Agroforestry Community Gardens as a Sustainable Import-Substitution Strategy for Enhancing Food Security in Remote First Nations of Subarctic Ontario, Canada

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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ABSTRACT

The high prevalence of food insecurity experienced by remote First Nation (FN) communities partially results from dependence on an expensive import-based food system that typically lacks nutritional quality and further displaces traditional food systems. In the present study, the feasibility of import substitution by Agroforestry Community Gardens (AFCGs) as socio-ecologically and culturally sustainable means of enhancing food security was explored through a case study of Fort Albany First Nation (FAFN) in subarctic Ontario. Agroforestry is a diverse tree-crop or tree-livestock agricultural system that has enhanced food security in the developing world, as low input systems with high yields of diverse food and material products, and various ecological services.

Four study sites were selected for biophysical analysis: two *Salix spp.* (willow)-dominated AFCG test plots in an area proposed by the community; one "no tree" garden control test plot; and one undisturbed forest control test plot. Baseline data and a repeatable sampling design were established to initiate long-term studies on the productive capacity of willow AFCGs as a means to enhance food security in subarctic FN communities. Initial soil and vegetative analysis revealed a high capacity for all sites to support mixed produce with noted modifications, as well as potential competitive and beneficial willow-crop interactions.

Identification of barriers to food security and local food production in FAFN revealed a need for a locally-run Food Security Program (FSP) in partnership with the AFCGs to provide the personnel, knowledge and leadership necessary to increase local food autonomy and local food education and to manage the AFCG as a reliable food supply. Continued research on AFCGs and the FSP may allow wide-scale adoption of this strategy as an approach to enhance community food security and food sovereignty in remote FNs across Canada. An integration of conventional crops and native species in

the AFCGs is recommended as a bicultural approach to enhance social, cultural and ecological resiliency of FN food systems. As an adaptable and dynamic system, AFCGs have potential to act as a more reliable local food system and a refuge for culturally significant plants in high-latitude FN socio-ecological systems, which are particularly vulnerable to rapid cultural and ecological change.

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LIST OF ABBREVIATIONS

AF	Agroforestry
AFCG	Agroforestry Community Garden
BD	Bulk Density
CFS	Community Food Security
FA	Fort Albany
FAFN	Fort Albany First Nation
FN	First Nation
FSP	Food Security Program
HD	Horizontal Distance
IC	Inorganic Carbon
IN	Inorganic Nitrogen
K	Potassium
SM	Soil Moisture
Mg	Magnesium
N	Total Nitrogen
SOC	Organic Carbon
ON	Organic Nitrogen
P	Extractable Phosphorus
s	Soil Structure
SOM	Soil Organic Matter
VD	Vertical Distance

A) <u>INTRODUCTION</u>

A 1) BACKGROUND

Canada's First Nation (FN) people are known to have a disproportionately high prevalence of health conditions linked to poor diet, including obesity, tooth decay, heart disease, Type 2 diabetes and hearing impairments, among other health conditions (Fagot-Campagna, 2000; Young *et al*., 2000; Bowd, 2005; Willows, 2005; Ho *et al*., 2008). The diet of Canadian Aboriginals is said to be low in fruits and vegetables (Willows, 2005), while high in fat and sugar (Willows, 2005; Ho *et al*., 2008). As Willows (2005) emphasizes, food selection is not necessarily indicative of food preference; poor dietary habits ubiquitous to FN communities are related to their high risk of experiencing food insecurity (INAC, 2004; Willows, 2005; Skinner *et al*., 2006; Stroink and Nelson, 2009).

Food Security can be defined as "access by all people at all times to enough food for an active, healthy life, including availability of nutritionally adequate and safe foods that can be acquired in socially acceptable ways" (INAC, 2004). Food security in remote FN communities of northern Canada is challenged by a modern dependence on an unreliable, import-based food system that sometimes lacks nutritional quality, bears high transportation costs and results in loss of traditional food systems and associated knowledge, ultimately degrading individual and community health (INAC, 2004; Willows, 2005; Skinner *et al*., 2006; Willows *et al*., 2008). This modern system is also extremely resource-intensive, while, it simultaneously perpetuates absolute reliance on the unstable fossil-fuel industry and global food economy (Bellows and Hamm, 2001; Polack *et al*., 2008). Modern food systems, therefore, prevent these historically vulnerable populations from regaining self-reliance, traditional culture, healthy livelihoods and sense of individual and community empowerment (Skinner *et al*., 2006; People's Food Policy, 2010).

These limitations characteristic of modern FN food systems have been well-recognized for some time. Only within the past seven years, however, have political bodies and NGOs throughout Canada directed significant efforts towards local and autonomous subsistence food production as a holistic means to remedy this (Section B 4). Efforts have been much more prevalent in southern FNs where growing conditions are more hospitable, despite the much more limited access to healthy foods experienced by geographically isolated communities of the north. However, the capacity for food production in subarctic and arctic zones continues to increase with a warming climate; researchers predict an increase in the length of the growing season, enhanced plant growth rates and greater soil nutrient availability in the north, and in turn, more hospitable conditions for growing a greater variety of edible plants (Shuur *et al*., 2008). Although increased productivity will subsequently increase carbon sequestration in biomass in high-latitude systems, the net effect will be a positive feedback towards warming due to significant levels of carbon release from permafrost thawing in the arctic (Oelbermann *et al*., 2008; Shuur *et al.*, 2008).

The spread of conventional agriculture to the north could perpetuate the climate change problem. Modern agricultural methods release large amounts of CO_2 and N_2O through heavy use of industrial machinery and chemical fertilizers (Robertson, 2004); they also result in extensive forest clearing followed by intensive land management that result in losses of carbon stores from both above-ground biomass and soil organic carbon (Gordon and Newman, 1997). Conventional agriculture is also characterized by replacement of diverse ecosystems with monoculture crops, pollution by high use of pesticides, fertilizers and herbicides, reduced ground water levels, soil degradation and pollution of surrounding undisturbed ecosystems (Gordon and Newman, 1997; Young, 1997; Robertson, 2004). Yet as FN populations continue to increase (Statistics Canada, 2001), climate change provides more hospitable temperatures for northern crop production (Shuur *et al*., 2008) and food insecurity of northern communities gains political attention (Section B 4), we should anticipate, and indeed encourage, an agricultural movement in the northern areas of Canada as an import-substitution strategy.

Previous efforts by European Missionaries to establish agrarian societies in northern indigenous communities during the 20th century did not endure to present day and in the process impacted traditional food systems and the current dependency on modern foods and government subsidies (Loring and Gerlach, 2010; People's Food Policy, 2010). In consideration of this, as well as the aforementioned dangers associated with conventional agricultural, enhancement of food security via food localization in remote FN communities requires a thoughtful investigation of socially, culturally, ecologically and economically sustainable means of agricultural production.

Agroforestry (AF) is an alternative land-use system to conventional agriculture that has been utilized as a socioeconomically and ecologically sustainable means to establish long-term food security in impoverished areas, mainly within the sub-tropic and tropic regions (Vogl et al., 2004; Huai and Hamilton, 2009). It is a relatively recent term for an ancient practice of agriculture, which, by definition, is a land-use system that combines woody perennials (trees, shrubs, etc.) with crops and/or livestock in spatial and temporal arrangements that optimize beneficial biological interactions and economic outputs (Gordon and Newman, 1997; Young, 1997). In the present study, I will explore the feasibility of introducing AF to isolated, northern FN communities as a sustainable food localization strategy to enhance food security in the light of climate change.

