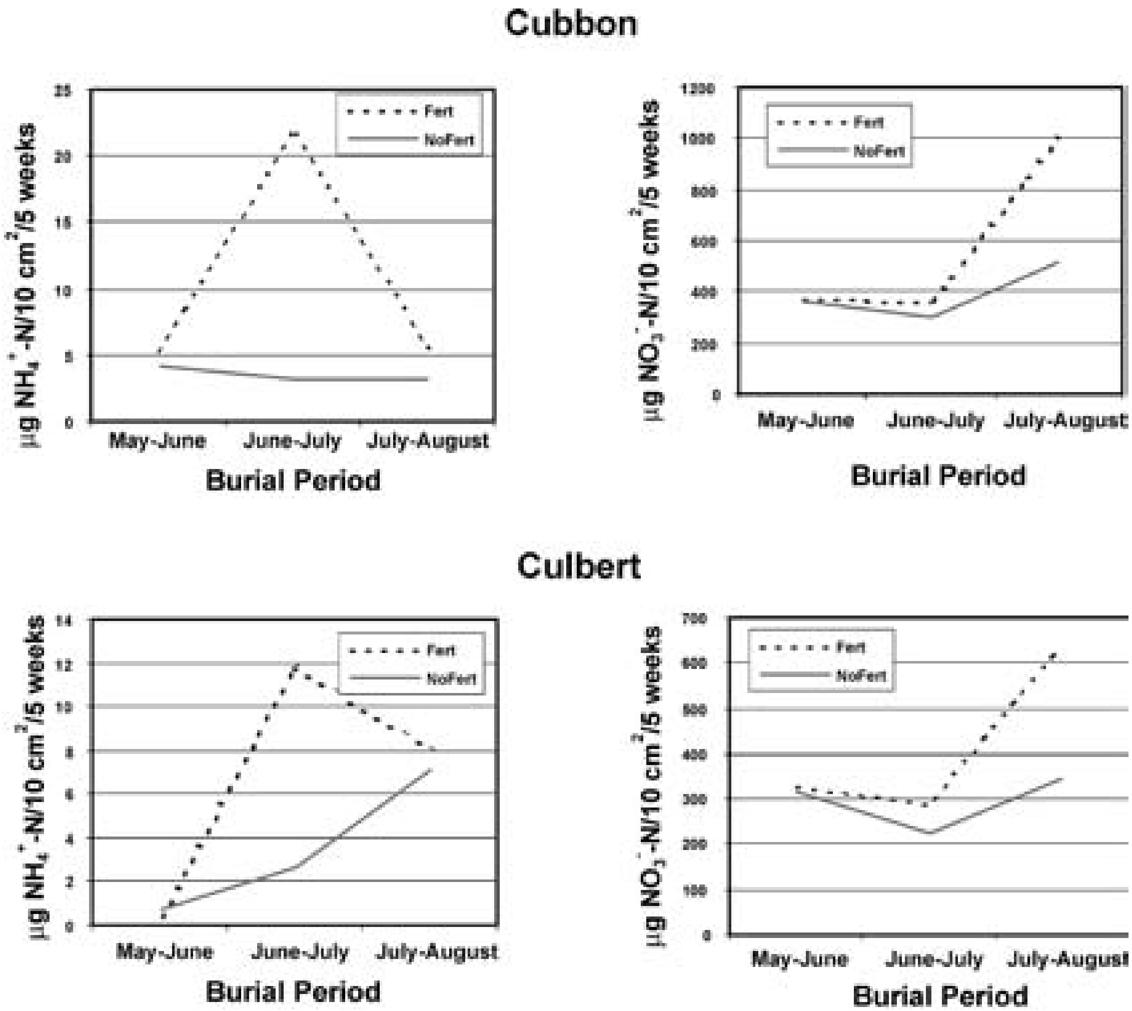

Figure 3. *Mean (n=18) NH_4^+-N and NO_3^--N supply rates, measured using in situ burials of PRS™-probes, in 2003 at two Meadow Lake hybrid poplar sites in plots with (Fert) and without (NoFert) broadcasted NH_4NO_3 fertilizer (100 kg/ha) on June 4, 2003. For each burial period, means having the same letter are not significantly different (P >0.05) using LSD.*

