A report on the Murdoch Lake Agroforestry Research and Demonstration Project: 2009-2011

Comparing aboveground biomass production of Walker Hybrid Poplar in an agroforestry systems (alley cropping) for forage production

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Executive Summary

This report presents a comparison of biomass production in alley cropping and biomass production from a traditional forage practice within the Murdoch Lake alley cropping research and demonstration project. It also provides an overview of expected benefits of agroforestry cropping practices. With the possible exception of field windbreaks little is known about the broader use of agroforestry practices and their ability to bring economic, diversification and ecological benefits to land managers in the Canadian Prairies. Alley cropping as used at Murdoch Lake is essentially a new practice in Alberta and there remain many unknowns before it could be implemented. The project site is located in the Boreal forest region and about 100 km NW of Peace River, AB. Biomass production in the agroforestry systems plays an important role for global, regional and local carbon cycles. This research study quantified and compared the biomass production from an agroforestry/alley cropping practice and a forage practice typical of the northern prairie in Alberta. Biomass production (trees plus forage biomass) in the alley cropping practice was slightly higher than in the forage only treatments and may offer producers alternatives to current forage production practices. The study site was split into three blocks as North, Centre and South. Within each block there were wide alley, narrow alley and forage only practices. The trees and forage used in the study were Walker Hybrid Poplar and the forage mix including alfalfa, timothy and brome. The total aboveground biomass was calculated for each treatment and then comparisons were made. The average aboveground biomass, based on three years of collected data, showed significant difference between treatments. The annual growth in 2011, at 7 years of age, found that hybrid walker poplar, under alley cropping practice produced 3.24 and 2.63 t/ha (annual) woody biomass in Narrow Alley and Wide Alley treatments, and the forage alone biomass production was 2.72 t/ha. The average height and DBH Narrow alley and wide alley were 8.94 m and 7.92 cm in Narrow alley, and 9.69 m and 8.13 cm, respectively. Forage production under the trees in Narrow alley were 0.97, 0.84 and 1.16 ton/ha/yr in 2009, 2010 and 2011, respectively. Our research results found that the largest amount of biomass production occurred in alley cropping, compared to forage crop alone. The average total above ground biomass (TAGB) for alley cropping trees (tree + forage + forage under trees) in Narrow Alley and Wide alley (tree + forage + forage under trees) were 4.33, 3.22 and 5.00, and 5.41, 3.89 and 4.85 ton/ha/yr in 2009, 2010 and 2011 respectively in north block. Statistically identical trend results were found for biomass production in centre and south block. Forage growth under alley crop trees was about 1/3 of the forage alone growth rates. A minor experiment designed to determine competition between trees and forages consisted of trenching in a plastic curtain, designed to stop forage and tree interaction. Trench and no trench results showed no significant difference in aboveground biomass production. In addition, no significant differences were found for soil moisture volume between the treatments but significant differences were observed between spring and fall results.

Introduction

In recent decades, the use of tree biomass has been rising in North America as the economics of fossil fuels change and concern about climate change occur (Kort, 2011). Growing woody plants in an agroforestry/alley cropping is an appealing concept for producing biomass in a relatively short period of time. While agroforestry, (including windbreaks, silvopasture, forest farming, alley cropping, riparian forest buffers as defined by Association for Temperate Agroforestry (AFTA) is a more generally accepted practice in developing countries, it is recently being considered as a component of sustainable agriculture systems in North America.

While this report examines the biomass produced by the two different practices, the project also hopes to support the application of alley cropping for appropriate parts of Alberta and the Canadian prairies.

What made this a true agroforestry project was the inclusion of trees, a forage crop and cattle with the intension of creating a system that produced more than one product (trees plus forage for direct consumption by cattle or for hay). In this project, trees modified the field microclimate, cattle controlled competition under trees and cattle left nutrients in trees and forage alleys.

While the primary objective of this study was to test the hypothesis that biomass production would be greater under an agroforestry system than under a conventional forage production practice or a "tree plantation" practice, it also was expecting to achieve more. Tracking biomass is a means of comparing productivity of different practices but equally important would be the test of applicability and possible acceptance of such an alley cropping system in the Peace River and similar regions. Among the concerns expressed was the ability to maintain weed control without tillage when used in combination with plastic mulch. There were also concerns by professionals and producers in the area that the introduction of cattle to the site would lead to excessive soil compaction and large amounts of tree damage. To make the system more realistic and useable, cattle were added each of the three years covered by this report.

The alley cropping practice was meant to "fit in" with three of the more common practices used in the parts of northern and central Alberta. Forage production, for grazing or hay, forest grazing, and trees as part of afforestation. Trees in the region are found in the form of woodlots, hedgerows and shelterbelts, so some level of acceptance of trees was seen as an indication to proceed with alley cropping as an alternate practice. In addition, some forest companies in central and northern Alberta were setting ambitious targets for poplar plantations. So the question could be asked: would an agroforestry system implemented in this region achieve the same higher overall production rates as reported in other parts of the agroforestry world.

Key Traits of Agroforestry Practices

In order to add perspective to take the best advantage of opportunities presented at this research and demonstration site, and other agroforestry projects, it’s likely useful to review the key traits of agroforestry. Agroforestry practices are intentional combinations of trees with crops and/or livestock that involve intensive management of the interactions between the components as an integrated agroecosystem. Four key characteristics - intentional, intensive, interactive and integrated - are what distinguish agroforestry from other farming or forestry practices. For the purists, a land practice must have all four of these components in order to be called agroforestry. As noted by the Association For Temperate Agroforestry (AFTA) Agroforestry is:

Intentional: Combinations of trees, crops and/or animals are intentionally designed and managed as a whole unit, rather than as individual elements which may occur in close proximity but are controlled separately.

Intensive: Agroforestry practices are intensively managed to maintain their productive and protective functions, and often involve annual operations such as cultivation, fertilization and irrigation.

