The Effect of Repeated Liquid Swine Manure Applications on Soil Nutrient Supply Rates and Growth of Different Hybrid Poplar Clones

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Key Words: hybrid poplar, manure application, Plant Root Simulator™-probes, soil testing

Abstract

Intensive hog operations generate large amounts of manure that must be dealt with in an environmentally responsible and economically practical manner. Repeated applications of liquid swine manure within nearby hybrid poplar plantations recently has been proposed as an effective alternative manure management practice, given that these fast-growing tree species have high soil moisture and nutrient demands and, therefore, represent a tremendous sink for the applied effluent. The objectives of this two-year study were to: i) evaluate the effect of repeated broadcast applications of liquid swine manure on soil nutrient supply rates and growth of five hybrid poplar clones (CanAm, Hill, Katepwa, Walker, and WT-66V) and, ii) assess the relationship between growing season soil nutrient supply rates, measured using *in situ* burials of ion-exchange membrane (Plant Root Simulator™-probes), and growth of different hybrid poplar clones. There was a limited effect of applied hog effluent on soil nutrient supply rates after the first year and hybrid poplar growth after two years, which is surprising considering the application rate was three times larger than the agronomic rate typically applied. The limited measureable difference following manure addition may be attributable to a number of factors, including: substantial volatilization, microbial immobilization, increased leaching and denitrification losses, timing of manure application being out of sync with temporal nature of nutrient uptake by the trees, and a delayed growth response as absorbed nutrients are retranslocated within the trees. Determining the effects of repeated applications of hog effluent on soil nutrient supply rates and subsequent tree growth should help to support effective management strategies, in terms of developing practical effluent management practices required to mitigate any adverse environmental effects, but also increasing plantation productivity and the concomitant non-wood product benefit of increasing biodiversity within the agricultural landscape.

Introduction

As the world population continues to increase exponentially, the need for a reliable and sustainable source of energy is becoming progressively more important. In addition, given the volatility of oil supply and environmental issues concomitant with petroleum-based energy, it is readily apparent that an alternative renewable clean energy source is needed to meet future demands. Currently, the use of biomass-derived energy accounts for approximately 10% of the global energy requirement (Berndes et al. 2003), however, with growing desire worldwide for a secure and environmentally-friendly energy source, there is increased interest in developing biomass production systems for use as a dedicated or 'purpose-grown' feedstock for bioenergy production. Canada is no exception, with its high per capita energy consumption and the majority of its energy demand used for transportation and building utilities (Cuddihy et al., 2005), Natural Resources Canada along with a number of Canadian provinces consider bioenergy to be a legitimate and sustainable source of energy that will constitute a significant portion of future energy production. In particular, the previous Saskatchewan government has committed to deriving one-third of its electricity from renewable energy sources by 2030 and short-rotation intensive culture (SRIC) plantations will play a key role in meeting these targets. Consequently, in 2005 the provincial government proposed an ambitious 1.6 million-hectare (i.e., 10 per cent of the province's arable land) afforestation initiative, with the intention of addressing not only the expected increased demand for woody biomass as differential markets develop, but also to mitigate the increasingly precarious agricultural sector within the province. The establishment of SRIC plantations, such as fast-growing hybrid poplar, therefore, represents a legitimate option for diversifying farmers trying to maintain an economically viable operation in the face of historically decreasing commodity prices, along with increasing input and transportation costs, especially in the northern regions where annual crops are grown on marginal agricultural soils. Complimentary to this would be the utilization of these SRIC plantations to assist nearby intensive livestock operations with manure management, not only from a logistical perspective in terms of dealing with the large amounts of manure produced, but more importantly from an environmental perspective by preventing contamination of groundwater (due to leaching) or surface water (due to runoff), along with mitigating the release of deleterious greenhouse gases, such as CH_4 and N_2O. The objectives of this two-year study, therefore, were to: i) evaluate the effect of repeated broadcast applications of liquid swine manure on soil nutrient supply rates and growth of different juvenile hybrid poplar clones, and ii) assess the relationship between growing season soil nutrient supply rates, measured using *in situ* burials of ion-exchange membrane (Plant Root Simulator (PRS)™-probes; Western Ag Innovations Inc., Saskatoon, SK) and growth of hybrid poplar. Determining the effects of repeated hog effluent applications on soil nutrient availability and subsequent hybrid poplar growth should help to support practical effluent management practices, but also increasing plantation productivity and associated biodiversity within the agricultural landscape.

