Literature Review: Windrow Woodchips as a Soil Amendment for Newly Cleared Agricultural Land in Yukon

August 25, 2017

Prepared For:

Energy, Mines and Resources Agriculture Branch

Yukon Government

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1.0 INTRODUCTION

Land suitable for agriculture in Yukon is limited to the major river valleys of the Yukon River drainage and sections of the Liard River drainage (Ball et al. 2013). Soils are typically low in organic matter and deficient in nitrogen and phosphorus, with potassium and sulphur also deficient in some areas (Ball et al. 2013). Permafrost occurs sporadically in the southern part of the territory and increases in frequency and area further north (Ball et al. 2013). The majority of agricultural activity takes place in the southwest Yukon where droughts often occur between April and July (Ball et al. 2013). Average heat units are the most limiting environmental factor in agricultural production (Ball et al. 2013).

1.1 Current Forest to Field Conversion Practices in Yukon

To convert boreal forest to agricultural fields, extensive land clearing is required. Between 2010 and 2012, 1171 ha of new agricultural land were titled in Yukon (Ball et al. 2013). Land disposition requires about 50% of land be cleared prior to title (Agriculture Branch 2006). If all farmers cleared the minimum requirement, this is equivalent to ~620 ha of cleared land in three years (Agriculture Branch 2006). Clearing involves the harvesting of merchantable timber (>3" DBH) and removal of other native vegetation (D. Murray pers. comm.). Non-harvestable woody debris is then piled in rows which can cover 20-30% of the cleared arable land (Land Resource Stewardship Division 2003).

The burning of windrows after clearing is standard practice in Yukon, as well as, other boreal forest jurisdictions including Alaska, BC and Newfoundland (Land Resource Stewardship Division 2003, Grünzweig and others 2004, BC Ministry of Agriculture 2014a). While burning is an efficient and practical removal method, concerns with air quality and carbon dioxide emissions (e.g. Johnson 2011) are starting to restrict the burning of wood wastes in many areas (Holtz et al. 2004; Miller et al. 2010). In Yukon, burning after land clearing is already restricted by the Land Development Branch of Community Services and recent clearing of the new Whistle Bend subdivision required chipping of wood wastes (L. Prentice, pers. comm.). Merchantable wood was salvaged and leftover wood residues were chipped and transported to the Whitehorse Waste Management Facility for composting. Chipping wood waste is an alternative to burning windrows on newly cleared agricultural land and may benefit both farmers and Yukoners.

1.2 Potential Benefits of Chipping Wood Waste from Windrows

Smoke from wood combustion is a source of airborne particulate matter which can negatively impact human health. Wood smoke from residential heating devices within Whitehorse results in many complaints each year and smoke concentrations are worst under calm winds with low temperatures that cause an inversion (Jones et al. 2014).

Burning of windrows after land clearing also elicits complaints to the Yukon Agriculture Branch (D. Murray, pers. comm.) and can significantly reduce air quality in rural areas for multiple days. Chipping rather than burning windrows would eliminate the production of wood smoke from land clearing. Chipping would not address the production of dust associated with clearing activities.

Burning ultimately "disposes" of wood waste, but chipped windrows still require some type of disposal. Incorporation of wood waste into soil is both a form of disposal and may also improve soil organic matter (OM). Improvements in soil fertility after wood waste incorporation have been demonstrated in many industries including forestry and agriculture (Holtz et al. 2004; Sanborn et al. 2004; Bulmer et al. 2007; Tahboub and Lindemann 2007). OM is a critical component of soil and Yukon soils tend to have very low levels of soil OM (Ball et al. 2013). The composition and form of organic matter amendments, however, greatly influence the effects on soil fertility. Material high in carbon (C) but low in nitrogen (N) (e.g. raw woodchips) can immobilize available soil N and reduce productivity of the soil for a period of time (Larney and Angers 2012). The incorporation of woodchips into newly cleared agricultural soils in Yukon, therefore, requires further investigation to determine whether woodchip amendments are likely to have a positive, negative or neutral effect on soil fertility (see Section 1.3 Objective).

From a global perspective, conversion from forest to agricultural land typically results in a net loss of C and this effect is most pronounced in boreal regions where forest soils have high carbon content (Grünzweig et al. 2004). Increased decomposition of organic matter, increased soil temperature and top soil erosion are principally responsible for C loss from agricultural soils (Grünzweig et al. 2004; Dawson and Smith 2007). Microbial degradation is also accelerated by practices such as tilling, fertilization and liming which increases microbial cellular respiration and releases carbon dioxide (Dawson and Smith 2007). Boreal forest soils contain 13-18% of global terrestrial carbon stock and with climate warming in northern regions, agricultural suitability of these areas will likely increase (Grünzweig et al. 2004). C loss from agricultural soils can be reduced through practices such as reduced tilling, maintenance of permanent cover crops, incorporation of crop residues and the application of organic amendments such as woodchips (Grünzweig et al. 2003; Dawson and Smith 2007; Lashermes et al. 2009).

1.3 Objective

Chipping instead of burning windrows could eliminate wood smoke production from current land clearing practices, increase soil organic matter and provide an avenue for carbon sequestration. The objective of this literature review is to evaluate the potential soil fertility benefits and assess the hazards of adding either raw or processed woodchips to newly cleared Yukon agricultural soils. The review will also briefly discuss other non-agricultural uses for woodchips in the territory.