Interactive: Agroforestry management seeks to actively manipulate the biological and physical interactions between the tree, crop and animal components. The goal is to enhance the production of more than one harvestable component at a time, while also providing conservation benefits such as non-point source water pollution control or wildlife habitat.

Integrated: The tree, crop and/or animal components are structurally and functionally combined into a single, integrated management unit. Integration may be horizontal or vertical, and above or below-ground. Such integration utilizes more of the productive capacity of the land and helps to balance economic production with resource conservation. (AFTA).

Adding trees onto agricultural land makes various supplementary profits for the farmer and society (Tsonkova and Bohm, 2012). Recently, agroforestry has been considered as an integrated applied science that has the potential for addressing many of the land-management and environmental problems found in both developing and industrialized nations (Nair, 1993; Nair et al., 2008)**.** Agroforestry is a collective term for land use systems that increase the environmental as well as economic benefits when trees and/or shrubs are integrated with crops and/or pasture (Gold and Garrett, 2009). Agroforestry practices have been shown to improve soil quality, carbon sequestration, and water quality in cropping systems (Lal, 2004; Nii-Annang et al., 2009).

There is a frequent mixing up of definitions, aims and potentials of agroforestry. For example, it may be presumptuous to simply define agroforestry as a successful form of land use, which achieves increased production and ecological stability. We can aim for these goals, and in many ecological and socioeconomic settings agroforestry approaches have a higher potential to achieve these more than most other approaches to land use. But, with the wrong choice of species combinations, management practices, and lack of peoples' motivation and understanding, agroforestry may indeed fail just like any other form of land use may fail, and it will still be agroforestry in the objective sense of the word.

At the same time agroforestry practice use is growing globally in recent decades and observed as providing ecosystem services, environmental benefits, and economic commodities as part of a multifunctional working landscape/land use and management (Jose, 2009). It offers a potential way to integrate perennial woody bioenergy crops with traditional agricultural crops to satisfy energy demands without sacrificing food production. Shelterbelts, alley cropping and working riparian buffer strips are ideal candidates for biomass production in North American (Holzmueller and Jose 2012).

The changing perception of agroforestry's role and impact has led to it being used to address some of these problems. This recognition has led to the development of Agroforestry applications in North America and other Temperate Zones such as Australia and New Zealand, Europe and China, demonstrating the range of conditions under which agroforestry can be successfully applied (Garrett, 2009; Nair et al., 2008).

Woody species grown for biomass typically includes fast growing, early successional species such as poplar (*Populus spp*) and Willow (*Saliy spp*.). These species are shade intolerant and have the ability to coppice when harvested (Holzmueller and Jose, 2012). Studies found that growing hybrid poplar plantations is ecologically and environmentally sustainable (Abrahamson et al., 1998). Somewhat recently, a comprehensive manual for hybrid poplar biomass production in the Prairies of Canada including clone properties, site selection, and recommended plantation systems was published to support farmers and other organizations planning to establish short rotation crops (SRC) systems (Oosten et al., 2006).

Attempts have been made to quantify environmental benefits of agroforestry; however, comprehensive reviews or synthesis has been rare. The available reviews have focused mostly on a single ecosystem service (Jose, 2009). The primary objective of this research project was to analyze the biomass data of alley cropping and compare that to a conventional forage production system. We also were hopeful that other advantages such as lower inputs or stable yields could be realized in a newly established alley cropping agroforestry system in the Peace River Region of Canada. Secondly, the purpose of this research project was to determine if there are productivity and other advantages to be realized in a newly establish alley cropping agroforestry system in the region. The project proponents also wish to explain how and why the growth advantage occurred.

Materials and Methods

Study site

The experimental site at Murdoch Lake was established in 2002. It borders the waterfowl rich Murdoch Lake and is approximately 60 acres in size. The entire site is protected from ungulates by a 8 foot high page wire fence. Tree plantations can be negatively affected by browse damage and this complicating factor was deliberately removed for the study. The research site is located at nearly 57 N latitude and in the boreal plains region of Alberta, Canada. The site is subject to a short frost free growing period and long cold winters.