A 2) THESIS PROPOSAL: Agroforestry Community Gardens (AFCGs) as a Sustainable Import-Substitution Strategy for Enhancing Food Security in Remote FN Communities of Subarctic Canada

A 3) RATIONALE

In contrast to conventional agriculture, the use of multiple components and multiple species in AF systems maintains ecological diversity and allows for diversification of food and economic products (Gordon and Newman, 1997) through a practice that is resource efficient and ecologically sustainable (Jose and Gordon, 2008). AF systems in the tropics, sub-tropics and temperate China have played a substantial role in enhancing food security, as low input systems with diverse and complementary food products (Ninez, 1987; Gordon and Newman, 1997; Boncodin et al., 2005; FAO, 2010). The reduced mechanical intervention allows for maintenance soil integrity and more closed nutrient-cycling (Young, 1997), subsequently, reducing the need for expensive and ecologically-damaging chemical inputs (Quinkenstein, *et al*., 2009). As potential carbon sinks and diverse agroecosystems, northern AFCGs may act as a strategic response to climate change in contrast to conventional agriculture, in both mitigating carbon dioxide and adapting to anticipated ecological changes (Kumar *et al*., 2009; Quinkenstein *et al*., 2009).

AF is much more prevalent in the tropics and sub-tropics, though it has been recently incorporated into conventional agricultural practices of temperate regions, primarily to enhance economic and ecological sustainability of crop production (Gordon and Newman, 1997). Even in temperate systems, inclusion of trees in agriculture has proven to enhance total output per unit area, increase yield via wind protection, provide financial diversity and flexibility, mitigate non-point source pollution, control soil erosion and create wildlife habitat (Gordon and Newman, 1997). However, it has not been widely applied in temperate regions as a means to address food security and no known use of AF in the subarctic or arctic regions has been documented. According to Gordon and Newman (1997), research of feasibility of transferring these systems to other regions is necessary.

Current food localization strategies in FNs of Canada are exploring community gardens to achieve simultaneous benefits of food security and community fellowship over the land (Section B 4). The present study seeks to bridge FN community garden initiatives with AF, a strategy that has proven to enhance food security in an ecological sustainable manner. However, AF literature identifies homegardens as the only AF system designed to support subsistence food production (Fernandes and Nair, 1986). There is currently no term for a community, subsistence AF system, thus, the concept of an "Agroforestry Community Garden" (AFCG) has been coined here.

The present study is intended to initiate a long-term investigation of the following novel research areas:

1. AF systems as a strategy to address food security issues in subarctic Canada, with potential application to temperate and arctic regions.
2. The transferability of subsistence AF designs to meet the needs of a region with drastically different ecological challenges than tropic and sub-tropic regions.
3. The transferability of subsistence AF designs to meet the needs of isolated FN communities which have a unique history of food systems and food security challenges.
4. The capacity of AF systems, in contrast to conventional agriculture, to sequester carbon and reduce the effects of unpredictable climate changes for high-latitude ecosystems.
5. A new form of AF that embodies agroecological design of the tree-crop component, while, promoting food security and community fellowship with each other and the land.

A 4) OBJECTIVES

To initiate this long-term investigation, the present study will focus on the following objectives:

1) Investigate the effect of Missionary settlement on indigenous food systems and landscapes, and highlight social and biophysical considerations for successful and sustainable reintroduction of agriculture to the north.

2) Begin assessing the feasibility of utilizing AFCGs as an import substitution strategy to enhance food security in remote FN communities and to assist these ecologically and culturally sensitive areas in responding to rapid cultural and environmental change.
3) Develop an AFCG test plot and sampling design for long-term studies to explore the capacity of subarctic AFCGs to act as food producers and ecological and cultural refuge

A 5) INTRODUCTION TO CASE STUDY: FORT ALBANY FIRST NATION

Fort Albany First Nation (FAFN), situated in the James Bay Lowlands of northern Ontario, Canada, is an isolated FN community that was used as a case study to implement the aforementioned study objectives. FAFN is located along the south coast of the Albany River about 20 km inland from the west coast of James Bay. In a population of 850, most FAFN residents inhabit Sinclair Island of the Albany River, nearby the mainland. FAFN has been selected as a case study for investigating the potential role of AFCG local food production in remote FN communities for several reasons. It is a geographically isolated community of subarctic Canada (52^{o} 15` N; $81^{o}$ 35` W; Tsuji, 1996) that is currently experiencing disproportionate effects from climate change (Hori, 2010). Despite successful (yet unsustainable) agricultural production by Christian missionaries in the mid-20^{th} century in FAFN, this community is currently battling barriers of food cost and availability of fresh, good-quality, perishable foods (Skinner *et al*., 2006). Although the Mission's agricultural movement was not a viable long-term approach to food security, it does act as witness to the area's potential ecological capacity to support basic fruit and vegetable cultivation.

FAFN is situated in the western portion of the James Bay Lowlands, which is nestled in the Hudson Bay Lowlands, the largest extensive area of wetlands in the world (MSSC, 1996). The James Bay ecoregion is thus mainly flat and dominated by poorly drained muskeg or peat moss (Hanson, 1953;

Kataquapit, 2006). The area is subject to abundant rain and cool, short summers (Kataquapit, 2006), with a mean annual temperature of -2^{o}C, and mean annual precipitation of 700-800 mm (MSSC, 1996). It is considered a perhumid high boreal ecoclimate and is an area of transition between the coniferous and mixed forests of the clay belt to the south and the tundra to the north (MSSC, 1996).

B) <u>LITERATURE REVIEW</u>

The ultimate purpose of this section is to explore the potential role of local food production in enabling Aboriginal (First Nations, Inuit and Metis) peoples of Canada to gain greater ownership and more diverse opportunities in their food systems by creating food systems that are ecologically and economically prosperous, as well as socially and culturally enriching.

B 1) ETHNOHISTORY OF FIRST NATION FOOD SYSTEMS

B 1.2) Traditional Indigenous Food Systems

Traditional foods can be defined as culturally acceptable foods from the local, natural environment (Kuhnlein and Receveur, 1996; Willows, 2005). The traditional diet of north Canadian Aboriginals prior to European colonization was composed mainly of wild meats including fish, ungulates, small mammals and waterfowl and a small portion of wild berries and other plant products (Guyot *et al.*, 2006); thus it required an intimate and reciprocal relationship with the land and each other, creating a community-oriented society that valued cooperation, sharing, generosity and respect (Milburn, 2004; Willows, 2005). Traditional foods continue to have nutritional, cultural and spiritual value to community members (Guyot *et al.*, 2006); the acquisition and preparation of traditional foods remains closely related to life satisfaction and social capital in indigenous communities (Stroink and Nelson, 2009; Trull 2009). Recent studies have also shown that sense of aboriginal identity is related to sense of community, emotional well-being and connectedness to nature, a trait valued by aboriginal cultures (Trull, 2009). Thus, traditional indigenous food systems have substantial social, cultural and nutritional value and have significant relations to individual and community well-being.

B 1.3) Degradation of Traditional Food Systems

In the mid-20th century, indigenous children were sent to residential schools, separated from their elders and prevented from speaking their native tongue or practising traditional ceremonies (Tsuji, 1996). These nomadic peoples were forced into sedentary communities of the agrarian lifestyle, thereby decreasing time and energy available for harvesting (Kuhnlein and Receveur, 1996). Similarly, neighbouring Alaskan natives were discouraged from sourcing locally-available foods and products because their dynamic, ecologically-based food system was interpreted as unreliable and nutritionally inadequate (Loring and Gerlach, 2010). With the introduction of a cash-based economy, the traditional indigenous lifestyle was impacted by employment and introduction of new foods (Kuhnlein and Receveur, 1996). Consequently, a loss of knowledge of harvest, preparation and preservation of traditional foods is evident in current populations of northern communities (Ohmagari and Berkes, 1997; INAC 2004; Willows, 2005; Stroink and Nelson, 2009).