Materials and Methods

Study site

The data for this study were collected from a hybrid poplar plantation established by AAFC-PFRA adjacent to the Pasquia Pork Producers commercial hog facility, located near Arborfield (NE 4 46 12 W2). The topography of the site is very gently undulating (i.e., slopes less than two percent) and the soil and site characteristics are reported in Table 1.

Experimental design

The experiment is a randomized complete block design, including five hybrid poplar clones (CanAm, Hill, Katepwa, Walker, and WT-66V), and replicated three times (Figure 1). Two years prior to manure application, the hybrid poplar clones were planted using a spacing of 2.0 x 6.5 m, to facilitate the accessibility of the manure application equipment. Liquid hog manure was applied during the third growing season on June 25 (i.e., Year 1) and again the following year on July 19 (i.e., Year 2), with an even 3 m spread (from the centre line of the tree row) at a rate of 14,000 L/ha, which is approximately three times the recommended agronomic rate. The manure was applied on both sides of each row resulting in a 6 m band of broadcasted manure (Figure 2). The height and stem diameter at breast height of the central 20 trees from the clonal plots, with and without manure application, were measured at the end of each growing season.

Table 1. Selected Characteristics of the study site located near Arborfield, Saskatchewan.

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
Eldersley	Orthic Gray Luvisol	clay-loam to loam	6.3	0.6	wheat	2	496 (Year 1) 393 (Year 2)	Tandem disc (x 2)	- Treflan (5 L/ha) - Sencor (395 g/ha)	-Tandem disc -Mowing	- Glyphosate (2.5 L/ha) - Linuron (4 kg/ha)

* For a complete description (i.e., map unit, parent material, stoniness, drainage, etc.) see Stonehouse and Ellis (1983).
† Agriculture capability classification (Class 2: moderate limitations due to poor soil drainage issues).
‡ During the period of PRS™-probe burials.