2.0 Organic Matter as a Soil Amendment

2.1 Effects of Organic Matter on Soil Properties

Organic matter (OM) can be defined as any material that was once living. The chemical composition (e.g. nutrients) and structure of OM is as diverse as the organisms on the planet and cannot be defined as a single substance. In soil, OM not only provides nutrients, but also fundamentally alters the soil's physical, chemical and biological characteristics (Larney and Angers 2012). OM amendments are known to improve soil aggregate stability (soil structure), increase microbial activity, reduce bulk density, improve water retention and increase soil fertility (Lashermes et al. 2009; Larney and Angers 2012). In addition to agricultural applications, OM amendments are used in in forestry to rehabilitate soils after timber harvesting and improve growth of planted tree seedlings (Zebarth and others 1999; Bulmer et al. 2007; Campbell and others 2008)

2.2 Hazard of Nitrogen Immobilization: the C:N ratio

The use of woodchips as an organic matter amendment in agricultural soils has been largely avoided due to the hazard of immobilizing essential soil nitrogen (N) (Tahboub and Lindemann 2007). N in organic material needs to be converted to inorganic N by soil microbes to become available to plants; this process is called mineralization (see Figure 1.) (Larney and Angers 2012). During mineralization, microbes also require inorganic N to metabolize the organic matter, essentially removing a portion of the N from the soil; the removal of N by microbes is known as immobilization (Larney and Angers 2012). The N used by microbes is unavailable to plants until the microbes die (Larney and Angers 2012). Whether applied OM results in net N mineralization or immobilization has historically been attributed to the carbon to nitrogen ratio (C:N) with 20-30:1 considered ideal (Edmonds 1987; Tahboub and Lindemann 2007). Wood residues typically have C:N ratios higher than 100:1 (e.g. white spruce (*Picea glauca*) stem wood is >500:1 (Brais et al. 2006)) indicating N immobilization is inevitable. The C:N ratio is not always an accurate predictor of N mineralization, however, and environmental factors affecting degradation rates (temperature, moisture) and the OM chemical composition are also influential (Aber and Melillo 1982; Tahboub and Lindemann 2007; Lashermes et al. 2010).

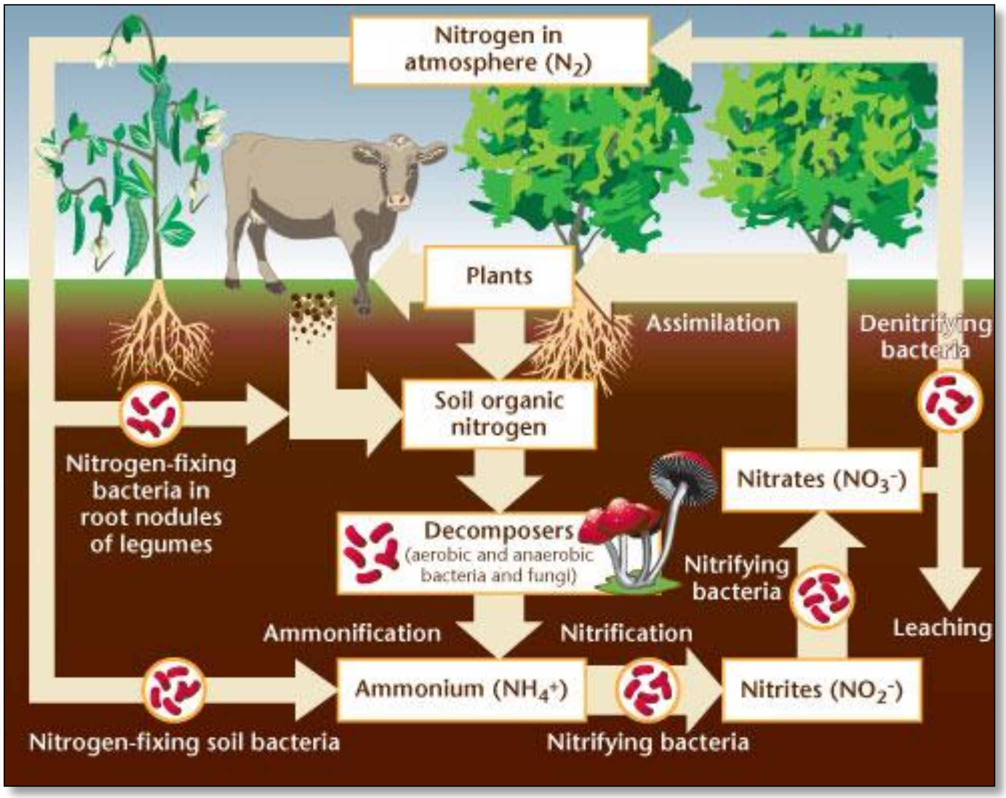

Image from Washington State University: http://cahnrs.wsu.edu/alumni/nitrogen-cycle/

Figure 1. The nitrogen cycle

There are similar environmental requirements for microbial degradation in agricultural and forested systems, but the sources of OM are markedly different (Aber and Melillo 1982). Woody residues contain high percentages of the complex compound lignin. Lignin is synthesized by vascular plants for physical support, the transportation of water and defense from disease (Campbell and Sederoff 1996). Lignin is resistant to microbial degradation and essentially surrounds and protects carbon (C) from decomposers (Tahboub and Lindemann 2007; Lashermes et al. 2009; Talbot and Treseder 2012). The presence of lignin lowers the amount of readily available C to decomposers, effectively reducing the functional C:N ratio. Lignin does not however, reduce the amount of N available to microbes (Talbot and Treseder 2012).

Woody residue decay rates are strongly influenced by initial N concentrations with higher net N mineralization reported with applications of high N organic matter (Flanagan and Cleve 1983; Laiho and Prescott 1999; Lashermes et al. 2010; Talbot and Treseder 2012). Initial N content increases the degradation rate of easily decomposable C until the resource is exhausted after which time lignin content largely determines the long term decay rate (Taylor et al. 1989; Lashermes et al. 2010; Talbot and Treseder 2012). The application of N fertilizer generally results in a reduction of lignin and corresponding "protected" carbon, potentially due to altering the microbial community composition (Edmonds 1987; Talbot and Treseder 2012).

For woody residues, the initial lignin to nitrogen ratio (L:N) is generally a better indicator of N dynamics than the C:N ratio (Melillo et al. 1982; Edmonds 1987; Talbot and Treseder 2012). Edmonds (1987) found that N mineralization can occur at C:N ratios greater than 300:1 and as the decay rate decreases, the critical C:N ratio increases. The higher the initial L:N ratio, the slower the matter decays (Melillo et al. 1982) and the thus, the hazard of N immobilization decreases despite the high C content of woody materials. Amendments rich in lignin are likely to have small but long term effects in soil as the organic carbon is relatively stable (Larney and Angers 2012).

