# Nutrient Cycling in Intensively Managed Short Rotation Hybrid Poplar Plantations

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**Abstract**

Hybrid poplars grown on short rotation offer rapid growth (20 years), biomass accumulation greater than native aspen stands, and a large sink for nutrients and carbon. The biomass and nutrients exported after harvesting however may affect long-term productivity with these shorter rotations. The objective of this study therefore was to construct a nutrient budget for two sites in the boreal transition zone near Meadow Lake, SK., on Orthic Grey Luvisol soils. The nutrient budget, which determines the inflows and outputs of an ecosystem in a specified time period, will be used to determine whether nutrient fluxes from harvesting can be sustained by inputs. The inputs and outputs that will be collected through the year include wet and dry deposition, leaf litter fall, mineral weathering, soil water samples at different depths and biomass samples. Using the data collected, a site nutrient budget will be constructed and evaluated to see if the site can be considered sustainable over a rotation.

**Introduction**

Afforestation is being promoted in many parts of the aspen parkland as a new way to diversify farm incomes and expand the forestry industry without using more native forestlands. Cultivation of *Populus* trees, such as hybrid poplars (HP), has received the greatest attention for achieving high fiber yield with short rotations in afforestation systems (Ceulemans et al., 1992; Anderson and Zsuffa, 1977; Eckenwalder, 1996). The objective of HP plantations is to produce trees with good rooting ability, disease, insect and frost resistance, fast growth and good wood quality (Zsuffa, 1979). Plantations of HP are expected to have shorter rotations (≤ 20 yrs) (Zsuffa et al., 1996) compared to native species (> 60 yrs), and are much more nutrient demanding. Select HP clones (Walker and Assiniboine) have a mean annual increment of 8 $m^3$ $ha^{-1}$ $yr^{-1}$ (Schroeder, 1999) in SK, which is nearly double that of aspen clones, but only $^1/_3$ of what would be expected in the Pacific NW. Walker poplar, (an open pollinated *P. deltoides* selection developed by PFRA in SK. (Zsuffa et al., 1996)), has consistently produced well in the prairies, especially in shelterbelts (Lindquist et al., 1979). HP could be harvested for lumber, oriented strand board, pulp or other value-added products.  Due to the location of the mills in SK., the most feasible areas for the establishment of the HP plantations are in the aspen parkland. These trees grow relatively well on marginal land compared to some agricultural crops (Zsuffa et al., 1996).

A nutrient budget is an account of nutrient flows (inputs and outputs) from a clearly defined agroecosystem (e.g. plantation) (Janssen, 1999), during a clearly defined time period (Oenema, 2003). The nutrient budget for the current project is a soil surface budget (Oenema, 2003), which records all nutrient inputs and outputs including atmospheric deposition, mineral weathering, harvesting, and biological fixation. There have been several studies that have looked at nutrient cycling and budgeting in natural hardwood forest ecosystems (Pastor and Bockheim, 1984; Silkworth and Grigal, 1982). However there have been no nutrient cycling-budgeting studies in HP plantations on the prairies. Fast growing trees like HP are very effective at retaining nutrients in the biomass (Pastor and Bockheim, 1984), and thus deplete them from the soil. It is important then to quantify where the nutrients are being added (fertilization, atmospheric deposition, plant decomposition) and removed (leaching, harvesting) from the system so that a proper accounting can be made for them. In forested ecosystems, Silkworth and Grigal (1982), found that in a harvested system only Ca and Mg would be limited in the future, whereas N, P, and K would be replaced via atmospheric deposition and mineral weathering.

The objective of this study was to determine what are the different pools and fluxes for the HP plantation agroecosystem at Meadow Lake, SK. and compare the different components between sites to construct a nutrient budget for determining the long-term viability of these plantations.

## Materials and Methods

*Site Description*

Two sites are being evaluated for the nutrient budget project: Cubbons (established and new plantations) and Culbert (new plantation) both near Meadow Lake, Saskatchewan. The Cubbons site is positioned on predominantly sandy-loam to loam Orthic Gray Luvisolic soils developed from calcareous glacial till (Loon River Association) (Saskatchewan Centre for Soil Research – SCSR, 1995). Stoniness is classed as moderate and slopes are gently undulating and < 2%. The Cubbons site was previously managed as an alfalfa field. The Culbert Site is situated on soils mixed with Brunisolic Gray Luvisols and Orthic Gray Luvisols with loam to clay-loam glacial till overlain by sandy glaciofluvial material (Bittern Lake association) (SCSR, 1995). Stoniness is light to moderate and slopes are < 3% and slightly undulating. The Culbert site was previously managed as a pasture.