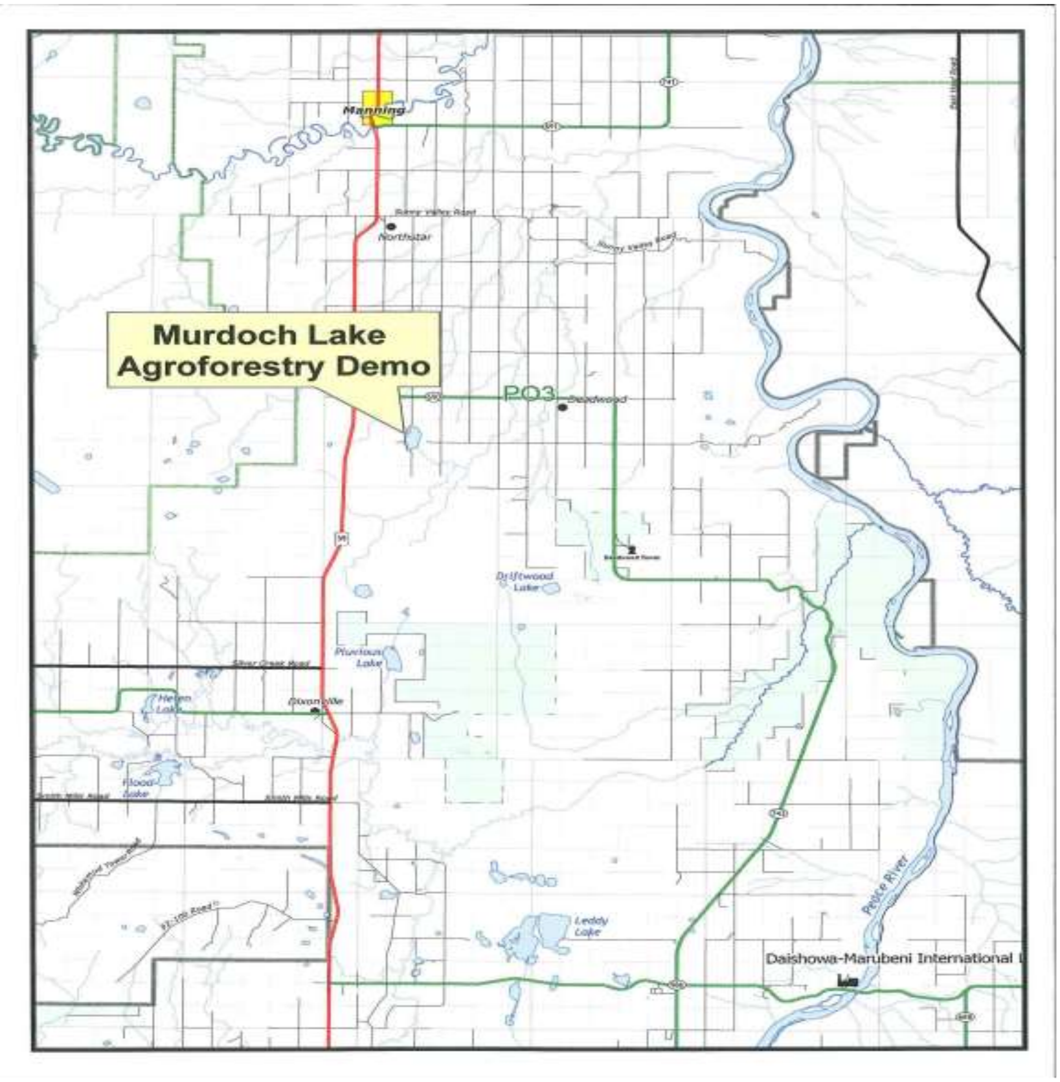

Figure1: Location of the Murdoch Lake research field

The Murdoch Lake study site was initially designed to evaluate differences of an alley cropping system and a conventional forage system and an all tree system. Half the tree blocks were planted with plastic mulch for weed control and half were planted without plastic mulch. For tree blocks with no plastic mulch, attempts were made to control weeds by mowing. This proved to be very difficult and after 5 years of growth it was decided to remove the tree blocks that had no plastic mulch, because both survival and growth rates were very poor. When no-mulch trees were removed, the all-tree treatment became a narrow alley cropping treatment. The treatment originally established as alley cropping became a wide alley cropping treatment.

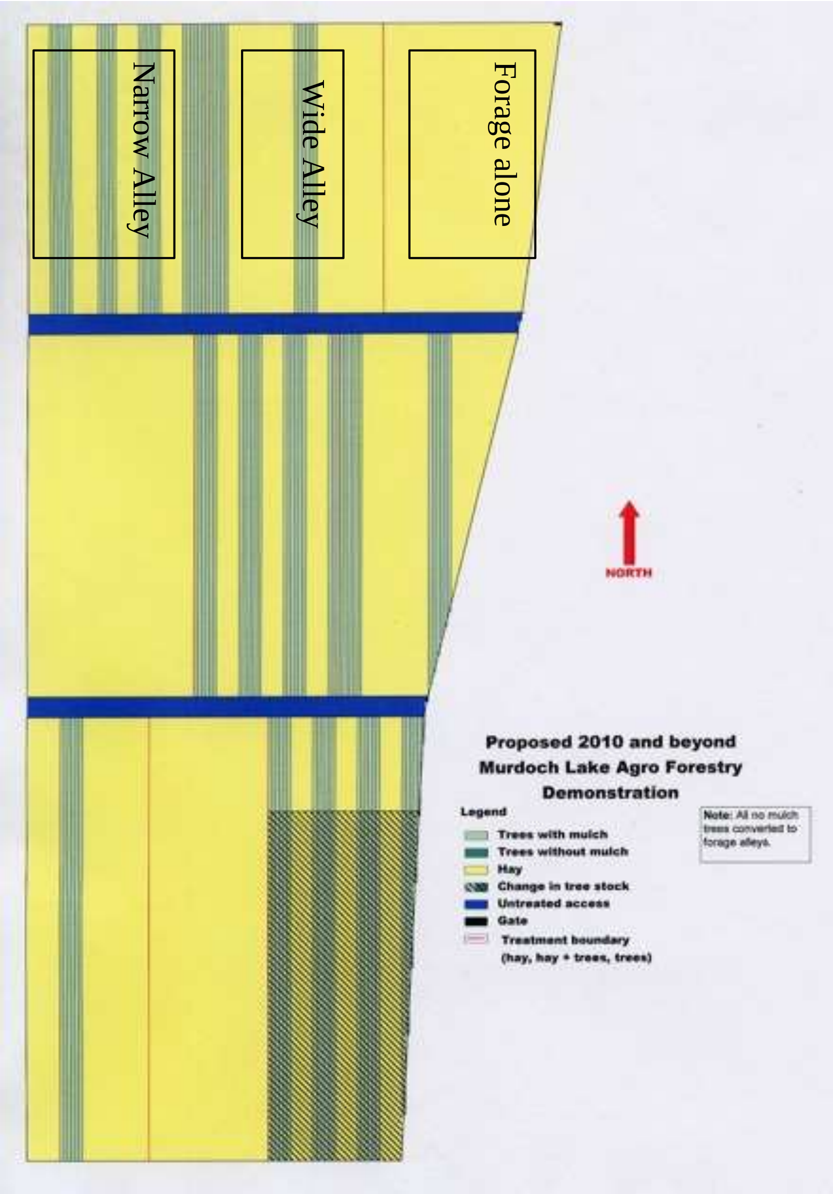

Figure 2: Experimental design and treatments

The mix of forages that naturally established in the understory of the all tree practice became the forage component in the narrow forage alleys. It was similar to the planted forages but with a slightly lower component of alfalfa. The alley cropping consisted of forage blocks and planted walker hybrid poplar tree blocks. The alley cropping tree component consisted of 6 rows of trees with 2.5 m x 2.5 m spacing. The alley cropping systems consists of three repetitions, North, Centre and South (Figure 2) and each repetition was roughly 7 acres or 2.8 ha in size.