Morrison (2008) of the BC Food Systems Network recognizes several factors contributing to the degradation of the health and abundance of culturally important indigenous foods including contamination, genetically engineered plants, as well as movement (either expansion or contraction of distributional range) of plant and animal species in response to global climate change. Contamination or displacement of local foods by continuous resource development and unpredictable climate changes appear to be the predominant threats to northern regions. Traces of heavy metals, organochlorides and other environmental contaminants are continually being found in natural resources utilized by indigenous communities (Kuhnlein and Receveur, 1996; Tsuji *et al.* 2001; Cooper *et al.* 2005; Tsuji and Martin, 2009). The impact of this contamination is not only degradation of individual health, but ultimately, restricted harvest of local, traditional foods (Kuhnlein and Receveur 1996).

Aboriginal peoples of sub-arctic and arctic regions are noticing changes in climate that are affecting traditional food harvest: changes in species composition, abundance, and migration (Guyot *et al*., 2006). These changes are considered to positively or negatively affect food harvest (Guyot *et al*., 2006). However, the unpredictability of climate change has been the only consistent factor (Guyot *et al*., 2006). Shorter ice-freeze in northern Canada, due to increasing temperature, has also limited accessibility to traditional foods (Ford *et al.*, 2008). As northern ecosystems are highly dynamic, they are vulnerable to global climate change (Elmqvist *et al*., 2004). Thus, climate change can be expected to further retard accessibility to local, traditional foods of the north. While acculturation caused severe degradation of traditional food systems, resource contamination and global climate change assist in perpetuating the loss and limiting its regeneration.

B 1.4) Introduction of Agriculture to the North

Agriculture was eagerly introduced to indigenous communities of the far north, because educators, administers and bureaucrats deemed Aboriginal diets as far less diverse and reliable than they truly were (Loring and Gerlach, 2010). Waisberg and Holzkamm (1993) report the success of an agricultural boom by the Ojibwa of northwestern Ontario, initially for commercial sale, and later as subsistence production as the population increased. The Canadian government provided the Ojibwa with farming equipment and livestock. In fact, Ojibwa depended primarily on fish and garden produce during the 1880s, with 467 acres dedicated to agricultural land. The gardens ranged in size from 0.7 to 2.03 acres where corn, pumpkins, potatoes, carrots, wheat and peas were grown. This agricultural initiative was challenged by provision of inadequate equipment, inferior livestock and insufficient training by the Canadian government. Further, the Canadian government discouraged Aboriginal cultivation and held tight control over the agricultural operations. Indeed, in 1881, the government prohibited Indians from selling their agricultural products to non-Indians, deeming the land unprofitable to its owners.

Eventually, the arable reserve land was appropriated for Euro-Canadian settlers.

Similarly, a long history of farming in Alaska has been ignored, because it too was never a sole means of subsistence for the population (Loring and Gerlach, 2010). Crop cultivation as well as family, community, and school gardens were components of a “flexible and diversified subsistence strategy” in Alaska during the mid-20th century. Despite the fact that indigenous Alaskans were gardening as early as 1765, prior to cultivation by Europeans in the area, state officials became frustrated by a lack of progressive transition to agriculture as a primary subsistence activity. They labelled the “garden outreach” program a failure and appropriated much of the land.

As a result indigenous agriculture never really established in the 20th and 21st centuries (Waisberg and Holzkamm, 1993), because communities of the subarctic and arctic Americas had to deal with unpredictable frosts, short growing seasons and a clear lack of self-determination over their land. Thus, these communities became dependent on social assistance to acquire expensive imports (Loring and Gerlach, 2010).

B 1.5) Modern Food Systems of Remote First Nations

Presently, traditional foods have been replaced by market foods in dominant food systems of FN communities. Stroink and Nelson's (2009) study in a FN of northwestern Ontario revealed that the communities did not value whether their food connected them to the land or not, rarely gathered berries and almost never grew vegetables, making grocery stores and convenient stores the most frequented sources for food. Within the market, fruits and vegetables are among the least purchased foods in subarctic communities of northwestern Ontario (INAC, 2004). Perishable foods make up a small fraction of the diet in these communities; the little fruit and vegetables they do eat are typically purchased frozen or canned, or come in the cheaper form of sugary juice crystals (INAC, 2004).

It has repeatedly been found that the greatest barriers to healthy eating in northern communities of Canada are costly and poor quality produce of little variety (Willows, 2005; Skinner, 2006; Skinner *et al*., 2006; INAC, 2009a; INAC, 2009b). Fly-in northern towns of Ontario are dependent on imported perishables that are expensive and more often than not, bruised and rotting (Skinner, 2006). Despite partial subsidization of produce transportation by the Canadian Food Mail Program, fruits and vegetables can be five to ten times more costly than in southern Ontario (Skinner, 2006). With high levels of poverty and greater reliance on social assistance, factors known to be associated with food insecurity, Aboriginal Canadians are further impeded from accessing these pricey imported foods (Willows *et al*., 2008). According to Tarasuk (2001), the primary indicator of hunger in Canada has been the use of charitable food assistance programs, known as food banks. It is therefore difficult to estimate the level of food insecurity in isolated northern communities who lack access to such programs. However, numerous studies have identified the persistence of food insecurity in northern aboriginal communities of Canada (INAC 2004, Skinner *et al*., 2006, Stroink and Nelson, 2009; Willows, 2005).

Most studies of remote FN food insecurity attributed this state to their dependence on unaffordable, poor-quality produce (INAC, 2004; Willows, 2005; Skinner et al.2006; Willows et al., 2008). However, a deeper investigation of values and behaviours of FN consumers reveals that this dependency may be rooted in a common experience of social insecurity and continuous environmental change (Stroink and Nelson, 2009). A study of FN community members in north-western Ontario reported health, ease, taste, familiarity, convenience, and affordability as factors driving their choice of food (Stroink and Nelson, 2009). Yet the authors note the greater frequency of bananas and oranges being consumed over blueberries and raspberries, despite the abundance of the latter in the wild (Stroink and Nelson, 2009). Contrary to self-reported values, such cases do not reveal affordability and abundance as forces that drive food choice behaviour in practice, making convenience and getting food from the grocery store more valuable to the citizens (Stroink and Nelson, 2009). Where previous literature on food security in FN is often based on self-reported claims of values and accessibility, these recent findings provide new insights to underlying causes of food insecurity in northern communities. Stroink and Nelson's (2009) study, suggests that remote FN communities feel more secure about the dominant food system than the local food system, and were comforted by the consistent convenience. INAC (2004, pp. 74) argues that "socio-economic status is a less important risk factor for chronic disease than stability in the physical and social environment, an individual's sense of understanding of his/her environment and control over events affecting his or her life". They report such known risk factors in FN communities as unemployment, extreme concern about alcohol and drug abuse, family violence and high food costs (INAC, 2004). Food localization strategies must therefore consider additional factors influencing food choice.

B 2) THE GLOBAL INDUSTRIALIZED FOOD SYSTEM

B 2.1) Impacts of Imports

In the past thirty years, the industrialized global food system has been recognized as unsustainable: globalization externalizes costs, disconnects producers from consequences of resource extraction and human resource abuse, eliminates ecological and social diversity, eliminates small business and makes local communities susceptible to collapse (Korten, 1995; Korten, 1999; Daly, 2002; Dale, 2005). North American food systems of the 20^{th} century were marked by an increase in crop specialization, production and petroleum-based transportation and a decrease in small, localized farms (Polack *et al.*, 2008). Food security and fossil-fuel supply are thus tightly linked, making nutritional acquisition subject to fluctuations in oil production and pricing. However, global oil field discovery has been in decline since the early 1960s, while global demand and prices continue to increase and the future of alternative energy sources remains uncertain (Polack *et al.*, 2008). Northern communities are impacted by high costs of gasoline, particularly for hunting (Guyot *et al.*, 2006, Stroink, Personal Comm., 2010); even traditional food systems are now dependent on petroleum and feeling the effects of its depletion. In addition to local impacts, this fossil-fuel dependent food system is exhausting a limited resource and making significant contributions to air pollution and carbon dioxide emissions, from which the entire globe suffers.