*Sampling Methods*

Soil solution was measured using lysimeters (SoilMoisture Equipment Corp., Santa Barbara, CA.). Lysimeters were installed in the new plantations at depths of 20 and 60 cm in both the fertilized and unfertilized plots, and also six lysimeters in the old plantation at the Cubbons site in each of the 3.1 x 3.1 m spacing un-pruned "Walker" poplar plots at the 20 and 60 cm depths. The samples were taken once per month from June through October (Pastor and Bockheim, 1984) for 2004 for a total 180 samples. The samples were sub-sampled (125 ml), and frozen until analysis took place in the fall of 2004.

Bulk deposition, wet and dry deposition was collected at Cubbons and Culbert in each block. Bulk deposition samples were collected without any interference from the canopy so as to avoid any changes in the water chemistry from throughfall effects (Pastor and Bockheim, 1984). Throughfall collectors were placed on wooden fence posts below the tree canopy to collect rainfall after it had passed through the tree foliage. The samples were collected and measured every 2 weeks or after rainfall events. Snow depths will be measured every winter when the weather stations are downloaded, and a snow sample will be taken to analyze for nutrient concentration. The samples were frozen and analyzed with the throughfall, stemflow, and lysimeter samples. The lysimeter, throughfall, stemflow, and rainfall samples were analyzed for N, P, K, Ca, Mg.

Leaf litter traps are placed in the plantation to measure litter fall throughout the year. These are placed in the new plantations and are placed in the 3.1 x 3.1 m spacing Walker poplar plots in the old plantation at Cubbons. The litter traps are 1 $m^2$ in size with a wood frame and several inches above the soil surface (Keenan et al., 1995) to keep microorganisms from decomposing the leaves. The leaves are collected monthly starting in August, air dried and then weighed. There were 30 leaf litter trap samples per year to be weighed, and analyzed. In the fall of 2002, 60 litterbags were placed on the ground to measure leaf decomposition. The leaf samples were weighed, and then placed in mesh bags and placed at Culbert, Cubbons in the old plantation, the new plantation, and the adjacent aspen forest. Twelve samples every year for three years will be picked up and measured for weight loss. 2 years of samples have been collected, cleaned, dried, weighed and compared to their original weight from 2002 to determine the level of decomposition.

In 2004, 1 tree from each of the old plantation (8 years old) 3.1 x 3.1 m spacing un-pruned "Walker" poplar treatments was destructively sampled. The tree was cut down, cut into 1 m sections and weighed. The 1 m sections were numbered, and the leaves and branches from each 1 m section were weighed in the same manner. The roots were excavated in a 3 $m^2$ area around the tree and weighed. All components of the tree were kept separate and weighed fresh. Sub samples of each component was selected and then taken back to the lab to be dried, weighed, ground, and analyzed for its nutrient and carbon content. The plant samples were digested using the $H_2SO_4$-$H_2O_2$ method and were analyzed for N, P, K, Ca, Mg.

Soil samples to a 1.2 m depth were taken to gather baseline data on soil mineralogy and soil nutrients. Three samples per block were taken for each of the new plantations as well as the old Cubbons plantation. The samples were separated based on 10 cm increments to 60 cm, and 20 cm increments to the 120 cm depth. Soil samples were analyzed for exchangeable N using 2 M KCL, P using the Olson P test, K, Mg, Ca using a 1 M $NH_4OAc$ extraction and total C using CNS combustion.

## Results & Discussion

The soil samples that were taken in the spring of 2004 showed a large difference in the amount of nitrate in the top 10cm (Figure 1). The Cubbons new plantation soil started in the top 10 cm with 70 kg ha$^{-1}$ $NO_3$-N compared to 25 and 5 kg ha$^{-1}$ $NO_3$-N for Culbert and the old plantation, respectively. It then decreased to about the same amount as what is in the Culbert soil at the deeper depths. The OHP soil was very low in $NO_3$ at all depths. These values show that the effect of the OHP with the older trees and more developed root mass are much more efficient at taking up the $NO_3$ in the soil. The $NH_4$-N in the same profiles was around 5kg ha$^{-1}$ for all sites.