Day length, precipitation, temperature

Climatic conditions, site and soil characteristics (i.e., site quality) have a significant effect on the biomass yield of hybrid poplar (Amichev et al., 2010). While temperature and precipitation data were collected throughout the study period, we relied on data collected at Peace River and Manning to characterize the site. Monthly average day length, degree days, monthly average temperature from 2009–20111 are shown in Figures 3, 4 and 5. Precipitation data was taken from the nearby Manning Weather Station. The average precipitation was found as 336.14, 285.14 and 393.85 mm in 2009, 2010 and 2011, respectively (Source: Agro-climatic Information Service (ACIS).

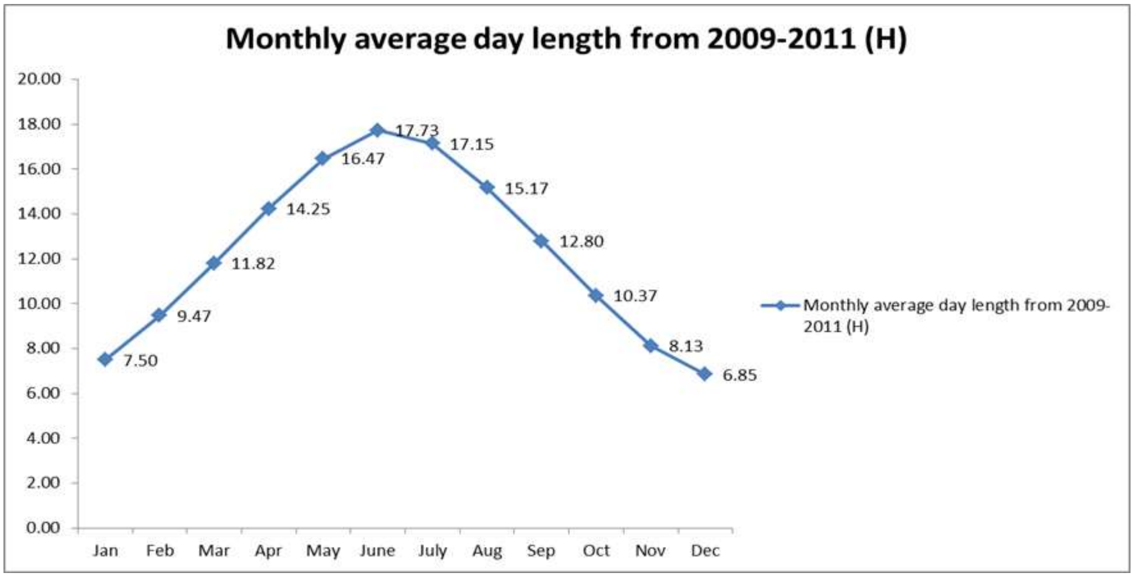

Figure 3: Monthly average day length for Murdoch Lake

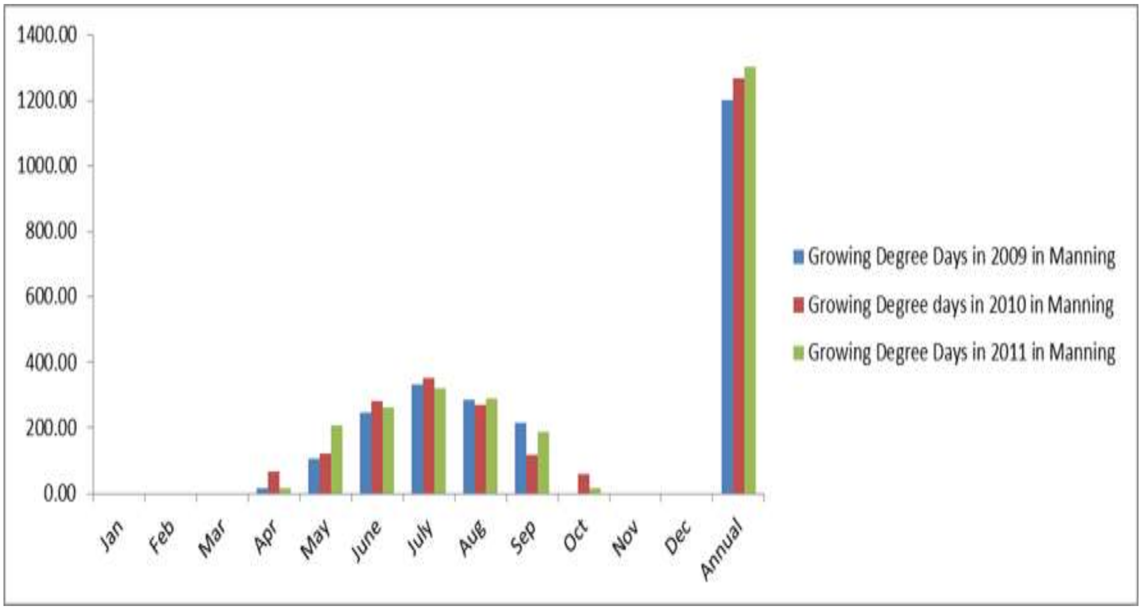

Figure 4: Growing degree days by month for Murdoch Lake

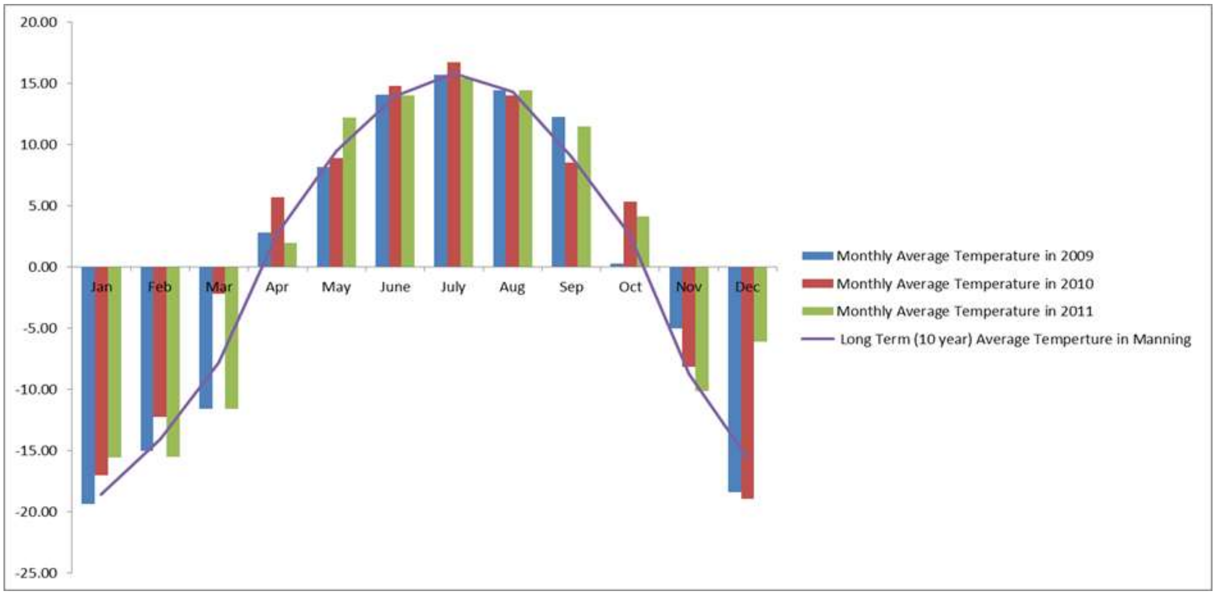

Figure 5: Monthly average temperature for Murdoch Lake

Soil type of the study area

Soils of the site are relatively consistent in terms of appearance and classification, and typical of much of the region. Soil profiles are Solonetzic Gray Luvisols and Gleyed Solonetzic Gray Luvisols. The soil is almost stone free. All soils have developed in clay textured glaciolacustrine deposits, often referred to as a lacustro-till, parent material. The Gleyed Solonetzic description implies that internal drainage is limited and for some time the soil material is saturated. The top 15-25 cm of the profile generally has a lighter texture of loam to clay loam while deeper parts of the profile are of a clay texture. The soils exhibit a moderate to strongly expressed coarse prismatic structure that is typical of a Solonetzic-like soil. However, the Ca:Na ratios are those of a Luvisolic soil. Though there are structural components of a Solonetzic soil, the observed structure hasn't prevented roots from growing through and around the soil structures, to a depth of about 100 cm. Despite that lack of a completely expressed Solonetzic profile, this could limit many kinds of crop production. Poor drainage in some parts of the field also could limit growth.

In some of the depressional or lower landscape positions of the research site very poorly drained soils are present. These soils characteristically have a darker coloured surface layer, and are distinctly wetter under foot. Prominent mottles are abundant within 50cm of the surface. Soil profiles exhibiting these characteristics are referred to as Gleysols and are of limited occurrence.

The soils of the area are developed in parent material of glaciolacustrine or lacustro-till. Lacustro-till is described as "fairly uniformed, gray to dark gray fine textured material that has occasional strata of yellowish brown and medium textured material that may be stony and often resembles till"(Scheelar and Odynsky, 1968). This description corresponds with the characterization of the soils described and sampled at the numerous excavation pits that were exposed at this research site.