2.3 Nitrogen and Carbon Dynamics in Newly Cleared Northern Agricultural Soils

Based on a study in Delta Junction and Fairbanks, Alaska, clearing boreal forest for agriculture can result in significant changes to C and N cycling (Grünzweig et al. 2003). In Alaska, summer soil temperatures increased by 4-5°C (Grünzweig et al. 2003). Nutrient dynamics followed patterns identified in the previous section. Net N mineralization after clearing was slow in newly cleared fields due to sparse root biomass, small amounts of easily degradable organic matter and low N concentrations (Grünzweig et al. 2003). Net N mineralization had a strong positive correlation with initial soil inorganic N and the amount of the easily degradable soil carbon (Grünzweig et al. 2003). N mineralization was likely limited by N rather than C (Grünzweig et al. 2003). Of note, fields left fallow after clearing had higher N mineralization than fields planted with barley (*Hordeum vulgare*) or oats (*Avena sativa*); the difference was attributed to higher soil moisture in fallow fields and possibly by competition for soil N between plants and microbes (Grünzweig et al. 2003). A critical moisture threshold for microbial degradation was identified between 0.15 and 0.2 mL H_2O/cm^3 (Grünzweig et al. 2003). Decomposition rates were largely insensitive to temperatures in cultivated fields (Grünzweig et al. 2003). Newly cleared soils in Yukon can thus be expected to have low soil N and low degradation rates under dryland conditions.

3.0 WINDROWS AS A SOURCE OF WOODCHIPS (ORGANIC MATTER)

3.1 Properties of Woodchips from Yukon Forests

The physical and chemical properties of woodchips differ by species and minor intraspecific variations are also common due to differences in growing conditions. In general, softwoods have higher carbon and lignin percentages than hardwoods (Lamlom and Savidge 2003). Within an individual tree, branches are typically higher in nutrients than stem wood and have lower carbon to nitrogen ratios (Merilä et al. 2014). Select characteristics of woodchips from boreal tree species are summarized in Table 1.

Table 1: Select characteristics of stem woodchips from common boreal tree species. Values derived from: (Alban and Pastor 1993; Lamlom and Savidge 2003; Conlin et al. 2004; Brais et al. 2006; Herrmann and Prescott 2008; Kim et al. 2009; Venner et al. 2011; Sable et al. 2012; Piggot and Janin 2017)

Species	**pH**	**C (%)**	**N (%)**	**C:N**	**Lignin (%)**	**L:N**
Trembling Aspen (*Populus tremuloides*)	4.8-5.1	47-49	0.11-0.45	92-465	20	45-180
Lodgepole Pine* (*Pinus contorta* var. *latifolia*)	5.0	50	~0.075	~790	26	~350
White and Black Spruce (*Picea glauca* and *P. mariana*)	3.5-4.4	50	0.04-0.11	530-1250	26	235-650

*only one reference found for nutrient concentrations, values estimated from a figure in Herrmann and Prescott (2008).

3.2 Estimated Woodchip Volumes from Yukon Forests

The volume or mass of timber residues left over after timber harvesting in Yukon is unknown (R. Sharples, pers. comm.). Near Prince George, an aspen forest in a moderately productive site (250 m^3/ha) yields approximately 42 tonnes (t) of wood waste per hectare (Conlin et al. 2004). An aspen forest in northern Quebec produced 52.3 t/ha wood waste (Belleau et al. 2006). Clear cut sub-boreal spruce, sub-alpine fir and transitional cedar-hemlock forests near Smithers and Hazelton, BC, yielded an average of 84.5 t/ha of wood waste (Kranabetter and Macadam 2007). A study in Manitoba reported 45.8-104.3 t/ha wood waste after boreal forest harvesting, with more waste being generated during winter than summer operations (Lieffers and Van Rees 2002).

Based on the values from southern boreal jurisdictions, the mass of slash produced after harvesting merchantable wood is 40-100 t/ha with conifer forests producing more waste wood than aspen forests. A major limitation of slash volume estimates after harvesting is they do not include stump biomass and slash mass is dependent on percent moisture which not constant. Recent land clearing for subdivision development in Whistle Bend, Whitehorse, produced considerably more than 100 t/ha of wood waste (data provided by the City of Whitehorse Water and Waste Services and Yukon Government Land Development Branch). Phase 3 clearing produced an average of 148 t woodchips/ha and Phase 3C resulted in 233 t chips/ha. The mass of woodchips is likely over estimated as there were significant amounts of "dirt" mixed with the chips. The mass of loads could also be influenced by precipitation or snow load depending on the season the chips were hauled to the City of Whitehorse Compost Facility.

More site-specific research is required to accurately estimate woodchip volumes from non-merchantable timber and wood residue generated from land clearing in Yukon.

3.3 Available Chipping Equipment in Yukon

There are currently three units dedicated to producing wood chips for biomass in the territory, with another being purchased in the near future (M. Thorpe, pers. comm.). Two of the machines are mobile and based in Haines Junction (Bear Creek Logging) and Watson Lake (Biomass North). The stationary unit is in Dawson City (Arctic Inland Resources). The Teslin Tlingit Council is in the process of purchasing a chipper/grinder for biomass energy production in Teslin.

A mobile 10' tub grinder is based in Whitehorse (Castle Rock Enterprises) and can handle clean wood waste of variable sizes. This unit, however, produces a 10 cm (4") chip which is quite large for biomass energy production, but may be suitable for agricultural amendments. Smaller capacity grinders/chippers are also used by the landscaping and tree removal services in Yukon, however these units are generally not suitable for large industrial applications such as chipping windrows.

3.4 Storage of Woodchips Prior to Use

Woodchips can be stockpiled for short periods of time, but the piles contain substances which can be toxic to both plants and fish (Conlin et al. 2004). Water percolating through woodchip piles can dissolve natural chemicals produced by trees and concentrate these compounds into a leachate. Leachate toxicity depends on the tree species, volume of stored chips, length of storage and amount of water entering the pile (Tao et al. 2005; Hedmark and Scholz 2008). Woodchip leachates can contain tannins, lignins, phenols, tropolones and resin acids (Hedmark and Scholz 2008). Of the dominant species in Yukon, trembling aspen chips generally produce a more toxic leachate than lodgepole pine or spruce chips (Rex et al. 2016). The leachates can cause direct toxicity to plant or aquatic life or reduce dissolved oxygen levels in watercourses (Tao and others 2005; Hedmark and Scholz 2008). As a soil amendment, woodchips are likely not concentrated enough to elicit a toxic response (Venner et al. 2011).