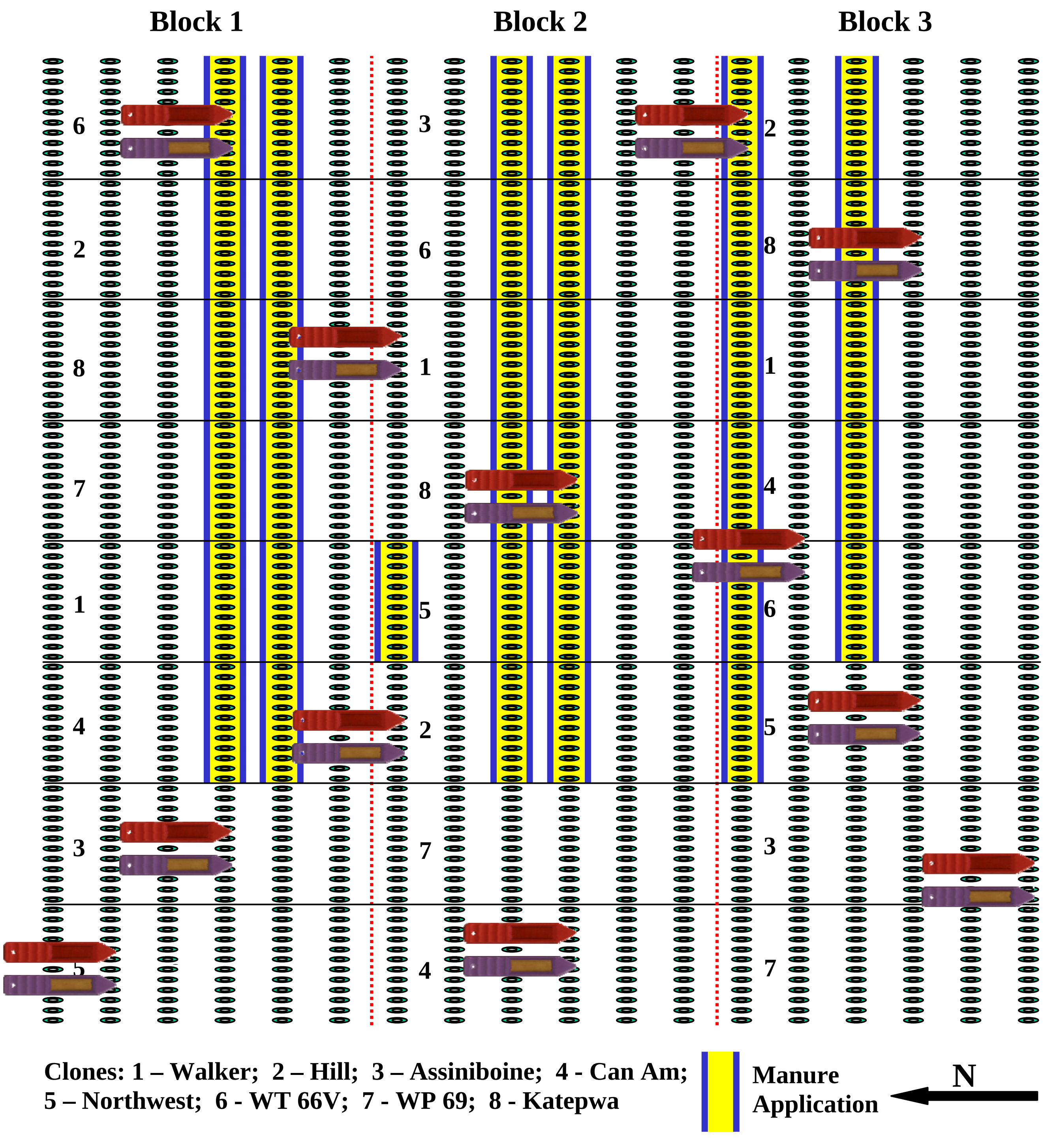

Figure 1. Experimental design used to assess the effect of liquid hog manure on soil nutrient availability and subsequent growth of hybrid poplar clones (Source: Garth Inouye). Approximately 14,000 L/ha broadcast applied on June 25 (Year 1) and July 19 (Year 2) after the fourth and fifth years, respectively. PRS™-probe locations indicated.

Figure 2. Liquid hog manure application (approx. 14,000 L/ha) broadcast applied on June 25 (Year 1) and July 19 (Year 2) at site near Arborfield. (Photo courtesy of Garth Inouye)

Soil nutrient analysis

Shortly before the manure application, PRS™-probes were placed in twelve randomly selected locations within the site, with three pairs (i.e., one cation- and one anion-exchange PRS™-probe) placed with control plots and another three pairs within manured plots, and 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 of measurement (Figure 3). The PRS™-probes have been used extensively in the past to quantify the effect of manure on soil nutrient availability and plant uptake (Qian and Schoenau, 2000a; 2000b; 2000c; 2002); however, no work has been done with hybrid poplar. 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. 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. The PRS™-probes were analyzed according to Hangs et al. (2004). Briefly, after elution with 0.5N HCl, the inorganic N as ammonium (NH_4^+-N) and nitrate (NO_3^--N) in the eluate was determined colourimetrically and the remaining nutrients (P, K, S, Ca, Mg, Cu, Zn, Mn, Al, Fe, B, and Pb) were measured using inductively-coupled plasma spectrometry. Unused PRS™-probe method blanks also were analysed to test for contamination during the regeneration and handling steps.

Hybrid poplar growth

At the end of each growing season, tree growth was assessed by measuring survival, height, and stem diameter at breast height of the central 20 trees from the clonal plots, with and without manure application.

Figure 3. Plant Root Simulator-probes™ used to measure the effects of broadcasted liquid hog manure on soil nutrient availability. (Photo courtesy of Dr. Ken Van Rees)

Statistical analyses

The soil nutrient availability and tree growth data were analysed 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 REG procedure in SAS (Version 8.0, SAS Institute Inc. Cary, NC) using pooled data (i.e., both treatments) to quantify the relationship between the soil nutrient supply rate data during each growing season and growth of hybrid poplar over the 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

Soil nutrient bioavailability with and without manure amendment

The application of liquid hog manure had a limited effect on soil nutrient supply rates, with only the total N and NO_3^--N supply rates larger in manured plots compared with control plots (Table 2), which is surprising, considering the application rate was three times larger than typical agronomic rates. Subsamples of the manure were not collected during application and analysed for macro- and micro-nutrient contents, so it is difficult to know the actual amount of each nutrient applied and, therefore, explain the possible mechanisms of why the manured

Table 2. Mean (n=3) cumulative nutrient supply rates (µg/10cm^2/15 weeks), measured using *in situ* burials of PRS™-probes, in plots with and without liquid swine manure application.