Trees and forage selections

The even aged Walker hybrid poplar ((*Populus x walker*) was selected for planting in this agroforestry systems because of higher expected growth rates (Amichev et al., 2010). Walker hybrid poplar is a large deciduous tree that is extremely fast growing and capable of putting on over 1.2 meters of growth per year and average mature height of 25 meters. It is favoured among forest product companies for use in fast growing plantations. Walker poplar is a prairie hardy female clone that produces some fuzz in the spring (AAFC). The forage only treatment was a hay mix including alfalfa, timothy and brome suited for the study area.

Experiment 1 Biomass production potential in agroforestry/alley cropping practices (land preparation tree plantation, data collection)

Tree sampling

Walker hybrid poplar trees were planted in blocks. From the trees planted with plastic mulch over 90% survived. No fertilizers were used in the experimental field during the study period. Data collected over a three year period, from what started as a 4 year old research site, for alley cropping provided data to compare the benefit of alley cropping to conventional forage production practice. A total of 60 sample trees were measured for DBH (diameter at breast height) from each treatment. Trees from permanent transects were sampled in each block and again 12 trees' data were sub sampled from collected tree data.

Diameter and height

Measurements were taken for tree diameter at breast height 1.3 m (DBH). DBH (mm) was measured in 2009, 2010 and 2011. These provided the annual measurement during the term of the research effort. DBH was recorded for each tree in the sample plots. Initially measures were taken with callipers and as trees grew larger, measurements were taken with a DBH tape. Height measurements were taken with height rods.

Forage sampling

Forage samples were collected from the three different forage types. Samples were from the forage only treatment, the forage alleys and from forage under alley cropping trees. Three sampling transects were used for each of the three replicates. To provide an unbiased sampling point, near designated points along sampling transects; the sampling square was randomly thrown over the shoulder to locate the final sample point. Any forage growing within the 0.25 m^2 forage sampling square was clipped to within about 2 cm of the ground. The samples were hung in cotton bags and air-dried. When a stable weight was reached the final weight was determined. For forage sampling, total of 12 samples (0.25 m^2) were taken for each type and each rep.