By relying on the industrialized food system, northern communities are both enablers of the globalized food system and victims of its impacts. In addition to being incredibly vulnerable to market fluctuations (Bellows and Hamm, 2001) and petroleum-related issues (Polack *et al.*, 2008), such local communities suffer losses in local self-sufficiency, alternative knowledge systems, cultural and ecological diversity, social and ecological resilience; thus, a capacity for locally based food security (Holling, 1995; Gibson *et al*., 2007; Polack *et al.*, 2008).

B 2.2) Conventional Agriculture in North America

A sustainable approach to food security must critique modern approaches to food production; as Bellows and Hamm (2001) explain, conventional agricultural techniques may not be suitable as part of a sustainable, local import substitution strategy. Prior to the 1960s, North American forests were relied upon for wood fuel, building materials, sugar, nuts, berries, wild game, woodash fertilizer, mushrooms, herbs and as a source of clean water for both European settlements and First Nations tribes (Gordon and Newman, 1997; Young, 1997). Government subsidies from 1960-1980 encouraged intensive agriculture to displace natural areas; even poorly productive lands were farmed with the intense management allowed by subsidization (Gordon and Newman, 1997). With the loss of woodlands, wetlands, windbreaks and hedgerows - and the rapid mechanical manipulation of the land - extreme land and water degradation occurred (e.g., loss of soil fertility, excessive soil erosion, soil compaction; Gordon and Newman, 1997; Young, 1997). Accompanied by the use of crop monocultures, conventional agricultural production on increasingly degraded lands became increasingly dependent on high use of pesticides, fertilizers and herbicides, further degrading natural resources and displacing native biodiversity (Gordon and Newman, 1997; Bellows and Hamm, 2001). Monocropping systems also created biological dependency on expensive, non-local technologies and inputs resulting in unsustainable working conditions and inconsistent labour requirements (Bellows and Hamm, 2001).

B 3) Towards Sustainable Food Systems in Remote First Nation Communities

B 3.1) Import Substitution via Local Food Production

Since the early 1980s, the concept of a more local, ecologically sustainable, and democratically controlled food system, as an alternative to a globalized food system run by large agribusinesses, has gained popularity in academic literature (Feenstra, 1997). Polack *et al*. (2008), for example, ask for re-localization of agriculture at the community and regional levels to ensure long-term food security. Bellows and Hamm (2001, pp. 271) define "import substitution" as a process where "community food security efforts lead to substituting local production for what has previously been imported".

According to the literature, import substitution may allow:

- Economic localization, encouraging good working relationships, creation of new local jobs and re-circulation of household food budgets back through the community (Korten, 1999; Bellows and Hamm, 2001)
- Establishment of self-reliance and loss of vulnerability to fluctuations and inequities of the global market (Korten, 1999; Bellows and Hamm, 2001; Vaidyanathan, 2002)

- Maintenance of resource efficiency, protection of local human and natural resources and reduced pollution generated by import transportation (Nozick, 1992; Korten, 1999; Bellows and Hamm, 2001).
- Increased food freshness and choice over food variety (Bellows and Hamm, 2001)
- Maintenance of traditional lifestyle and unique community culture (Vaidyanathan, 2002)

Bellows and Hamm (2001) argue, however, that there is no certainty that local food systems will produce local autonomy and sustainable development. These authors define local autonomy as "the political capacity of a diverse public to negotiate its food needs both locally and *vis-a-vis* non-local food system actors" (pp. 281) and sustainable development as "the ability of the more local-based food systems to contribute to the future integrity and health of human and non-human environments" (pp. 281). They identify autonomy and sustainable development as characteristics for which potential local food systems should be analyzed. According to these authors, when determining whether a local import substitution inspires these characteristics, it is imperative to consider potential consequences of displaced and unsustainable labour outcomes, unequal participation in the benefits or compromises of non-human environments, human livelihoods and political capacity. Since these authors examine American food systems, the applicability of their considerations to remote communities of Canada may need to be further examined. These considerations do, however, warrant a cautious approach to localization in the north and ask for a more relevant examination of potential risks and adaptive management plans to northern food localization.

B 3.2) Beyond Food Security: Community Food Security and Food Sovereignty

Polack *et al.* (2008) characterize a sustainable, local food system as one using ecologically sound production and distribution practices, and enhancing social equity and democracy for all community members. Referring specifically to poor communities, Ekin (1990) argues that such communities need to meet their own needs from their own resources in order to take an independent stand, become self-determining and make their own contribution to the common good. As Feenstra (1997) emphasizes, the role of food extends beyond nutritional acquisition, affecting environmental, social, spiritual and economic well-being.

Like food security, Community Food Security (CFS) ensures that all households have nutritionally adequate and safe food, acquired in socially acceptable ways (Winne, 2010). It differs, however, with an emphasis on community self-reliance, empowerment, social justice, and democratic decision making (Hamm and Bellows, 2003; Winne 2010). It involves decreasing the distance that food needs to travel, ensuring food security and adequate wage earning and working conditions, and inclusion of all food system participants in decision making about availability, cost, price, quality and attributes of their food. Hamm and Bellows (2003, pp. 37) sum CFS as: “a situation in which all community residents obtain a safe, culturally acceptable, nutritionally adequate diet through a sustainable food system that maximizes community self-reliance and social justice”.

By contrast to simplistic food assistance and emergency food distribution programs of North America, Community Food Security Coalition claims to address the underlying causes of hunger and food insecurity, reaching for long-term system-based solutions (Winne, 2010). The complex history of northern food systems and inter-related socio-economic issues call for the systems-based approach of CFS, as opposed to food security initiatives alone.

Food sovereignty is also a recent term for a systems approach to food security. It is defined by the Working Group on Indigenous Food Sovereignty as the “newest and most innovative approach to addressing the complex issues impacting the ability of individuals, families and communities to respond to their own needs for healthy culturally adapted Indigenous foods" (Morrison, 2008, pp. 11). The major contrast to CFS is its specialized representation of indigenous food systems and their unique complexities. The Working Group coined the term, food sovereignty, in 2007 and began engaging Aboriginal communities in discussion that would enable the group to support their work on increasing food security. From these discussions, the group highlights four key principles of Indigenous food sovereignty (Morrison, 2008, pp. 12):

1) Sacredness: nurturing healthy, interdependent relationships with the land, plants and animals
2) Self-determination: responding to their own needs and freedom from dependence on grocery stores or corporately controlled food production and distribution in market economies
3) Participatory- maintaining traditional food strategies
4) Policy- impacting traditional land and food systems

They also concluded that indigenous food systems are best described in ecological rather than neoclassical economic terms: "indigenous food systems include all of the: land, soil, water, air, and culturally important plant, fungi, and animal species that have sustained Indigenous peoples over thousands of years or participating in the world" (Morrison, 2008, pp. 5). Values of interdependency, respect, reciprocity and ecological sustainability were identified (Morrison, 2008). Consideration of these indigenous perspectives and values, which were notably lacking during the Missions of the 20th century, is vital to successful introduction and sustainability of local food systems in FNs.