Treatment	NH_4^+	NO_3^-	Total N	P	K	S	Ca	Mg	Mn	Fe
	Year 1									
With Manure†	8a††	1369a	1378a	3.4a	65a	141a	4164a	1090a	13.0a	52.8a
Without Manure	6a	633b	639b	2.5a	65a	112a	4143a	955a	3.8a	25.2a
	Year 2									
With Manure	15a	1597a	1612a	42.0a	119a	208a	7084a	1518a	60.4a	164.8a
Without Manure	9a	147b	157b	9.7b	52a	227a	6426a	1375a	6.2b	45.1b

† Approximately 14,000 L/ha broadcast applied on June 25 (Year 1) and July 19 (Year 2).
†† For each year, means within a column followed by the same letter are not significantly different (P >0.05) by LSD.

plots were not different than the controls. Looking at the temporal changes in soil N availability during the first year of application, the effects of manure addition on increasing N availability are readily apparent following the application (Figure 4); however, this effect is short-lived and within four weeks the total N supply rates were no different than in the control plots. Assuming an N content of 30 Kg N/1600 L (Dr. Jeff Schoenau, personal communication), approximately 260 Kg N/ha was applied with the manure, which is a large amount of N added to the soil, so one would expect the differences in N supply rates between the manured and control plots to have been much larger. Nevertheless, it has been long known that injecting hog manure into soil significantly increases the nutrient use efficiency of applied manure, especially N, because ammonia losses from broadcasted manure can range from 10-90 % of the applied N (Hoff et al., 1981). In addition to these volatilization losses, a large portion of the manure N would have been immobilized as microorganisms metabolized the large amounts of soluble carbon present in the manure; however, this N will be mineralized and available for tree uptake the year after application (Thomsen et al., 1997; Wen et al., 2003). Lastly, the dramatic decrease in total N supply rate following manure application could be attributed to increased leaching and denitrification losses of the applied manure-N due to the above-average rainfall at the site in Year 1, which resulted in prolonged saturated soil conditions (Figure 5). Herein lies an important advantage of using *in situ* burials of PRS™-probes, in that whatever affects nutrient supply to a plant root out in the field, such as these extended periods of saturated conditions, will likewise affect what the PRS™-probe measures; thereby, resulting in a more accurate measure of nutrient bioavailability.