Experiment 2: Trench and no trench

One alley cropping tree block in each of the north, centre and south replicates was selected for this experiment. A total of 4 trenches were created at the edge of each tree block with a tractor mounted chain trencher to the depth of one meter. Each trench was 12.5 m long, or a length equivalent to 4 trees plus ½ the distance to the next trees. Locations for all trenches were determined randomly. A piece of 6 ml vapour barrier plastic was inserted into each trench and then the trench was backfilled. The plastic curtain was meant to create a short-term root barrier to eliminate or reduce tree/forage competition. Prior to the start of the 2009 growing season, the plastic curtains were inserted. The trench was created 1.5 to 1.7 meter away from the outer tree row. Given a tree spacing of 2.5 meter between and within rows, this separation would give each tree an unrestricted growing area of about 2.5 m x 3.0 m or about 7.5 m^2. Each of 4 trees behind the trench was measured and compared to 4 trees to the north of the trench unless there was a dead or missing tree in that area. In the case of a dead or missing tree to the north, the 4 trees to the south of the trench were measured. Tree measurements were taken in the spring and fall of each of 3 years of studies. By comparing growth rates of trees with and without the barrier the significance of forage and tree competition could be determined

Figure 6: Installing a plastic curtain in a soil trench to assess competition

Experiment 3: Soil moisture (data collection and soil moisture volume calculation)

Soil sampling

Soil samples were collected twice per year to monitor soil water content. The first set of samples were collected at the end of May, prior to start of the growing season and second set of samples were collected in late summer or early fall, when crop growth had stopped.

Samples were taken to represent soil moisture at three depths: top (0–30); middle (30-60); and bottom (60-90 cm) of the soil profile for all reported parameters.

Samples were taken along the same transects each year, and in almost the same location, in order to reduce the effect of site variability. Two transects were used in each replicate.

Results allowed comparison of early season moisture levels between treatments that could be the result of snow trapping. Late season sampling will be able to compare moisture use throughout the growing season for 3 each of the treatments.

Soil sampling was done with a 5 cm Dutch soil auger for top 30 cm profile and a King tube with a drop hammer for 30-60 cm and 60-90 cm. Because of the gravelly/sandy subsurface layers, it was cumbersome and labour intensive to collect samples from deeper layers particularly during dry periods and thus sampling depth was sometimes restricted to 60 cm only. Samples were collected from each treatment during May to June for spring and September to October for fall, in 2009, 2010 and 2011. The samples were stored in soil moisture tins. The soil samples were first weighed for wet weight. The samples were then oven dried for 24 hours at 105° C and weighed for dry weight. For soil bulk density, samples were collected from all three depths in each block

Soil moisture calculation

$q_g = (W_w - W_d)/(W_d - W_c)$

$q_v = q_g * r_b / r_w$

where, q_g = gravimetric water content (g of water g^{-1} of soil), q_v = volumetric water content (cm^3 cm^{-3}), W_w = mass of wet soil and container (g), W_d = mass of dry soil and container (g), W_c = mass of container (g), r_b = bulk density of the soil (g cm^{-3}), and r_w = density of water (g cm^{-3}) (Klute, 1986).

Biomass calculation

Many equations have been developed to quantify tree aboveground biomass. We used the equation developed by Amichev (2010) for the calculation of walker hybrid poplar tree biomass. Based on the nature of our data, this equation was the best fit for calculating biomass production in our research study.

Above-ground wood = f(DBH)

$W_s = 0.077097 * (DBH^{2.2704})$

where, W_s (stem, bark and branches) = total biomass (kg/tree), DBH= Diameter at breast height (cm)

Statistical analysis

Biomass data were subjected to Shapiro-Wilk test option of SigmaStat 12 to account for homogeneity of variance and normality test before running an ANOVA. A separate analysis was performed to assess whether landscape (block/plot) positions for biomass productions and soil moisture volume were significantly different. This was conducted for only three treatments. Since landscape (block/plot) positions and their interactions were not significantly different, an additional analysis was run comparing only treatments. In case of no significant interactions, the data were pooled. Trench and no trench data from all three blocks were pooled before analysis as there is no significant difference between data in blocks. Whenever a significant interaction was observed between factors, the level of one factor was compared to each level of the other factor by all pair wise multiple comparisons. Where significant F values were obtained ($P<0.05$), treatments means were separated using Tukey-Kramer HSD test developed from an analysis of variance.

Results and Discussion

Experiment 1: Biomass production

Three years of research were completed to evaluate and compare of biomass production using agroforestry alley cropping concept at the Murdoch Lake site. Our observation indicates that the integration of trees in agroforestry systems can increase the amount of biomass compared to a monoculture field of forage. In 2011, total biomass contributions evaluated were statistically significant different in north block ($F= 17.31$; $df= 2, 17$; $P=0.001$). The total biomass production in both narrow alley and wide alley were significantly greater than the biomass production from forage alone. In 2011, we found that total annual biomass productions were 4.89, 5.00 and 2.72 t/ha in wide alley, narrow alley and forage only, respectively (Table 1). We did not observe any significant difference on the biomass production between narrow alley and wide alley ($F= 17.31$; $df= 2, 17$; $P= 0.226$). However, we also observed that a non-significant difference in biomass production of trees alone in wide alley and Narrow Alley between 2009 and 2011. Identical results were found from the data collected in 2009 and 2010. We found similar results in Centre and South blocks. Annual tree biomass was found to be highest in 2009 when trees were the youngest (3.52, 2.45 and 3.24 t/ha in 2009, 2010 and 2011, respectively). Second highest production was in 2011. The amount and timing of precipitation may help to explain these somewhat unexpected findings. Annual precipitation taken from August 1 to July 31, for each considered years, was 336, 285 and 394 mm in 2009, 2010 and 2011, respectively. The low growth in 2010 can possibly be explained by the lowest precipitation of the 3 year period. Perhaps the 2011 growth was relatively lower than 2009 because the majority of the rain (about 100 mm) occurred in July 2011, which was likely too late to contribute to significant tree growth. The average annual precipitation in Manning for the 10 years period from 1999 through 2008 was 480 mm. The difference between the 10 years average and the average during the 3 years project was about 140 mm per year.