B 4) Current Food Localization Initiatives in First Nation Communities

Canadian FN communities are showing recent interest in local garden initiatives as holistic means to encourage individual and community health. Within the past eight years, political bodies and NGOs throughout Canada have directed significant support towards local and autonomous subsistence food production:

Working throughout North America, the Working Group on Indigenous Food Sovereignty has included food box programs, community gardens, ethno-botany tours, greenhouses and kitchens as part of their mission to encourage food sovereignty (Morrison, 2008). They have a heavy community education focus on topics such as traditional food, cooperation between generations, healthy food choices, social networking and community development, which they deliver through workshops, booklets and magazines.

British Columbia appears to be the leading province on the FN gardening initiative. The FN Agricultural Association of BC builds capacity for large-scale agricultural production to enhance economic development in FNs. The FN Community Food Systems for Healthy Living Project has been providing food gardens to FNs since 2005 as a means to provide better access to local, fresh and healthy foods, create opportunities to connect with the land and to build community connections (BC Ministry of Healthy Living and Sport, 2010). The group has received extended funding from the provincial government's ActNow Incentive Fund to promote the connection between fresh food and good health, create local, sustainable food systems that simultaneously increase employment, preserve the integrity of the land and promote self-reliance (Ministry of Agriculture and Lands, 2007). In addition to local food provision, the group acknowledges additional benefits to human health including physical activity, outdoor therapy and maintenance of "traditional connection to land-tenure". FN communities continue to receive funding from ActNow for clearing, fencing, seeds, small machinery and root cellars.

From 2003 to 2008, almost 40 communities in British Columbia have "received grants through the

Aboriginal Agriculture Initiative (AAI) to establish community and allotment gardens, build greenhouses and water systems, and buy tools, bedding plants and seeds" (Levenston, 2008). For example, the Eniyud Health Services Root Cellar and Greenhouse Project of the Xeni Gwet'in FN community provides "healthy, clean, locally-grown vegetables and contributes to the ecological integrity of the local bioregion" (Levenston, 2008). The Neskonlith Indian Band near Chase, BC, uses AAI funding to support their "Promoting Healthy Food and Healthy Families by Allotment Gardening" project to grow nutritious food and create an aesthetically pleasing community gathering space (Levenston, 2008). The AAI also supports the BEADS (Building Economics through Agricultural Diversity & Sustainability) project in Canim Lake, B.C., which teaches horticultural techniques and traditional gathering and preserving of indigenous foods (Levenston, 2008). The AAI strives to enable FN communities to become self-sustaining in the area food production and to create employment for Band members (Levenston, 2008).

The Okanagan Indian Band in BC receives funding from Health Canada to teach environmental education through their community garden project (BC First Nations Head Start, 2002). The indoor garden allows children, parents and elders to learn about and experiment with plants and also provides a supply of a variety of vegetables to be donated to elders. At the University of British Columbia, the UBC Farm has developed a Musqueam Community Kitchen Garden which supplies produce to the Musqueam community kitchen to address nutrition concerns, such as diets compatible with diabetes (UBC Farm, 2010).

Within northern Ontario, The Lakehead University Food Security Research Group (2010) has been introducing community and backyard gardens in three different remote, FN communities of northern Ontario. The project includes works with community members of all cohorts to build and maintain gardens, compost bins, paths and root cellars and educating the community on food preparation and preservation. The anticipated benefits of establishing community gardens in these FN communities are maintenance of traditional knowledge, healthier eating through access to fresh vegetables, increased self-esteem through community accomplishment, increased physical activity, and greater connection of the community with each other, their traditional culture and the land; in other words, to promote overall health and well-being.

The Indian Agricultural Program of Ontario (IAPO), a non-profit organization owned by Status Indian farmers, holds the mission to "cultivate sustainable economic growth of Ontario FN People through a loans program, advisory service and a youth training program geared towards agricultural projects" (IAPO, 2010). Beyond Factory Farming (2010) works to promote livestock production that is "safe, fair and healthy for the environment, farmers, workers, animals, neighbours, communities and consumers". They promote the protection of FN land from environmental consequences of factory farming and industrial agriculture. Acting as an information hub for other FN agricultural organizations, they highlight several non-profits currently working to promote sustainable food systems in FN communities of British Columbia, Manitoba, Saskatchewan and Ontario.

Local food action in Canadian FNs can also be found throughout the prairies; Muskoday Organic Workers Co-op of the Muskoday First Nation in Saskatchewan initiated several organic community gardens in 2008, with the intention of making the reserve more ecologically and economically sustainable, and has already observed the benefits of community unification over the gardens (The StarPhoenix, 2008). The Waywayseecappo First Nation of Manitoba has rehabilitated old rodeo grounds into a community garden and walking trail and planted around 200 hills of vegetables (Healthy Together Now Chronic Disease Prevention, 2010); as a result of their community planting workshop and nutrition bingo, they have observed greater interest creating their own flower and vegetable gardens.

In summary, a variety of institutions in Canada have turned to food localization as a means to achieving a variety of desirable outcomes, including economic diversity and development, employment, preservation of ecological integrity of FN lands, community resilience and self-reliance, connection to the land and each other, preservation of traditional culture, inter-generational cooperation and socialization, self-esteem, physical activity and overall health and well-being. These are commonly being sought through provision of nutritional, clean, locally-grown foods via sustainable agricultural practices and education on harvest, preparation and preservation of traditional and other nutritional foods.

B 5) AGROFORESTRY

B 5.1) Socioeconomic and Cultural Services of Agroforestry

AF systems in the tropics, sub-tropics and temperate China have played a significant role in enhancing food security as diverse, resilient and reliable local food systems (Ninez, 1987; Gordon and Newman, 1997; Boncodin *et al.*, 2005; FAO, 2010). By incorporating multiple species in production systems, AF adds diversity at field, farm and landscape levels (Gordon and Newman, 1997); thereby, reducing risk of devastating crop losses from environmental catastrophe (Vogl-Lukasser and Vogl, 2004; Jose and Gordon, 2008).

The mix of annuals and perennials increases land-use efficiency, resulting in long- and short-term returns and multiple outputs that provide a sustainable and stable flux of diverse products (Gordon and

Newman, 1997). Crops may provide short-term return, while, the less labour-intensive tree component can provide timber in the long-run (Gordon and Newman, 1997). The tree component may also provide more immediate services, such as, fodder for livestock, decreased soil erosion and improvement in soil organic matter, nutrient status and soil structure, thereby enhancing agricultural sustainability (Gordon and Newman, 1997). The tree component also acts to modify microclimate, protect crops from winds, reducing evaporation and transpiration, increasing soil moisture and humidity, minimizing natural disasters and, subsequently, increasing crop yield (Gordon and Newman, 1997). Having flexible management options and low requirements for expensive fertilizers and pesticides, subsistence AF can provide long-term food security for vulnerable communities. Diverse AF systems of the tropics, particularly homegardens, are also known to have played a role in conservation of crop germplasm resources (Huai and Hamilton, 2009); thus, providing refuge for culturally significant plants from rapid environmental change (Huai and Hamilton, 2009).

B 5.2) Ecological Services of Agroforestry

The use of trees and multiple species in AF systems maintains ecological diversity year-round, providing refuge and corridors for local wildlife (Gordon and Newman, 1997). The tree component of AF systems is also known to assist in mitigating non-point-source pollution, reducing wind erosion and improving water and air quality (Gordon and Newman, 1997). In contrast to conventional agriculture, the presence of trees with diverse crops results in less soil erosion and runoff of sediment and nutrients (Young, 1997). Less mechanical intervention and enhanced biological diversity also allow for maintenance of natural nutrient-cycling and soil integrity (Young, 1997) and reduces dependence on fossil fuels and ecologically-damaging chemical inputs (Quinkenstein, *et al.*, 2009), and emissions of N_2O and CO_2 (Robertson, 2004).