The relatively dry climates in most areas of Yukon indicate leachate generation is not a high hazard, however, leachate may still be generated during extreme precipitation events (Samis et al. 1999). Similar to best practices for storing manure, the storage site for woodchips should be located away from drainage features, water wells, and environmentally sensitive areas (Agriculture Branch 2015; Rex and others 2016). The BC Ministry of Agriculture policy states woodchips should not be stored more than two years and storing chips under cover reduces the hazards of leaching (BC Ministry of Agriculture 2014b). Storing woodchips in a cone-shaped pile rather flat-topped mound also reduces the production of leachate (Samis et al. 1999). Regardless of storage method, it is up to the landowner to ensure woodchip piles do not release contaminants (leachate) into the environment.

4.0 Woodchip Application Methods and Potential Effects on Soil Properties

4.1 Incorporation of Raw Woodchips into Soil

Due to the hazard of nitrogen (N) immobilization, the use of raw woodchips as organic matter (OM) amendments in agriculture is not well documented. Sources of woodchips for amendments are typically from livestock feedlot bedding (mixed with manure) and pruning wood waste from the horticultural industry. Woodchips have been promoted and used as an amendment for disturbed boreal forest soils post-timber harvest and these studies provide additional insights into woodchip effects on soil properties.

Reports of a decrease in inorganic soil N or yield were inconsistent with many studies reporting a negligible effect on soil N or yield after woodchip applications (N'Dayegamiye and Angers 1993; Entry et al. 1997; Tahboub and Lindemann 2007, TCC and CDSCIA 2016). When N immobilization occurred, yield reductions were short-term (one growing season) and often positively related to the application rate (Beauchemin et al. 1990; Beauchemin et al. 1992; Zeng et al. 1993; Holtz et al. 2004). Direct links between carbon, nitrogen and lignin were not possible to analyze as the chemical compositions of the woodchips were rarely reported. The pattern of short term N immobilization followed by a return to normal or "control" levels of soil N is consistent with the two phase degradation model of rapid decay; easily degradable nutrients are broken down quickly until lignin inhibits the majority of carbon breakdown (Taylor and others 1989; Lashermes et al. 2010; Talbot and Treseder 2012). High initial lignin:nitrogen ratios, large chip sizes or environmental factors limiting microbial degradation likely mitigated N immobilization in studies reporting no net effect on N dynamics (Aber and Melillo 1982; Tahboub and Lindemann 2007; Lashermes et al. 2010).

When woodchip incorporation was used as a fertilizer rather than as waste disposal, most studies added N in synthetic or organic forms. N was added to woodchips at a rate that balanced the C:N ratio between 20-30:1 (Entry et al. 1997; Miller et al. 2004; Tahboub and

Lindemann 2007). The N input generally increased soil inorganic N, but not necessarily yield (Sommerfeldt and Mackay 1987; Zeng et al. 1993; Entry et al. 1997; Miller et al. 2004; Sanborn et al. 2004; Tahboub and Lindemann 2007). For example, the application of fresh manure and straw resulted in higher mineralized N than the application of fresh manure and woodchips, however barley yield in both plots were similar (Miller et al. 2004). Yield is dependent on factors limiting plant growth and the effects of woodchips on soil properties other than soil N are also beneficial.

Woodchip amendments consistently improved soil moisture both in agricultural and forest soils (Beauchemin et al. 1990; Zeng et al. 1993; Gasser et al. 1995; Sanborn et al. 2004; Bulmer et al. 2007). When soil moisture was limiting, woodchip amendments improved potato yields (Gasser et al. 1995) and the survival of lodgepole pine seedlings (Bulmer et al. 2007). Chip size can also have an effect on soil moisture improvement: small chips increase water holding capacity better than large chips (Venner et al. 2011). Decreases in soil bulk density are also common after the incorporation of woodchips (Sanborn et al. 2004; Bulmer et al. 2007). In one study, very high rates of coarse chip fragments resulted in negative changes to soil texture; Norway spruce (*Picea abies*) growth was inhibited in woodchip amended mineral soil likely due to the coarse texture reducing water retention (Hallsby 1995). In Ontario, the incorporation of woodchips after land clearing reduced seeding success as large wood chunks presumably displaced the seed drill (TCC and CDSCIA 2016). Phytotoxic effects from woodchip leachates were not reported and leachates are not considered a hazard of applying small volumes of woodchips (Venner et al. 2011).

Based on the literature presented above, the immobilization of soil N after the addition of woodchip amendments is much less likely than commonly believed. The decomposition of woody residues are not primarily determined by the C:N ratio as seen in herbaceous plants, due to high percentages of lignin in wood tissue (Talbot and Treseder 2012). The chemical composition of aspen indicates aspen woodchips would be more likely to cause N immobilization than spruce or pine chips. Woodchip amendment effects on soil N were generally rate dependent which suggests there is likely an acceptable application rate for woodchips to most soils where degradation rates are inherently slow (Tahboub and Lindemann 2007). Application rates ranged from 18 t/ha (Tahboub and Lindemann 2007) to 100 t/ha (N'Dayegamiye and Angers 1993) in agricultural settings and up to 140 t/ha in forest soils (Sanborn et al. 2004). To achieve a net N benefit from woodchip amendments, an additional organic or synthetic N fertilizer was generally required. Fresh manure mixed with woodchips to achieve a C:N ratio of 30:1 performed well (Miller et al. 2004). If soil moisture is the limiting factor in crop growth, no fertilizer may be required to see a net benefit in crop yield (e.g. Gasser et al. 1995).