Table 1: Different treatments of North, South and Centre Blocks; used for comparing Biomass production in 2009-2011

Wide Alley **($F_{ut} + F_{wf} + Tr_{alone}$)**	**Narrow Alley** **($F_{ut} + F_{wf} + F_{Tf} +$ Alley Tr_{alone})**	**Forage alone (F_{alone})**

Forage under Trees (F_{ut})	Forage under Trees (F_{ut})	Forage alone (F_{alone})
Wild Forage (F_{Wf})	Wild Forage (F_{Wf})	
Trees alone (Tr_{alone})	Tame Forage (F_{Tf})	
	Alley Trees (Alley Tr_{alone})	

Table 2: Biomass production in wide alley, narrow alley and forage alone treatments in 2009-2011

Annual biomass production (t/ha)			
	2009	**2010**	**2011**
Narrow Alley			
Trees alone (Tr_{alone})	3.52	2.45	3.24
F_{ut}+ F_{Wf}	0.81	0.77	1.76
Total annual biomass production	**4.33**	**3.22**	**5.00**
Wide Alley			
Alley Trees alone (Tr_{alone})	3.49	1.7	2.63
F_{ut} +F_{Wf}+ F_{Tf}	1.92	2.10	2.22
Total annual biomass production	**5.41**	**3.89**	**4.85**
Forage alone			
Forage alone (F_{alone})	**3.54**	**2.82**	**2.72**

Our observation indicated that the yield of forage alone reduced significantly over the years from 2009 to 2011 (F= 26.51; df= 2, 22; P= 0.001). It was also found that the wild forage yield significantly increased over the years in both wide alley and narrow alley from 2009 to 2011 (F= 10.16; df= 2, 22; P= 0.001) (Table 3). Increasing yield may be due to the moisture conserving effect of alley cropping comparing to the more open field of forage alone. In addition there might be the effect of establishment of a diversity of plants, including N-fixers such as buffalo berry. Possibly increase nutrient cycling with these forages and other “native” plants took longer to establish because they naturally established over time.

Table 3: Annual Biomass production of different forage treatments from 2009-2011

Annual biomass production (t/ha)			
Treatments	**2009**	**2010**	**2011**
Wide Alley			
Tame Forage	3.26	2.82	2.46
Forage under trees	0.97	0.84	1.16
Wild forage	1.52	1.46	2.35
Narrow Alley			
Tame Forage	3.26	2.83	3.00
Forage under trees	1.03	1.23	1.00
Wild forage	1.41	2.24	2.67

Hybrid poplar growth and biomass yield can vary significantly as a function of site characteristics, physiochemical soil properties, climatic conditions, and species genotype (Laureysens et al., 2004; Hansen 1992; Kopp et al., 2001). The aboveground biomass production of 4-yr old hybrid poplar stands in Europe (in short-rotation coppice culture) (Laureysens et al., 2004) and north central USA (Hansen, 1992) varied between 2 and 11 t/ha year^{-1} with considerable differences between clones. Growth and yield data reported in western Canada showed that 4-yr old walker hybrid poplar stands from five locations in Saskatchewan averaged stand volume from 1.91 to 2.07 m^3/ha (data from the Prairie Farm Rehabilitation Administration (PFRA) Agriculture and Agri-Food Canada; published in Anderson and Luckert (2007). The Prairie Farm Rehabilitation Administration (PFRA) has the longest measurement records for stands of different hybrid poplar clones in western Canada with stand age ranging from 4 to 25 yr. In some of the older hybrid poplar trials, PFRA yield data showed that 15 and 25 year old walker hybrid poplar stands volume 104.56 and 142.76 m^3/ha, respectively and which were considerably lower than the hybrid poplar yields reported in Europe and USA.

Results from different studies shows that biomass production is variable, ranging from 5.4 to 30 t/ha year^{-1} in the North Central Region of USA (Riemenschneider et al., 2001; Tufekcioglu et al. 2003; Geyer 2006; Goerndt and Mize 2008). Johansson and Karacic (2011) reported that poplar stands could produce 70-105 ton/ha biomass after 10-15 years growth. Similar research studies showed that a minimum productivity of approximately 5 - 6.5 t/ha year^{-1} was measured for *Populus* spp. on marginal site in Germany (Weisgerber, 1983; Busch and Kreysa, 1985; Dimitri, 1988). Heilman et al. (1993) published that mean annual aboveground leafless biomass production averaged 14.8, 11.4 and 24.3 t/ha year^{-1} at harvest at 4 years of age for *Poplus trichocarpa* Torr & Gray, *Poplus Deltoides* Marsh., and *P. trichocarpa* x *P. deltoides* hybrids, respectively.

Experiment 2: Trench and no trench

At the Murdoch Lake study, the results for tree biomass production did not differ significantly between trench and no trench treatments (F= 2.89; df= 1, 47; P= 0.096, F=2.718; df= 1, 47; P=0.106 and F=0.643; df= 1, 35; P= 0.428 for 2009, 2010 and 2011, respectively) though the three years research findings showed that biomass production in trenched trees were slightly higher than no trenched trees. We observed that the biomass in trenched trees were 1.9, 1.87 and 2.54 t/ha in 2009, 2010 and 2011 respectively whereas 1.72, 1.37 and 2.3 t/ha in no trenched treatments for years of 2009, 2010 and 2011, respectively (Table 4). No supportive studies with trenched and no trenched practices for walker poplar biomass production were found to corroborate our findings.