These agroecosystems can be more resource efficient because they require fewer inputs and productivity per unit area of land tends to be greater (Jose and Gordon, 2008). Further, nutrients and moisture are better maintained by greater synchronization between diverse components with diverse temporal resource use (Schroth and Sinclair, 2003; Jose and Gordon, 2008).

B 5.3) Agroforestry in North America

While formal study of AF as a science began relatively recently, the practice itself is more than 6000 years old (Gordon and Newman, 1997). Before the European settlement of North America, First Nations utilized AF systems much like subsistence farmers in other parts of the world (Gordon and Newman, 1997); they manipulated the environment through fire, seeding and transplanting and created AF systems to produce diverse food and material products and as a means to control soil erosion (Gordon and Newman, 1997). Soil management was a strong component of indigenous AF systems (Young, 1997) and became a major incentive for modern agriculturalists to return to AF strategies (Gordon and Newman, 1997).

AF started re-appearing in North America in the 1980s with the realization of the economicaly, socially and ecologically unsustainable nature of conventional agriculture (Gordon and Newman, 1997). The main drivers were economic diversification, environmental impact mitigation, land and water rehabilitation and restoration, habitat enhancement, and profitability (Gordon and Newman, 1997). However, AF practices in temperate, industrialized countries tend to focus on few, highly-valued crops as to improve the economic profitability of farms, rather than meeting subsistence needs (Long and Nair, 1999).

B 5.4) Agroforestry and Climate Change

Fossil fuel depletion and rapid climate change have been recent instigators expanding interest in agroforestry (Quinkenstein *et al*., 2009). In response to climate change, Shuur *et al.* (2008) predict that local ecological changes in high-latitude ecosystems may either offset or accelerate the effects of carbon release. Permafrost thawing is predicted to release substantial levels of organic carbon into the atmosphere, while, increased productivity create more carbon sinks in northern biomass. According to Schuur *et a.l* (2008), however, the net effect will be a positive feedback towards a warming climate. Lengthening of the growing season, enhanced plant growth rates and increased soil nutrient availability are suspected to forge more hospitable conditions for growing a greater variety of edible plants over a longer period of time (Shuur *et al*., 2008). While this is promising for local food production in northern communities, traditional ecological resources continue to be threatened by the rapid rates of these climatic and ecological changes (Guyot *et al*., 2006).

AF systems offer relief, particularly in contrast to conventional agriculture, in their capacity to both mitigate atmospheric carbon dioxide and adapt to anticipated ecological changes. The AF sector has received recent attention for its potential to mitigate atmospheric carbon dioxide in the cold climate Trans-Himalayan region and in temperate Europe (Kumar *et al*., 2009; Quinkenstein *et al*., 2009). AF systems have high potential as carbon sequesters because of their inclusion of the tree component, high levels of soil organic carbon and low mechanical tillage (Kumar *et al*., 2009; Quinkenstein *et al*., 2009). Being more diverse, and thus more resilient to environmental disturbance than conventional agriculture, they have potential to act as a more reliable local food system (Ninez, 1987; Boncodin *et al*., 2005), a refuge for culturally significant plants (Huai and Hamilton, 2009) and habitat for conservation of local wildlife (Gordon and Newman, 1997). These assets are vital to climate change resilience in high-latitude communities, which are already vulnerable to rapid cultural and ecological change and experience patchy and inconsistent resource availability (Elmqvist *et al.*, 2004).

B 5.5) Agroforestry Design

Agrisilvicultural (tree-crop) AF systems are designed to emulate natural conditions by using perennial and annual mixtures, contrasting the linear design of annual monocultures used in conventional agricultural (Young, 1997). Similar to ecological systems, AF systems allow disturbance to provide a periodic window for annuals (Jose and Gordon, 2008) and maintain fertility via internal recycling between plants and soil in a naturalized equilibrium (Young, 1997). Use of the right species combinations in the right locations with the correct spatial and temporal configurations can encourage biological interactions between wildlife and farming systems, as well as between crops and tree species that optimize desired ecological and socioeconomic services (Gordon and Newman, 1997). The most common types of AF systems and their services are briefly described below:

- *Shelterbelts* (*Windbreaks*): linear plantings of trees or shrubs that provides wind and snow protection to adjacent fields and changes microclimate in these fields, resulting in improved crop quality and yields or improved health of livestock (Gordon and Newman, 1997). They can also be used to protect homes, filter airborne sediment, buffer waterways and serve as wildlife corridors (Gordon and Newman, 1997).
- *Silvopastoral Systems*: intentional maintenance of tree and livestock components for the purposes of sheltering livestock and diversifying income (Gordon and Newman, 1997; AFTA, 2010).
- *Tree-based Intercropping* (*Alley-cropping*): planting crops between rows of trees to control wind erosion, create sheltered microclimates to improve crop yield and quality, create wildlife habitat, and diversify income (Gordon and Newman, 1997; AFTA, 2010).
- *Riparian Forest Buffers*: planting strips of trees, shrubs and grass between cropland or pasture and surface water courses to protect water quality and reduce erosion and flooding (AFTA, 2010).

- *Forest Farming Systems*: utilizing existing forested or wooded areas to produce timber and other economically valued products on a regular or annual basis (Gordon and Newman, 1997).
- *Plantation Systems*: cultured trees grown on former agricultural sites to improve soil structure, increase organic matter content, slow erosion and improve nutrient status, while also buffering adjacent areas from negative impacts of agricultural activities (Gordon and Newman, 1997). Trees may be used for biomass production for fuel, fibre, fodder and waste management (Gordon and Newman, 1997).
- *Homegardens*: association of multipurpose trees and shrubs with annual and perennial crops, and sometimes livestock, within the compounds of individual houses (Fernandes and Nair, 1986). These highly diverse, multistrata systems are the primary AF system for subsistence production because of their ability to produce diverse products, including nutrient rich foods, timber, medicine and spices, in small areas (Huai and Hamilton, 2009).

Selection of a particular AF system is entirely dependent on social, ecological and economic needs (Huai and Hamilton, 2009). As previously mentioned, no term for a community garden style of AF currently exists in the literature. Thus, homegarden, tree-based intercropping and shelterbelt system designs are further explored below for their potential contribution to AFCGs. The benefits of subsistence production of diverse, nutritious foods by homegardens, and the ability of tree-based intercropping and shelterbelt systems to protect crops from harsh weather conditions, act as wildlife habitat and sequester carbon, are functions desirable for AFCGs in remote FN communities of the north.

i) Homegardens

In agroforestry literature, the term “homegarden” refers to “landuse practices involving deliberate management of multipurpose trees and shrubs in intimate association with annual and perennial agricultural crops and, invariably, livestock, within the compounds of individual houses, the whole crop-tree-animal unit being intensively managed by family labour"” (Fernandes and Nair, 1986, pp. 281). While the term is often used in other literature to describe any gardens adjacent the household, homegarden will be used here strictly to refer to gardens that include the tree or shrub component. Homegardens are the primary AF system used for subsistence production for enhancing food security, especially in areas where food cost and distribution are barriers to proper nutrition (Fernandes and Nair, 1986; Ninez, 1987). The FAO (2010) emphasizes the role of homegardens in producing direct access to a diversity of nutrient rich foods and complementary food sources during seasonal lean periods. Thus, homegardens may support traditional food systems of the north if crops complement seasonal hunting and fishing.

Homegardens include ecologically adapted and complementary species and are marked by low capital and labour input, simple technology and high productivity (Ninez, 1987; Huai and Hamilton, 2009). They have become increasingly popular as an ecologically sustainable means to improve income, food production and family nutrition, maintain soil fertility and soil structure and contribute to biodiversity by displacing commercial monocultures and acting as germplasm banks for indigenous and endemic plants (Boncodin *et al.*, 2005; Huai and Hamilton, 2009). They provide diverse products which have been used as timber, shade, forage, medicine, fruits, vegetables and spices (Huai and Hamilton, 2009).