4.2 Composting Woodchips Prior to Incorporation in Soil

An alternative to amending soil with raw woodchips is composting woodchips with a high N material such as manure prior to use. Composting accelerates the aerobic microbial degradation of organic materials. The C:N ratio of compost is variable depending on the input materials, temperature and aeration and the finished compost C:N ratio is expected to be lower than the initial C:N ratio of inputs (Hubbe et al. 2010). The cation exchange capacity of compost is generally higher than raw residues (Larney and Angers 2012).

In a long term experiment evaluating manure with straw or woodchip bedding, fresh manure mixes consistently released more inorganic N than composted manure mixes (Miller et al. 2010). Composted manure and straw also released more inorganic N than manure composted with woodchips (Miller et al. 2010). Despite differences in soil N, composted and fresh manure amendments had a similar effects on barley yield (Miller et al. 2004). Composted woodchips can still immobilize N in certain situations and Beauchemin et al. (1992) reported decreased yield of potatoes after composted woodchip applications compared to N fertilizer amendments. Composted woodchips can also contain high levels of soluble salts and negatively affect plant growth. For example, the application of composted woodchips and biosolids resulted in the highest soil N of all amendments tested, however the high salinity significantly reduced survival of lodgepole pine seedlings (Bulmer et al. 2007). In the literature presented above, there was not a clear net benefit to justify the extra effort of composting woodchips prior to incorporation if woodchip disposal was the primary objective.

4.3 Conversion to Biochar Prior to Incorporation in Soil

Biochar is the generic term for a material produced by the combustion of biomass under very low oxygen conditions; the process is known as pyrolysis. When windrows are burnt in the field, only 2-3% of the biomass remains as charcoal and most of the N and sulphur is lost (Atkinson et al. 2010). Yield increases where windrows were burned are common in Yukon and attributed to increases in soil cation exchange capacity, the ability to "hold" nutrients rather than an increase in nutrients themselves (D. Murray, pers. comm.) Through controlled pyrolysis, about 50% of the carbon remains as well as many nutrients (Atkinson et al. 2010). The resulting biochar is predominantly stable C that can resist microbial breakdown for hundreds of thousands of years (Jeffery et al. 2011). The chemical and physical composition of biochar is dependent on the type of source material (e.g. manure, woodchips) and the pyrolysis temperature (Atkinson et al. 2010).

Adding biochar to soils to improve soil properties is not a recent activity. Anthropogenic Dark Earths or *terra preta* are soils in the Amazon basin amended with charcoal by indigenous peoples thousands of years ago (Glaser and Birk 2012). In natural rainforest soils, organic matter degrades rapidly and nutrients are leached by the heavy rainfall (Glaser and Birk 2012). The biochar amended *terra preta* has higher cation exchange capacity which facilitates the "holding" of nutrients which limits nutrient leaching (Glaser and Birk 2012). Recent interest in biochar has centred around biochar's potential for sequestering carbon in agricultural soils, reducing heavy metal mobility in contaminated soils and increasing productivity of agricultural soils (Jeffery et al. 2011; Stewart and Siciliano 2015). As an agricultural amendment, biochar can increase the water holding capacity, cation exchange capacity and pH of soils (Atkinson et al. 2010; Jeffery et al. 2011). Despite having a very high carbon to nitrogen (C:N) ratio, the carbon resists microbial breakdown and thus restricts N immobilization (Atkinson et al. 2010). Biochar effects on crop productivity are highly variable and site specific research is needed to determine impacts on crop yields (Atkinson et al. 2010).

In Yukon, the effects of biochar as a soil amendment were studied under both agricultural and mine remediation conditions from 2011 to 2015. In 2011, Zakus Farms produced biochar from multiple local materials including woodchips from black spruce (*Picea mariana*), trembling aspen (*Populus tremuloides*) and balsam poplar (*Populus balsamifera*) (Drury 2014). The woodchip biochar was the most desirable product tested (Drury 2014).

Table 2. Select characteristics and nutrient content of Zakus Farms' woodchip biochar (adapted from Drury 2014)

pH	**Total N (%)**	**NO_3 (%)**	**NH_4 (%)**	**Total P (%)**	**Total K (%)**	**Total Ca (%)**	**Total Mg (%)**
~7	0.97	<0.01	0.26	0.15	0.57	1.71	0.26

In field studies on three mine tailings sites in Yukon, compost with Zakus Farms biochar amendments had the highest vegetation cover (Nordeen 2015). Biochar as the only amendment, however, was not effective (Nordeen 2015). In greenhouse studies, biochar with fertilizer amendments resulted in less above ground biomass of native plants than other treatments, but significantly improved nitrogen fixation when *rhizobium* bacteria were also added (Stewart and Siciliano 2015). Improved nitrogen fixation after biochar amendments has also been reported in other studies (Jeffery et al. 2011). Biochar amendments without fertilizer caused stunting of native plants in the greenhouse (Stewart and Siciliano 2015).

In a three year agricultural trial involving multiple farms and crops, biochar with fertilizer amendments were not found to increase yields (Drury 2014). In one trial, biochar applications decreased potato yield and made foliage more susceptible to frost (Drury 2014). Biochar amendments influenced nutrient uptake, but no consistent patterns were detected (Drury 2014). With inconclusive results after three years, continued research before large scale applications of biochar was recommended (Drury 2014). The extra expense and effort to convert woodchips into biochar prior to incorporation in agricultural soils is likely not warranted.

4.4 Applying Raw Woodchips as a Mulch

Applications of woodchip mulches are very common in the landscaping industry where mulch typically reduces competition from weeds, improves soil moisture retention and moderates soil temperatures for ornamental species (Maggard et al. 2012). Isolated cases of N immobilization are occasionally reported (e.g. Larsson et al. 1997), but not common. Woodchip mulches have also been studied as method of site rehabilitation after timber harvesting (Bulmer 2000; Bulmer et al. 2007; Hallsby 1995). Reduced summer soil temperatures at a forestry site near Prince George had negative impacts on lodgepole pine growth after three years (Bulmer 2000). Low soil temperatures can also negatively affect root growth and water uptake of plants (Campbell et al. 2008). The lower soil temperatures, however, are also expected to limit microbial decomposition and could reduce the immobilization of N by microbes (Bulmer et al. 2007). In interior Alaska, a 10 cm woodchip mulch reduced soil temperatures by 8°C and caused N deficiency in ornamental plants; soil N was the same as the non-mulched control and the reduction in N uptake was attributed to the cooler soil temperatures or extensive rooting at the soil/mulch interface (Holloway 1992). There were no differences reported in lodgepole pine survival and height after woodchip mulch vs. incorporated woodchips; both wood waste treatments increased tree survival compared to no amendments (Bulmer et al. 2007). Woodchip mulches also improved Norway spruce survival with effects attributed to reducing competition from understorey vegetation and protecting the original humus layer from erosion (Hallsby 1995).