Table 4: Annual incremental tree biomass (t/ha) from 2009-2011

Treatments	Biomass (t/ha)		
	2009	2010	2011
Trench	1.9	1.87	2.54
No trench	1.72	1.37	2.3

Experiment 3: Soil moisture

In our study we found that there was statistically significant difference in soil moisture volume between Spring and Fall data in all three years, F=14.80; df=5, 135; P=0.001, F=10.94; df=5, 150; P=0.001 and F=7.84; df=1, 30; P= 0.009 for 2009, 2010 and 2011, respectively. We did not find any research findings to support our results. No significant differences were found between the depths for all three years.

In all but one treatment/depth item is an increase of soil moisture from spring to fall in 2011. This was due to significant summer rains.

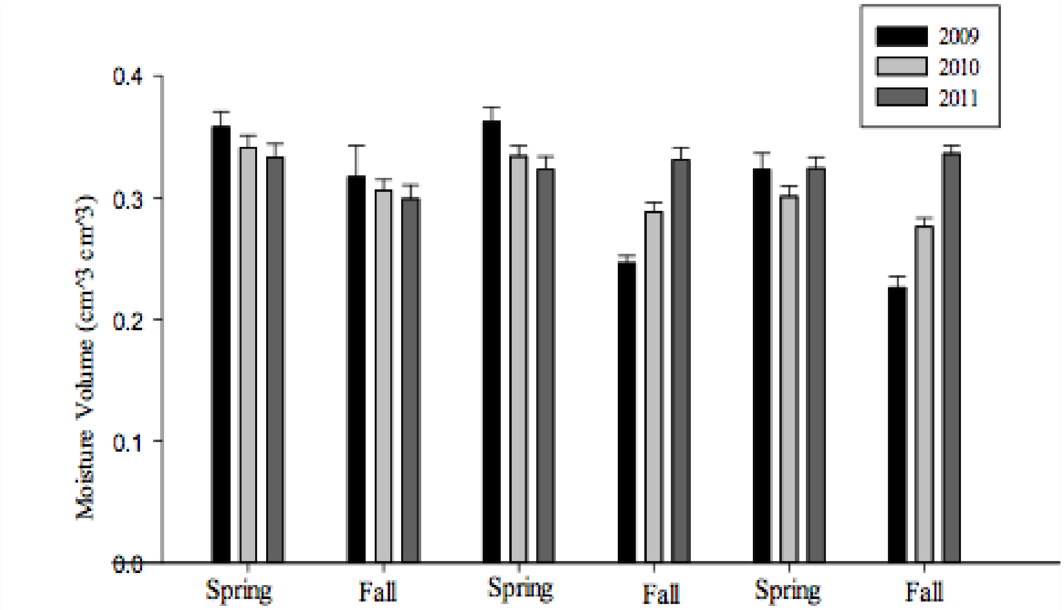

Figure 11: Mean (±SE) soil moisture content different treatments from 2009 - 2011. Columns marked with the different letter are significantly different (P > 0.05, ANOVA. Tukey's multiple mean comparisons)

Conclusion

To our knowledge, this is the first time in Western Canada that a research project has documented the growth of hybrid poplar in an agroforestry/alley cropping system and compared those results to biomass production of forage alone. The complete method for estimation above-ground biomass of Walker Hybrid Poplar was a time consuming but accurate sampling procedure. It is obvious from this study that Walker Hybrid Poplar can do well in plantation with forage mix agroforestry/alley cropping systems. Regardless of whether plantations are established on private or public land, they may increase expected future yield (Anderson and Luckert, 2007). Trench and no trench had no effect on biomass production of walker hybrid poplar, suggesting that there was little root competition between the trees and forage. This is consistent with the non-significant difference in tree biomass found in the narrow and wide alley cropping study. Identical results were observed for available soil moisture volume. No significant differences were observed between the soil depths 0-30, 30-60 and 60-90 cm. The data suggest that the alley cropping in agroforestry system would be more profitable for the farmers than forage alone if all biomass was valued equally. Forage alone biomass was gradually decreased over the years during the study periods and forage biomass in narrow alley and wide alley was increased over the years. This could be the result of no fertilizers being applied and tame forage stands tend to decrease in productivity over time without significant inputs. However, the increased forage biomass in narrow and wide alley was possibly due to improved moisture levels resulting from reduced evaporation from tree sheltering and snow trapping. It is also possible that nutrient pumping may have contributed to increased forage yields within alley cropping. The concept of nutrient pumping, as discussed in agroforestry, is that tree roots extend into portions of the soil profile (B and C horizon) that may not be accessible to annual crop root systems and that tree crops extract nutrients from these portions of the profile. These nutrients can then be redistributed over the entire cropping area through leaf litter. Based on values achieved in this single study, alley cropping may be recommending as a means of biomass production and established as a model for economic benefit as well for sustainable development. If the value of Walker Hybrid Poplar biomass for pulp and timber is low then perhaps it could be used as biofuel and burned for heat or electricity power production. The crop itself under agroforestry system may not differ significantly from other sources, however, agroforestry practices also provide additional integrated social environmental and economic benefits. We think that farmers and industries should be be interested in growing walker hybrid poplar trees in agroforestry/alley cropping system. This could be made easier if there was an additional monetary value provided by C sequester from trees. We also recommend further studies for walker poplar biomass production in alley cropping systems and observe the economic viability from the farmers' perspectives. While not statistically valid, the measurement of soil compaction data collected 2011 showed that compaction measured with a penetrologger was reduced under trees where cattle had an opportunity to graze, when compared to the forage alone treatment. Casual observation of tree health up to four years after cattle were grazing under trees indicated no significant signs of damage to the trees.

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