Emulating natural systems, homegardens are dense, multistoried and inherently dynamic, maintaining overall structure and function of the system over time (Fernandes and Nair, 1986; Gordon and

Newman, 1997). Homegarden success is prominent in tropical areas, where there is greater sun exposure and a longer growing season; however, vegetation layering is not a functional adaptation for household gardens in cooler, sun-poor regions of the world (Ninez, 1987). Thus, despite the common experience of vegetable gardens in homesteads of Canada, significantly less research has been conducted on homegardens in temperate climates (Vogl *et al.*, 2004). However, Ninez (1987) describes general homegarden design appropriate for temperate or high-altitude areas; in contrast to tropical homegardens, trees and bushes are well-spaced with ground-covering species left unshaded. Since annual seed culture is prominent in northern hemisphere due to distinct warm and cool seasons, annual seed cultures which can easily be rotated will dominate. There is also reduced inter- and mixed-cropping, resulting in a more open vegetation canopy for full use of solar radiation; unlike tropical systems, northern ecosystems lack the "erosive torrential rain patterns" that require dense canopies to protect the understory. Spontaneous soil regeneration takes place to a minor degree, with less organic matter production, slower decomposition rates and increased surface exposure to wind and rain.

ii) Shelterbelts

Shelterbelts, or windbreaks, are linear plantings of trees or shrubs that provide wind and snow protection to, and changes microclimate in, adjacent crop or livestock fields (Gordon and Newman, 1997; AFTA, 2010). Within the protected area, this results in improved crop quality and yields, or improved animal health and feed efficiency (Gordon and Newman, 1997; AFTA, 2010). Shelterbelts are useful in semi-arid regions to improve crop water use efficiency and in cold climates to protect crop and livestock from wind stress (Gordon and Newman, 1997). In northern areas, properly designed shelterbelts can assist in uniform snow distribution across a field, making more moisture available to crops (Gordon and Newman, 1997; AFTA, 2010). They can also be used to protect homes from extreme weather conditions, filter airborne sediment, buffer waterways and serve as wildlife corridors (Gordon and Newman, 1997). The tree component may also provide timber, fuel, fodder, specialty foods or decorative products (AFTA, 2010). Shelterbelts can also be used as significant carbon sinks; a 0.4 ha field windbreaks is said to store over 21 metric tons of carbon dioxide in the trees by age 20 (AFTA, 2010).

Different tree species and densities can be used in windbreaks to complement the cropping system through soil, pest and crop protection, as well as to provide any of the aforementioned services (Gordon and Newman, 1997). For crop protection, usually one or two rows of trees should be located perpendicular to the prevailing or most troublesome winds (Gordon and Newman, 1997). Wind speed is reduced in an area directly proportional to the height of the windbreak, called the "protected zone" (Gordon and Newman, 1997). Windspeed reductions occur on the leeward side of the windbreak to a distance of the height of the windbreak, and to a lesser degree, also on the windward side (Gordon and Newman, 1997). For wind and snow protection, the most windward row of the windbreak should be 30-60 m from areas needing protection (Gordon and Newman, 1997).

iii) Tree-based Intercropping

Tree-based intercropping, or "alley cropping", involves planting several crops together in strips or alleys between hedgerows of trees and shrubs (Gordon and Newman, 1997; Quinkenstein *et al.,* 2009). The trees can be used to modify micro-climate, protect crops from winds (reducing water loss), minimize natural disasters, reduce soil erosion and provide habitat connectivity for local wildlife (Gordon and Newman, 1997; Schroth and Sinclair, 2003; Quinkenstein *et al.,* 2009). Tree-based intercropping differs from shelterbelts, however, in that the trees themselves provide products of socioeconomic value, such as fruit, biofuel, fodder or timber, and thus may differ in species, location and density (Gordon and Newman, 1997). Several rows of trees can also provide litter to protect the soil surface, prevent night chilling and frost damage, recycle nutrients, replenish soil organic matter and provide carbon substrates for soil biota (Schroth and Sinclair, 2003; Anderson and Ingram, 1989).

The tree row is capable of extracting nutrients at deeper horizons that would have otherwise been leached, and return them back to the soil through leaf litter for use by crops. They also play a role in purifying air and water (Gordon and Newman, 1997). However, intercropping trees may also compete for radiation or soil moisture (Anderson and Ingram, 1989).

B 6) COLD CLIMATE SUBSISTENCE GARDENING

Subsistence gardens are similar to homegardens, but lack the tree component; they often include staple leaf vegetables, tubers, herbs, spices, fruit and animals, and are grown to supplement permanent or shifting field production of few staple foods, such as grains, in areas where easily accessible and dependable, or affordable retail markets are lacking (Ninez, 1987). In temperate regions, garden staples can nutritionally supplement field staples for most of the year and provide a daily supply of high quality carbohydrates, such as tubers, between the period at the end of stored field staple supply and new harvest (Ninez, 1987). According to Ninez (1987), animals are typically included in subsistence production and are fed by garden and kitchen waste, fodder and pasture**.**

Vogl-Lukasser and Vogl (2004) describe the success of cold-climate, high altitude communities in Eastern Tyrol, Austria, in producing a variety of crops through subsistence gardens. Vegetables were grown in 12-220 m^2 plots with ordered raised beds on moderate slopes, located next to farmhouses. *Solanum tuberosum* (potato) dominated the gardens, though *Brassica oleracea var. capitatata alba* (white cabbage), *Phaseolus vlugaris ssp. vulgaris var. Nanus* (French bean), *Pisum sativum ssp. Sativum* (snow pea), *Frageria vesca var. vesca* (woodland strawberry) and *Rubus idaeus* (raspberry) were also introduced. Dairy cattle, pigs, hens and sheep were also kept in meadows. This community used manure for fertilizers and rarely applied synthetic fertilizers, pesticides or herbicides. Prior to the 1960s, this area also kept subsistence gardens for herbs, vegetables, cereals and fodder, forests for timber, fodder, bedding and firewood and even fruit tree pastures, complementing hunting and gathering. Vogl-Lukasser and Vogl (2004) describe the area as "an experimental plot to test species and techniques under the process of human adaptive response and innovation".

Isolated fishing communities in northern Newfoundland have relied heavily on "lazy-bed potato gardening" to meet basic nutritional requirements. These communities are unable to produce field agriculture due to unpredictable weather, pronounced seasonality, short growing season and marginal soils, and competition with peak fishing times (Omohundro, 1985). The growing season is 90-100 days and the only frost-free month, July, averages 10.5^{o}C. However, at a high latitude of 5^{o}N, intense solar radiation compensates for a brief summer by stimulating rapid growth. Potato production was considered necessary to support the growing population in 1945, thriving in opposite weather conditions from peak fishing times and providing calorie and income sources when fishing failed. In poor fishing years of the19th century, potatoes and dairy products assisted in increasing population and decreasing the threat of scurvy and other nutrient deficiencies. The potato fields were located in grass meadows, forests, or on islands and were complemented by "kitchen gardens" located next to the house. Kitchen gardens hosted a variety of root vegetables as well as herbs, domestic berries and flowers. However, since potatoes require little care, grow in poor soil, provide large nutrient content/hectare and store well, they made up to 90% of the vegetable produce. Omohundro (1985) attributes the ability of these communities to meet nutritional requirements in a challenging environment to their concentration on few, reliable gardening techniques, limited gardening investment, sharing of labour and diversification into foraging, animal husbandry and wage work.