There is limited research on the effects of woodchip surface applications to pasture. In Tasmania, woodchip fines were applied to three year old pasture and rates of >20 t/ha caused negative effects on species composition and yield (Lane et al. 2001). The authors determined rates of 10-20 t/ha were acceptable without N fertilization, however, pastures without legumes or already low in soil N would likely benefit from additional N inputs regardless of woodchip application rate (Lane et al. 2001). In Ireland, timber residues were added to cattle overwintering areas and the resulting manure/woodchip residue was applied to perennial ryegrass (*Lolium perenne*) pasture (Augustenborg et al. 2008). The woodchip mulch did not alter N uptake of perennial ryegrass, but reduced the first silage yield due to shading of the soil (Augustenborg et al. 2008). Subsequent silage yields were not affected as the woodchips were naturally being incorporated in the soil (Augustenborg et al. 2008).

In Yukon agricultural soils, both soil temperature and soil moisture can be limiting factors in crop growth. Based on the information presented above, it is unclear whether woodchip mulch would have a net benefit on pasture productivity. Woodchip mulch needs to be applied after the pasture is established which would require storage of chipped material for a number of years prior to application. Bulmer et al. (2007) found that both incorporated and mulched woodchips improved soil moisture and the extra effort of storing woodchips prior to mulching may not be economical. Woodchip mulch about 10 cm thick would be suitable for pathways and other areas require vegetation control.

4.5 Other Uses for Woodchips

As the burning of wood wastes becomes a less acceptable practice, the need for alternative disposal methods has encouraged the development of multiple uses for woodchips. In Alberta, cattle and other livestock farmers are switching to woodchip bedding rather than straw bedding where woodchip wastes are readily available (Miller et al. 2010). Woodchips have also been used in construction to reduce erosion and stabilize slopes (Buchanan et al. 2002). Composting of municipal biosolids (sewage sludge) using woodchips as the carbon component is also be used as a method of waste treatment (Raichura and McCartney 2006). At the Yukon Research Centre, woodchips are being studied as a carbon substrate for passive treatment of mine effluent (Janin et al. 2016, Piggot and Janin 2017). With the remote nature of most Yukon mines, however, woodchips would likely be sourced on site rather than trucked in from agricultural areas.

In Yukon, there has been increasing interest in biomass energy with multiple municipalities considering woodchip biomass energy production for public buildings (Joannou 2016; CBC News North 2017). Raven Recycling in Whitehorse has also installed a wood boiler to test the efficacy of woodchip heat production (Cold Climate Innovation n.d.). The Yukon Government released a Yukon Biomass Energy Strategy in early 2016 which strongly supports the development of biomass energy for both public and private buildings (Yukon Government 2016). Local demand for high quality woodchips is expected to increase over time.

5.0 Synthesis

The application of raw woodchips to agricultural soils is considerably less energy intensive than composting chips or converting chips into biochar prior to use. If the objective is to dispose of woodchips, the literature indicates composting is generally not necessary. In addition, the inconclusive results of Yukon agricultural trials do not justify the additional expense and time of chip conversion to biochar. Mulching with woodchips significantly reduces soil temperatures which is likely to cause adverse effects on field crop yield in northern soils. Incorporation of woodchips into soil is the most economical method of disposing of woodchips created from clearing agricultural land.

There is likely a beneficial rate of woodchip incorporation into newly cleared northern agricultural soils. The high lignin content of boreal tree species and relatively slow decomposition rates in Yukon soils suggest the carbon component of woodchips will degrade slowly, posing little risk of severe N immobilization. Net N mineralization of organic materials remains dependent on the initial N concentration, which is low in boreal tree woodchips. Woodchips are therefore unlikely to provide a meaningful contribution to soil N. Incorporation of woodchips in soil can increase soil water retention which could be a major benefit for dryland production in Yukon where soil moisture is often a limiting factor in crop yield. If Yukon develops a drier climate with climate change, the increase in soil water retention after woodchip additions may become increasingly beneficial for dryland crop production. A combination of woodchips mixed with fresh livestock manure has frequently been cited as a beneficial soil amendment improving soil properties and fertility. Planting N fixing legumes as the first crop is another method of adding N to new soils. Even when woodchips are not incorporated, boreal soils are generally low in soil N and Yukon Government's Agriculture Branch recommends planting a N fixing green manure crop the first year after a field is cleared (Agriculture Branch 2006).

Application rates of woodchips in the literature varied widely and whether the rates were based fresh weights or dry weights was not reported consistently. In general, woodchip application rates in agricultural settings were between 20-50 t air dried chips/ha or approximately 5-12 cm depth of chips/ha tilled in. The amount of woodchips produced from clearing new land is uncertain, but 50 t/ha of woodchips is at the lower end of the rough estimates of woodchip volumes. Incorporation of all woodchips produced from clearing agricultural land may not be beneficial, however many other on and off farm uses for woodchips exist.

In addition to application rates, the method of clearing land and processing woodchips may influence the effects of woodchip incorporation into soil or usability of woodchips for other purposes. If woodchips are to be used solely for incorporation back into the soil, storage is not of concern. If woodchips will be used for mulch or biomass energy, more care is required to ensure the resulting woodchip product is stored clean and dry (preferably under cover on a paved surface). Another consideration is the size of woodchips produced. The size of woodchip particles influences the chip's ability to hold moisture and the speed at which chips degrade. Smaller chips hold more moisture, but are also degraded faster than large chips. If the end use of the woodchips is biomass energy production, the size of the chips needs to meet the boiler's specifications. Woodchips sizes for biomass are described in the EU Standard EN 14961 (See Figure 2). Whichever the planned end use, long term storage of woodchip piles is not recommended due to the leaching hazard.