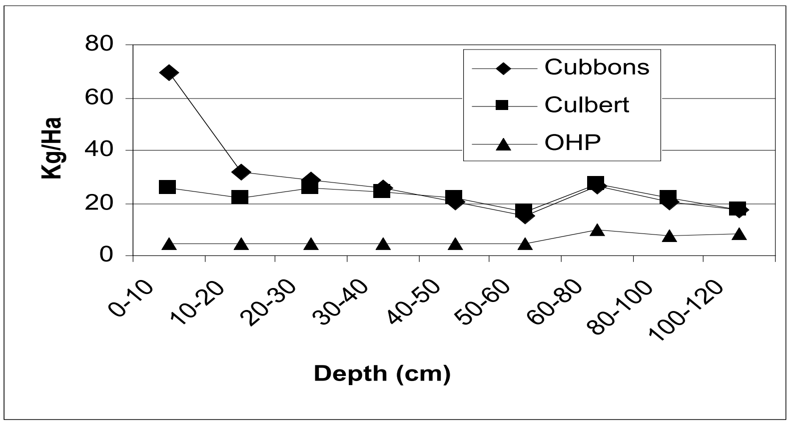


**Figure 1.** Available soil $NO_3$ at Cubbons, Culbert and OHP-Cubbons

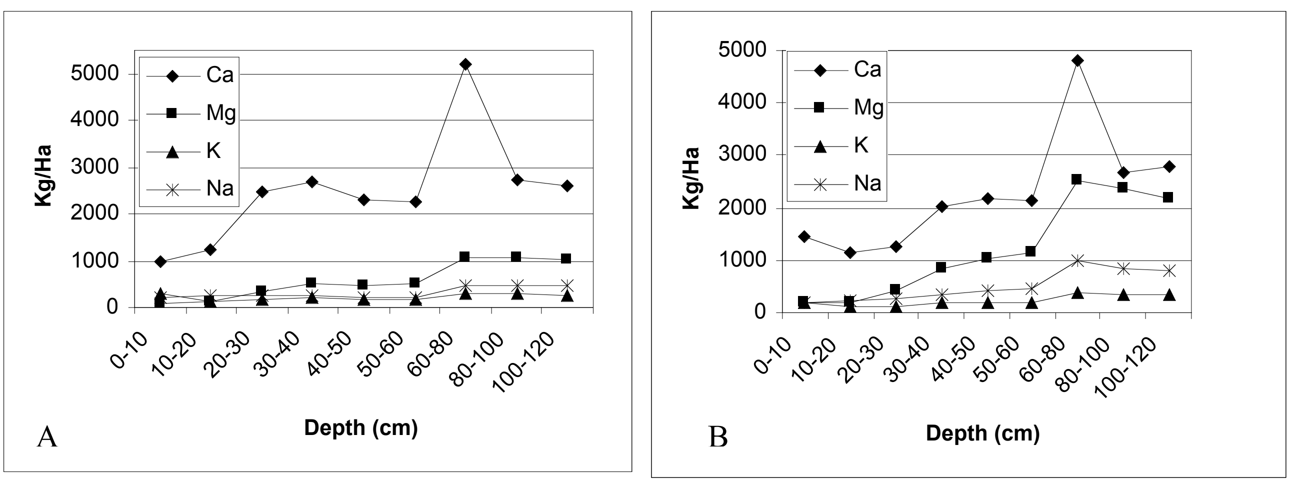


**Figure 2**. Exchangeable base cations to depth at the Cubbons (A) and Culbert (B) sites

Base cation amounts (kg ha$^{-1}$) in the Cubbons old plantation and the Cubbons new plantation were very much the same, and Culbert only varied from them in the amount of Mg and Ca that was at depth (Figure 2). At the 30 cm depth the amount of Mg at Culbert started diverging from Cubbons. Calcium is higher at the 30-80 cm depths at Cubbons and his may be due to changing mineralogy of the soils at this depth.

In the summer of 2004, three trees from the old plantation were harvested from the 3.1m x 3.1m spacing plots. Heights, diameter at breast height (dbh) and root collar diameter (rcd) were measured for all three trees. The trees ranged from 7.5 – 10 m tall. Even though the trees were not all the same size, the component percentage of the total biomass remained relatively equal (Figure 3). Coarse root and branch biomass was relatively similar in amount.