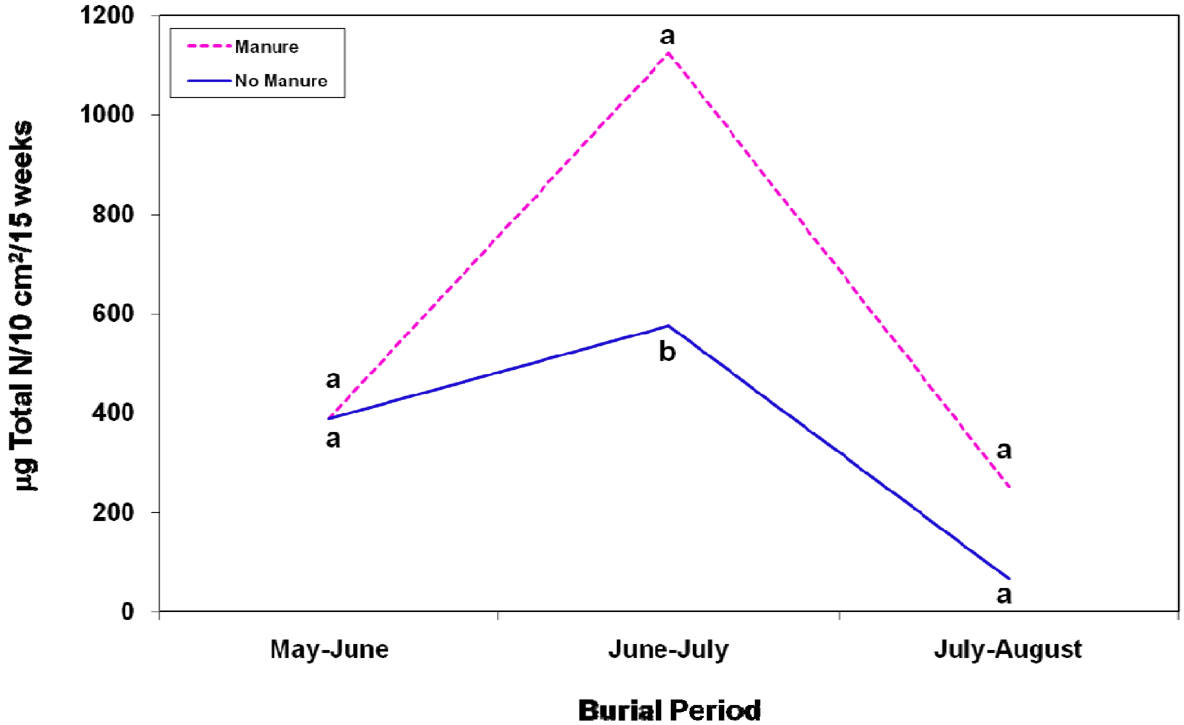

Figure 4. Mean (n=3) total N supply rates in Year 1, measured using *in situ* burials of PRS™-probes, in plots with and without the application of liquid hog manure on June 25 at a rate of approximately 14,000 litres/hectare. For each burial period, means having the same letter are not significantly different (P >0.05) using LSD.

Figure 5. Year 1 field moisture conditions in August 2004 at the site near Arborfield.

As expected, there was a pronounced effect of sustained manure addition on soil N supply in Year 2, with a 20% increase in available N (Table 2), despite a 20% decrease in growing season precipitation (data not shown). Once again, however, the applied liquid hog manure had a limited effect on soil nutrient supply rates, with only the N (NO_3^--N, and total N), P, Mn, and Fe supply rates larger in manured plots compared with control plots. The occurrence of increased labile P and heavy metal availability often is reported with successive manure applications (Dormaar and Chang 1995, Tran and N'dayegamiye, 1995; Campbell et al., 1997; Schoenau and Davis, 2006; Stumborg and Schoenau, 2008). In Year 2, the residual effect (i.e., mineralizeable N) of manure application the previous year was apparent immediately, with larger measured N availability in the manure plots during the first two sampling periods (Figure 6) and this residual effect has been reported elsewhere (Thomsen et al., 1997; Wen et al., 2003). Due to the delayed manure application date in Year 2, the effect of applied manure on increasing N availability is not apparent until the third burial period (Figure 6).