Dimensions (mm), Analysis method EN 15149-1 [16]			
	Minimum 75 w-% in main fraction, mm [a]	Fines fraction, w-% (< 3,15 mm)	Coarse fraction, (w-%), max. length of particle (mm), max. cross sectional area (cm^2)
P16A	$3,15 \le P \le 16$ mm	≤ 12 %	≤ 3 % > 16 mm, and all < 31,5 mm The cross sectional area of the oversized particles < 1 cm^2
P16B	$3,15 \le P \le 16$ mm	≤ 12 %	≤ 3 % > 45 mm and all < 120 mm The cross sectional area of the oversized particles < 1 cm^2
P31,5	$8 \le P \le 31,5$ mm	≤ 8 %	≤ 6 % > 45 mm, and all < 120 mm The cross sectional area of the oversized particles < 2 cm^2
P45A	$8 \le P \le 45$ mm	≤ 8 %	≤ 6 % > 63 mm and maximum 3,5 % > 100 mm, all < 120 mm The cross sectional area of the oversized particles < 5 cm^2
[a] The numerical values (P-class) for dimension refer to the particle sizes (at least 75 w-%) passing through the mentioned round hole sieve size (EN 15149-1).			

Figure 2. European standard (EN 14961) for wood chips and hog fuel (Alakangas 2010).

Over the last 15 years, woody residues have become more frequently viewed as a resource than a waste. Woodchips can be used in agriculture as a soil amendment or as a horticultural mulch. Woodchips can also provide a carbon substrate for composting of municipal biosolids or reducing heavy metals in mining effluent. Woodchips are a source of fuel for biomass energy production. Chipping windrows rather than burning them reduces air pollution and can provide a local resource valuable to multiple industries.

5.1 Recommendations for Further Research

Plot scale research on application rates of locally produced, air-dried woodchips at rates of 25, 50, 75 and 100 t/ha is recommended. Trials would benefit from both nitrogen fertilized (organic or synthetic) and unfertilized sections. Conducting experiments in newly cleared soils would be ideal, however trials in established fields would also provide valuable information. Measuring both soil properties and plant biomass/yield over three seasons would likely be sufficient. As with any agricultural research, increasing the number and diversity of research site increases the applicability of the results to different areas. An draft experimental design is included as Appendix 1.

The other gap of knowledge further research could address is the volumes of woodchips produced after land clearing activities in Yukon. The current Costs of Agricultural Development in Yukon guidance document divides vegetation cover into five categories:

- *Open (scattered light aspen and willow with some small conifers)*
- *"Buck brush" dwarf birch and/or thick willow and scattered conifers*
- *Light aspen and burns*
- *Medium timber (open canopy with timber generally less than 90 years old)*
- *Heavy timber (mature spruce/pine with heavy and thick branches down to ground and a nearly closed canopy)* (Agriculture Branch 2017)

Considering the heavy equipment involved in clearing land, plot level research is not an accurate representation of clearing activities. Collecting data from already planned land clearing would be more beneficial and cost effective. Characterizing original vegetation into one of the five categories already established by the Yukon Agriculture Branch, clearing the land through common methods and measuring the volume of chipped wood waste would add accuracy to the estimates available in the literature. Extrapolation of woodchip volumes from piled windrows is also feasible, but would increase the uncertainty in estimates. Including measurements on the time required to chip wood from newly cleared land with also increase the value of the research.

6.0 Acknowledgements

The author would like to thank Laura Prentice at the Yukon Government Land Development Branch and Dawn Stagg at the City of Whitehorse Water and Waste Services for taking the time to compile data on the amount of woodchips coming out of Whistle Bend. Thank you also to Myles Thorp at the Yukon Wood Products Association for providing information about chipping equipment in Yukon. Robin Sharples, Alex Goeppel, Cory Chouinard and Aldo van Eyk at the Yukon Government Forest Management Branch also provided valuable information on current forestry research in Yukon and forest inventory methods – thank you. The reviews and suggestions by David Murray and Randy Lamb at the Yukon Government Agriculture Branch were also appreciated and improved an earlier version of this document.

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8.0 Appendix 1 – Proposed Experimental Design for Testing Woodchip Amendments

Introduction:

Based on an initial review of the draft "Literature Review: Windrow Woodchips as a Soil Amendment for Newly Cleared Agricultural Land in Yukon" on June 13th, 2017, the Yukon Agriculture Branch indicated interest in pursuing further research into woodchips as a soil amendment. The following is a rough outline of an experimental design for a field scale experiment at a single site.

Research Objective:

The primary objective is to determine if the incorporation of woodchips into newly cleared agricultural soil affects soil properties and crop yields. This study also seeks to evaluate if effects are dependent on application rate and/or influenced by the addition of nitrogen fertilizer.

Site Description:

The ideal test site would have no prior intensive land use and be representative of a mid to late successional northern boreal forest. To document initial conditions, a forest cover and soil characteristics inventory is required before clearing. Ideally, the test site would be near a large area suitable and desirable for agricultural development (i.e. where the information is most likely to be used in the future).

A forest inventory of both the timber and understory vegetation is recommended. If the site is within the Southern Lakes Boreal Low (BOLsl) biogeoclimatic subzone, determining the ecosite classification would also be valuable. A forest inventory will provide more information for interpreting research results than simple classification into the five categories recognized in the "Costs of Agriculture Development" (Agriculture Branch 2017). Variable radius (prism) plots are the most efficient way to calculate forest volume. Sampling intensity depends on the area to be cleared and heterogeneity of the forest stand. Five or six plots per stand type is usually sufficient, but for a detailed description of determining sampling intensity, see Forestry and Agrifoods Agency (2016). If several forest stand types are encompassed by the parcel, the area should be stratified prior to sampling. Within each stand type, plots can be randomly selected on a grid pattern. The prism size (basal area factor; BAF) should be selected to sample 7-11 trees per plot and kept consistent for the entire sample area (Ogden 2008). For each tree in the plot, record the species, diameter at breast height (DBH) and height. A 1 m x 1 m subplot of vegetation cover is sufficient for sampling understory vegetation.