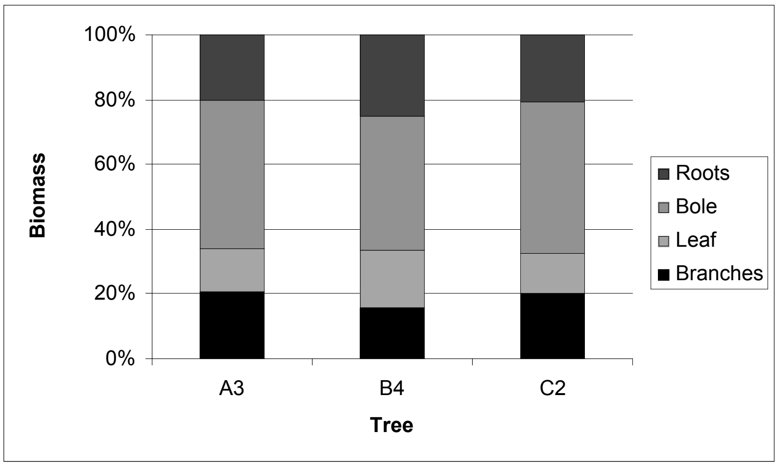


**Figure 3**. Component % of total biomass (roots, bole, leaves, branches)

**Table 1.** Mean nutrient content (kg/ha) of aboveground biomass for trees in an 8-year-old plantation

| | **N** | **P** | **Ca** | **Mg** | **K** | **Na** |
|---|---|---|---|---|---|---|
| **Bolewood** | 31.2 ± 9.4 | 7.7 ± 2.7 | 23.9 ± 9.6 | 7.5 ± 3.9 | 62.0 ± 33.5 | 0.2 ± 0.1 |
| **Branches** | 23.5 ± 12.9 | 6.3 ± 3.1 | 34.0 ± 18.2 | 6.4 ± 3.3 | 28.2 ± 15.2 | 0.4 ± 0.2 |
| **Leaves** | 95.6 ± 23.5 | 8.0 ± 1.9 | 27.5 ± 6.3 | 8.2 ± 2.3 | 80.3 ± 20.7 | 0.3 ± 0.1 |

Leaves are a very large source on nutrients to the plantation system compared to the bolewood and branches. If whole tree harvesting is done on the plantation in the summer when leaves are still on the trees, there is a huge excess of nutrients that are being exported off of the site, which could affect long-term productivity.

Deposition of nutrients added to the sites by dry and wet deposition showed that N decreased from rainfall to throughfall as the leaves scavenge the N (Figure 4). The base cations, especially K and Ca increase in throughfall compared to rainfall, as K was leached out of the leaf and Ca was high in dry deposition and washed off of the leaf as the rain passed through the canopy.

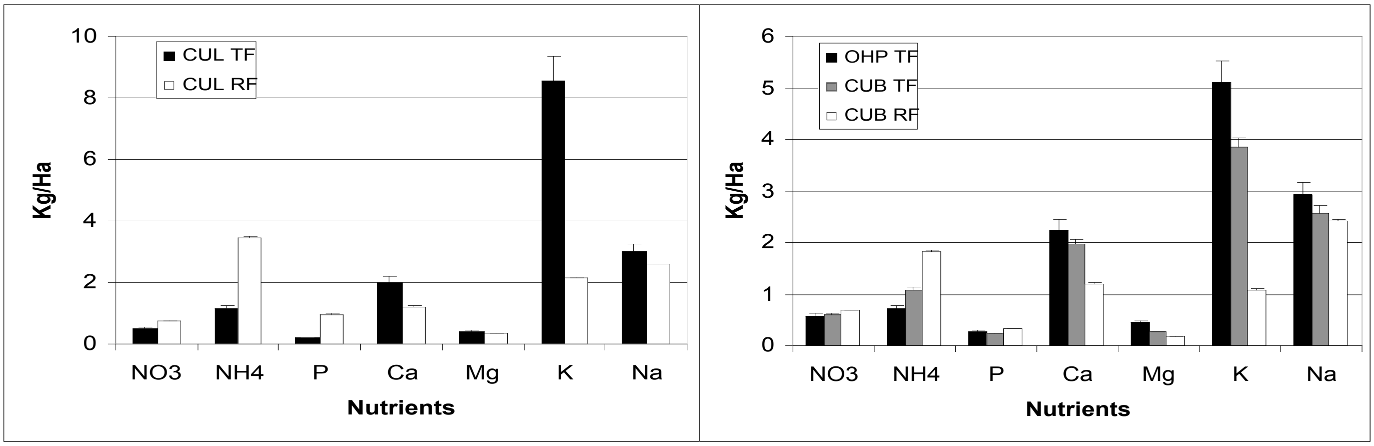


**Figure 4.** Rainfall and throughfall nutrients in kg ha$^{-1}$ for Culbert, Cubbons and OHP-Cubbons sites for 2004 field season

Leaf litter fall and decomposition played an important role in the recycling of nutrients back into the plantation. Figure 5 shows the amount of nutrients in kg ha$^{-1}$ returned via litterfall for the old plantation and both the Cubbons and Culbert new plantations. OHP had much higher values because there was more leaf fall returned each year for the older trees. The fertilized trees also had relatively more leaf fall in the new plantations.