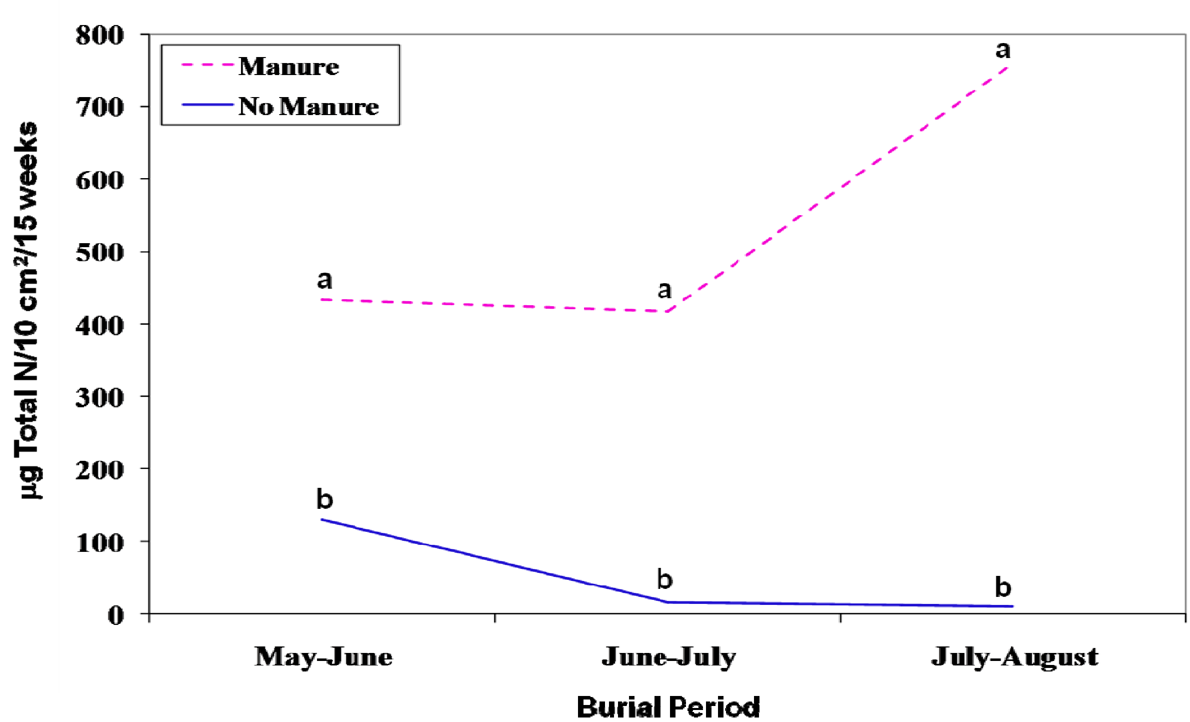

Figure 6. Mean (n=3) total N supply rates in Year 2, measured using *in situ* burials of PRS™-probes, in plots with and without the broadcast application of liquid hog manure (approx. 14,000 L/ha) on July 19. For each burial period, means having the same letter are not significantly different (P >0.05) using LSD.

Hybrid poplar growth with and without manure amendment

Despite increasing soil N availability, broadcast application of liquid hog manure had minimal impact on hybrid poplar growth, except for the clone Katepwa (Table 3). The lack of measured growth response to consecutive years of manure amendments may be attributable to a number of factors, specifically: i) substantial volatilization losses due to broadcast application (Hoff et al., 1981); ii) microbial immobilization given the large amount of soluble carbon in manure (Thomsen et al., 1997; Wen et al., 2003), iii) increased leaching and denitrification losses, caused by above-average rainfall supporting prolonged saturated conditions, iv) timing of manure application being out of sync with temporal nature of nutrient uptake by the trees (i.e., applied after the period of maximum nutrient uptake), therefore, resulting in low manure use efficiency, and v) a delayed response as absorbed nutrients are retranslocated within the tree tissues to support increased growth in subsequent years, which is commonly reported for many tree species (Nambiar and Fife, 1991; Hawkins et al., 1998; Salifu and Timmer, 2003). Currently, the knowledge of the temporal nature of nutrient uptake by tree species is incomplete. Unlike annual crop species that take up the majority of their nutrients within the first few weeks (i.e., 80 % of their N requirement; Dr. Jeff Schoenau, personal communication), the temporal nature of nutrient uptake for perennial tree species is unknown, thereby warranting further investigation.

Table 3. Mean (n=3) height, diameter at breast height, and stem volume growth increments for hybrid poplar after Year 2, in plots with and without applied liquid swine manure.

Treatment	CanAm	Hill	Katepwa	Walker	WT-66V
			Height (cm/year)		
With Manure†	92.1a††	96.8a	113.3a	117.2a	89.3a
Without Manure	125.4a	86.8a	100.9a	119.7a	88.2a
			Diameter at Breast Height (cm/year)		
With Manure	1.1a	1.3a	1.5a	1.5a	1.1a
Without Manure	1.3a	1.3a	1.3a	1.5a	1.2a
			Stem Volume (cm^3/year)		
With Manure	351.1a	489.8a	685.5a	588.8a	304.6a
Without Manure	380.2a	500.4a	568.0b	576.8a	290.2a

† Approximately 14,000 L/ha broadcast applied on June 25 (Year 1) and July 19 (Year 2).
†† For each growth parameter, means within a column followed by the same letter are not significantly different (P >0.05) by LSD.

Relationship between soil nutrient availability and hybrid poplar growth

Over the two years of this study, the total N supply rate often was better correlated with seedling height, stem diameter at breast height, and stem volume growth than other nutrients (data not shown). Albeit significant, the relationship between total N supply rate measured during Year 2 and height growth of the five hybrid poplar clones that year, in plots with and without manure addition, was not as strong as expected (Figure 7; Hangs et al., 2004), which probably can be attributed to the large micro-scale variability in soil N supply rates present at this site, along with poor drainage issues resulting in large differences in soil moisture availability among plots.