Mechanistic models that predict the early growth of outplanted seedlings not only require accurate estimates of soil N supply throughout the growing season (Kelly and Mays 1999), but more importantly, a biologically meaningful index of N availability that is correlated with outplanted seedling N uptake and growth. Notwithstanding the relatively good correlation between soil N availability measured using the PRS™-probes and the early growth of hybrid poplar seedlings, frankly speaking the R^2-values were smaller than expected, considering the strong correlations with plant uptake and growth often reported (Qian and Schoenau 2002, Hangs et al. 2004). The relatively dry conditions at each site certainly would have contributed to the weaker than expected relationship, because presumably soil moisture would have been a factor limiting seedling growth. Also, it is plausible that other nutrient limitations, such as phosphorus at the Meadow lake sites, may have limited seedling growth to a certain degree (Van Rees, unpublished data). Considering Western Ag Labs' historic *critical nutrient supply rate* levels for growing annual crops in Saskatchewan (data not shown), phosphorus would be considered insufficient for growing an annual crop. Although the differences in nutrient requirements of hybrid poplar compared with an annual crop are undefined at this time, this illustrates the importance of a balanced approach to soil fertility assessments (i.e., complete crop nutrition plan and, therefore, not simply N) and

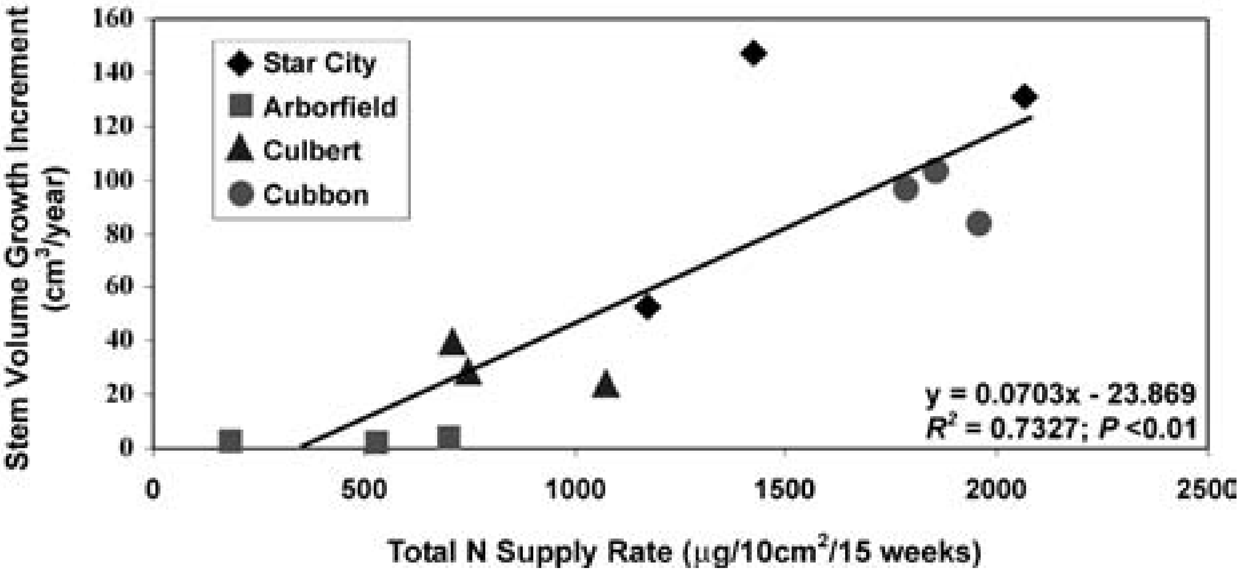

Figure 4. *Relationship between total N supply rate, measured using in situ burials of PRS™-probes, and hybrid poplar (var. Walker) seedling stem volume growth increment. Each data point is a mean of either 9 (Arborfield) or 25 (Star City, Cubbon, and Culbert) seedli□*
the site.

amendments prior to planting hybrid poplar seedlings and throughout the early establishment phase.

Conclusion

The results of this study support the assertion that *in situ* burials of IEM provide biologically meaningful data and, therefore, are a very useful tool for measuring nutrient availability in hybrid poplar plantations during the early establishment phase. Specifically, the PRS™-probes were sensitive enough to measure differences in soil nutrient supply rates among sites differing in past management practices, soil types, and climatic conditions. In addition, they were capable of quantifying differences in N supply rate following fertilizer N addition and the temporal changes in NH_4^+-N and NO_3^--N supply rates throughout the growing. And finally, but most importantly, their data is strongly correlated with seedling growth. Further research is needed to determine the threshold soil nutrient supply rates for different hybrid poplar clones during the early establishment phase. Determining the relationship between soil nutrient supply rates and seedling growth should help to support effective management strategies, in terms of proper site selection and the elucidation of possible fertilizer requirements.

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