Soil classification and inventory is often completed before an area of land is designated suitable for agriculture in Yukon. If not already known, the following parameters at 0-15 cm and 15-30 cm should be tested prior to clearing:

- texture
- pH
- Total N, NH_4, NO_3
- Total Organic C
- Available P
- Extractable K
- Cation Exchange Capacity (CEC)
- Other nutrients: Mg, Ca, S, etc. if possible

At least three separate samples are required to determine the variability of soil characteristics. The variability of site conditions largely determines study design and it is important to understand the complexity of the site. The more soil samples the better the data, however taking several composite samples can help increase sampling accuracy while mitigating analytical costs.

Clearing and Piling Windrows:

Once initial site conditions have been established, clearing may commence following standard practices. The type of equipment used, time of year and operational procedures are important to document. Any anecdotal information on keeping woody debris free of foreign material should also be noted as clean input material greatly increases the quality of the end product. The threshold for what was operationally considered salvageable wood and how logs were separated also needs to be recorded.

Chipping and Storage:

The equipment selected for chipping and the time required to chip windrows is essential information for future project planning and economic assessment. The storage method and time stored before use is also important to note. Immediately prior to using chips, five composite subsamples from the chip pile should be analyzed for the following:

- Carbon
- Nitrogen
- Lignin
- pH
- % moisture

Experimental Design

The recommended plot size is a minimum of 100 m^2, with the exact dimensions subject to the equipment available to incorporate the woodchips. For each treatment, a minimum of four replications is recommended. The optimal experimental design is dependent on site conditions and equipment capabilities (Gomez & Gomez 1984). If the site is relatively homogenous and it is feasible for equipment to apply treatments to each individual plot, a 2 x 5 factorial arrangement in a complete randomized design (CRD) is best. Complete randomization gives the best statistical power per plot, but requires environmental conditions to be relatively homogenous across the site.

If considerable environmental variation exists, the site can be stratified into "blocks" and factorial treatments are randomized within each block. Rather than four replicates, there are four blocks. Some statistical power is lost when the experiment is blocked, but blocking reduces the error associated with environmental variability.

If equipment function limits the ability to apply treatments to individual treatment plots, a strip plot (sometimes called a split plot) design can be used. This is a relatively common design in agricultural studies, but the statistical analysis is more complicated and main effects are harder to detect (loss of statistical power). For a strip-plot design, the study area is divided into a grid and each factor is randomized and applied in a vertical or horizontal strip (see Figure A-1). Replicates are done in separate blocks.

	A_1	A_3	A_2	A_5	A_4
B_2	B2A1	B2A3	B2A2	B2A5	B2A4
B_1	B1A1	B1A3	B1A2	B1A5	B1A4

Figure A-1. Strip plot experimental design.

Recommended treatments are four rates of air-dried (13% moisture) woodchip applications and a control with a single nitrogen fertilizer rate and control. Suggested woodchip rates are 25, 50, 75 and 100 t/ha. The nitrogen application rate is best based off soil testing results and in the mid to high range of the recommended rate. Whether the fertilizer is organic or synthetic can be chosen by the landowner. If an organic product such as manure is used, however, sampling the manure to determine the nutrient content is essential.

Crop Selection

Crop selection can be decided by the landowner provided the crop is representative of field crops grown in Yukon.

Sampling

Soil processes are relatively slow in Yukon and three growing seasons are likely needed to understand the effects of woodchip applications on soil properties. Monitoring temperature and precipitation during each growing season is standard practice for agricultural research. Because woodchip applications are expected to improve moisture holding capacity of soil, sampling soil moisture in the top 10 cm once every two weeks in each plot would also be beneficial. A known sample volume is required for determining soil moisture gravimetrically.

For crop yield metrics, randomly sample four 1 m^2 subplots within each plot, at least 1 m from the edge of the plot on all sides. Determine the dry biomass, dry grain yield and grain protein content from each subsample. Average the values from each subplot to determine the dry biomass, grain yield and grain protein content for each plot. Note that subsamples are not replicates as they originated from the same plot. If desired, samples could also be analysed for nutrient content such as percent nitrogen.

Soil samples at 0-15 cm and 15-30 cm should be collected from each plot prior to planting in the first season and each fall after harvesting. Parameters to measure are:

- texture
- pH
- Total N, NH_4, NO_3
- Total Organic C
- Available P
- Extractable K
- Cation Exchange Capacity (CEC)
- Other nutrients: Mg, Ca, S, etc. if possible

Statistical Analysis

The statistical analysis for the study is dependent on the experimental design selected. The simpler the experimental design, the more sensitive the analysis is in detecting treatment effects. For yield variables, the differences between treatments are of more interest than the differences between years (differences between years are also due to environmental conditions, not just treatments). For ease of analysis and interpretation of results, yields each year could be analyzed separately with an analysis of variance (ANOVA). Comparisons between years could be made at a general level without statistical testing as differences within each season are likely more important than differences between seasons.

For soil parameters however, differences between years are of more importance. Measurements taken at the same plot over time violates the ANOVA's assumption that all measurements are independent and a different approach to analysis is required. This is generally done with a mixed-model or split-plot design depending on the experimental design. Alternatively, the difference between initial soil parameters and soil parameters after Year Three could be analyzed with an ANOVA to determine treatment effects on soil properties.

Benefits of the Research

Incorporating woodchips from windrows into newly cleared agricultural soils could reduce wood smoke production from current land clearing practices, increase soil organic matter and provide an avenue for carbon sequestration. As woodchips are high in carbon, there is a hazard of nitrogen immobilization by soil microbes reducing soil fertility for a period of time. A review of literature regarding woodchip applications to soils indicated the high lignin content of woodchips reduces the likelihood of nitrogen immobilization, however, studies in northern regions were limited. This research would provide Yukon-specific information on the volumes of woodchips produced from clearing agricultural land and directly examine the impacts of woodchip applications on soil properties and crop yield. If woodchips applications have a neutral or beneficial impact on crop yields, policy on land clearing practices could be expanded to include chipping rather than burning windrows.

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