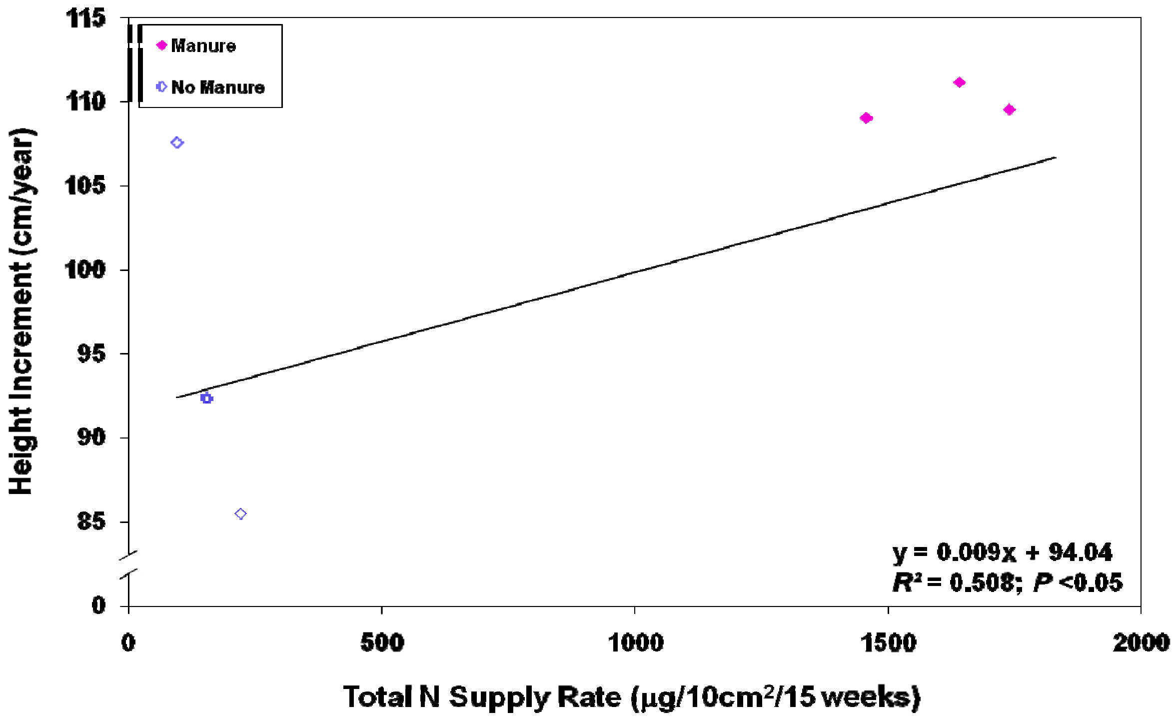

Figure 7. Relationship between total N supply rate, measured in Year 2 using *in situ* burials of PRS™-probes, and Year 2 height growth increment of five hybrid poplar clones (CanAm, Hill, Katepwa, Walker, and WT-66V). Each data point is a mean of 50 four-year-old trees, in plots with and without broadcast applied liquid swine manure (14,000 L/ha) on June 25 (Year 1) and again on July 19 (Year 2).

Conclusion

The two-year results of this study continue to support the assertion that *in situ* burials of ion-exchange membrane 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 measured differences in soil nutrient supply rates in plots with and without additions liquid hog effluent and their data were significantly correlated with tree growth. The limited effect of applied hog effluent on soil nutrient supply rates and hybrid poplar growth is surprising, however, considering the application rate was three times larger than typical agronomic application rates. This limited effect may be attributable to a number of factors, including: substantial volatilization, microbial immobilization, increased leaching and denitrification losses, timing of manure application being out of sync with temporal nature of nutrient uptake by the trees, and a delayed response as absorbed nutrients are retranslocated within the trees. Additionally, this may indicate that the amount of manure applied did not reach the tolerable limit and, therefore, it is possible that multiple applications could be safely applied annually given the tremendous nutrient sinks these plantations represent, thus eliciting a greater growth response. Consequently, more research addressing the maximum quantities of liquid hog effluent that can be safely applied to these poplar plantations, from both an agronomic and environmental perspective, is required. Determining the effects of repeated applications of hog effluent on soil nutrient supply rates and subsequent tree growth should help to support effective management strategies, in terms of developing practical effluent management practices required to mitigate any adverse environmental effects, but also increasing plantation productivity and the concomitant non-wood product benefit of increasing biodiversity within the agricultural landscape.

Acknowledgements

The authors thank the Saskatchewan Forest Centre for funding this research, Pasquia Pork Producers Inc. for providing the land, Garth Inouye (AAFC-PFRA) for his logistical support in the field, and our *Sus scrofa domestica* collaborators for their in-kind contributions that made this research possible.

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