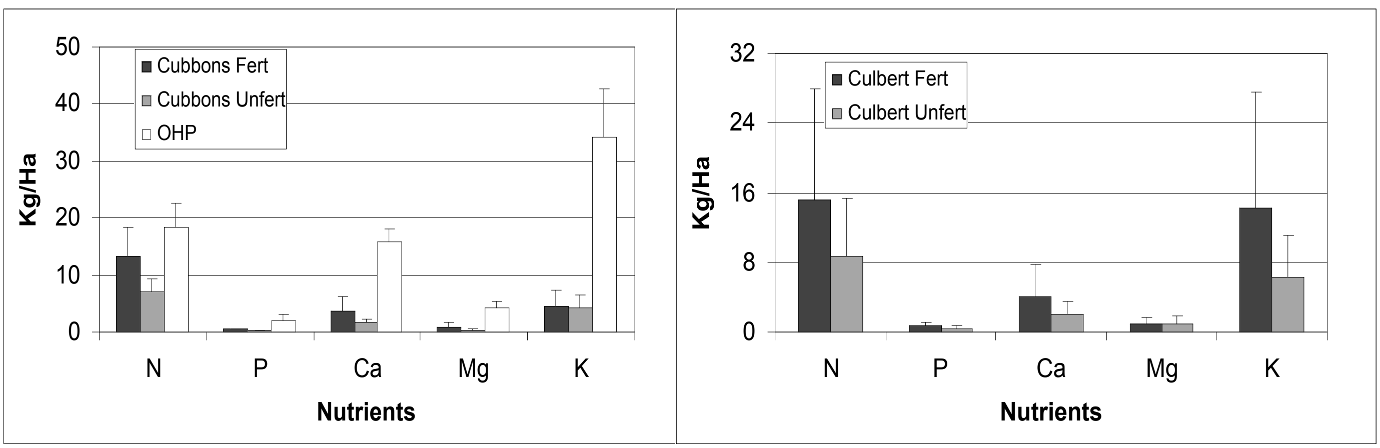


**Figure 5**. Nutrients returned to plantation via litterfall at the Cubbons and Culbert sites for new and established plantations.

How fast these nutrients are returned to the soil in the plantations relies on how fast they are able to decompose. In Figure 6, the decomposition of the leaves in the old plantation and the adjacent aspen forest site was much faster than in the new plantation sites. This is a result of the leaves in the older plantations having better contact with the soil and forest floor. The forest floor contains many more microorganisms that will help break down the litter than the mineral soil. The new plantation litterbags were in contact with the mineral soil because they have not yet developed a forest floor.

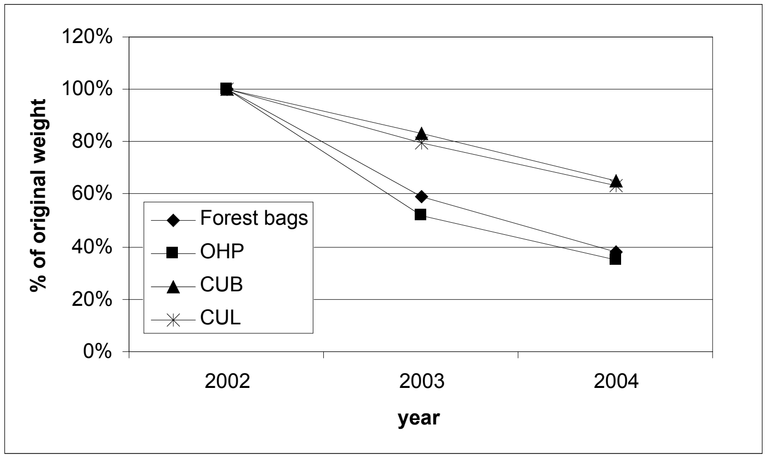


**Figure 6**. Decomposition for litterbags placed in the Cubbons, Culbert, OHP and forest sites at Meadow Lake, SK.

**Summary**

The largest nutrient output from the plantations is the eventual harvest from these sites. If whole tree harvesting takes place during the summer, more nutrients are going to be exported off of the sites than if harvesting were done in the winter or if stem only harvesting was done. To offset the losses from harvesting, mineral weathering of the soil and wet and dry deposition from the atmosphere are going to have to have large inputs. As the trees increase in size, the canopy is able to filter more deposition from the atmosphere, and take up nutrients from the soil more efficiently, thus leading to less leaching. The ability of the trees to scavenge nutrients from the atmosphere should allow the nutrient budget to be balance over the long term.

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