C) CASE STUDY PART 1: ENVIRONMENTAL CONTEXT

C1) INTRODUCTION

The above review of FN food systems, food localization, sustainable local food systems, AF systems and cold climate subsistence gardens, provides considerations for implementation of AFCGs in the subarctic. The following case study of historical and modern food systems of Fort Albany First Nation (FAFN) provides a deeper examination how the food system components discussed in previous literature may be applied realistically as AFCGs in an isolated FN community.

From the literature review, it was determined that food security initiatives need to be viewed through the more holistic lenses of Community Food Security and Food Sovereignty. Several authors agree that sustainable local food systems are those that maximize self-reliance, democratic decision making, empowerment, self-determination and participatory action (Ekin, 1990; Hamm and Bellows, 2003; Morrison, 2008; Polack *et al.*, 2008; Winne, 2010). Therefore, a critical review of previous studies and interviews with FAFN community members were seen as the necessary first steps in assessing the viability of AFCGs into the community of FAFN.

C 2) OBJECTIVES

1) Explore historical and modern food systems in FAFN and identify barriers to food security and local food production in FAFN.
2) Determine acceptability and suitability of AFCGs for subsistence food production in FAFN.
3) Develop considerations for implementation of AFCGs in FAFN and other isolated FNs, based on Objectives 1 and 2.
4) Determine the potential areas in FAFN for introducing an AFCG community garden according community preferences and experiences, and subsequently select sites for long-term biophysical

research of subarctic AFCGs.

5) Guide AF design and thereby sampling design for initial biophysical analysis of the potential AFCG test plots.

C 3) METHODS

Interviews of community members (n=8) and a brief survey of the land were completed in the initial visit to FAFN in June 2010 to meet the aforementioned objectives. Community members were selected purposively for knowledge on past community agricultural initiatives: community members who had experience working with the Mission; gardening within the community; and working on food security-related projects in FAFN. Interviewees were kept anonymous and identified as FN#.

Interview questions were open-ended and verified by closed-ended questions, allowing interviewees to provide personally and culturally important information. Interviewees were asked about historical land-use by FAFN, the Mission, and local traditional foods and associated knowledge. They were also consulted on whether or not they found an AFCG favourable and/or feasible, where they might like to have it located, previous successes and failures growing food in the community, as well as any potential concerns with local food production. Interviewees who worked the land with the Mission (FN 1; FN 6) identified historical agricultural land-use on a satellite image of the area. The land-use map was created using ArcMAP, verified by the same interviewees and then modified accordingly. The historical map (Appendix 1) should be treated as a reference; slight discrepancies were found between interviewees' recollections and a full land-use history analysis is beyond the scope of the present study. In addition to community interviews, a literature review was utilized to meet the above objectives.

C 4) RESULTS

C 4.1) Traditional Food Systems in Fort Albany First Nation

Prior to Mission Settlement of FAFN, indigenous peoples survived primarily by hunting and trapping wild game, including *Castor canadensis* (beaver), *Alces alces* (moose), *Rangifer tarandus* (caribou), fish, and waterfowl, and harvesting berries such as *Vaccinium macrocarpon* (cranberries), *Rubus ideaus* (raspberries), *Fragaria ananassa* (strawberries), *Ribes grossularia* (gooseberries), *Viburnum edule* (moooseberries), *Vaccinium uliginosum* (blueberries) and *Gaultheria procumbens* (ground berries) (FN 1; FN 2; Tsuji *et al.*, 2005). *Cladonia rangiferina* (caribou moss) and *Larix laricina* (tamarack) root were also prepared as food (FN 3). *Picea spp.* Spruce and *Thuja occidentalis* Cedar bows were taken as tea, while a variety of other flora was used as medicines (FN 2; FN 3). In fact, any food eaten by the moose was considered good food and so the stomach contents of a fresh kill would be boiled as food or medicine (FN 3). In Attawapiskat, a community north of FAFN in the James Bay region, Honigmann (1961) observed consumption of several other traditional foods, during his visit in 1948: *Rhododendron s.* (labrador tea), "gull" eggs, bud of *Juniperus spp.* (juniper), *Salix spp.* (willow) and *Rosa spp.* (wild rose), sap of *Picea spp.* (spruce), *Populus* (poplar) and *Larix laricina* (tamarack), "long-reed" or "kitciika miwask", root of tamarack and *Alium spp.* (wild onion), *Rheum rhabarbarum* (rhubarb), mosses and honey.

C 4.2) Degradation of Traditional Fort Albany First Nation Foods

Christian Missionaries settled the mainland of Fort Albany, while most indigenous locals settled the adjacent island, Sinclair Island. The Missionaries destroyed indigenous artefacts and suppressed indigenous behaviours that were considered integral to FAFN traditions, weakening their spiritual and physical well-being (FN 3). The grandfather of a modern FAFN elder was told that his traditions followed the works of the Devil (FN 3). Consequently, this grandson "grew up not knowing anything at all"; he explains that "it took a long time for everybody to wake up, especially when you're put to sleep some more in residential school. There was the abuse of the autonomous person" (FN 3). While one other respondent was grateful to the Mission in providing her with the opportunity to learn in school and get a job, she still regrets that she lost her culture and does not remember how to prepare traditional foods (FN 1). Time-consuming jobs and high gasoline prices are blamed for preventing frequent hunts (FN 1); "Everyone was kept busy" working six days a week clearing the fields, farming and constructing buildings, so they did not have time to go fishing or to fix the boat, motor or snow shoes (FN 1; FN 3).

FAFN residents are weary of local contamination by the abandoned Mid-Canada Radar Line (FN 1; FN 4). Site 050 of the Radar Line is located near Fort Albany and has contaminated local, traditional food sources and exposed FA citizens to relatively high levels of organochlorides (Tsuji *et al*. 2001; Tsuji *et al.*, 2005, Tsuji *et al*., 2006). Community members are also concerned about changes in the climate and the subsequent changes to the local ecosystem. They report specifically that the winters from 1982-1988 reached lows of -40^{o}C and then began to change, now averaging only -24^{o}C and reaching a low of -30^{o}C (FN 3). Less precipitation and fewer berries have also been observed over the past few decades (FN 3; FN 4). The ability to re-introduce certain traditional food strategies, such as burying meat in the ground as preservation, is questioned by one resident who notices the temperature rising (FN 2). As previously discussed, both degradation of the environment and abundance of culturally and nutritionally important foods, as a consequence of resource development and climate change, stand to further threaten food security in northern communities such as FAFN.

C 4.3) Introduction of Agriculture to Fort Albany First Nation

The Mission introduced agriculture to FAFN in 1930 (FN 3; FN 5; FN 6), directing most produce to the residential schools (FN 6). Produce was appreciated by families of school children: “My dad always said it helped him quite a bit because there (were) a lot of us and he couldn't feed us all if the school wasn't there. Those were hard times” (FN 1).

Areas of the mainland were cleared for a barn, chicken-coup, grazing lands and crop land, which supported inclusion of cows, horses, pigs and egg-laying chickens (Appendix 1) (FN 1; FN 5; FN 6). The majority of acreage was dedicated to field production of *Solanum tuberosum* (potato), *Brassica rapa* (turnip) and hay (FN 11), but *Beta vulgaris* (beet), *Daucus carota* **(**carrot), *Raphanus sativus* (radish), *Lactuca sativa* (lettuce), *Fragaria ananassa* (strawberry), *Brassica oleracea var. capitata* (cabbage), *Solanum lycopersicon* (tomato) and *Allium spp.* (onion) were also grown (FN 1; FN 2; FN 5; FN 6; FN 7). Small gardens beside the school supplied most of the diverse produce as well as flowers (FN 1; FN 7). A couple of respondents also recall growth of rice and some sort of grain that supplied flour (FN 4; FN 6).

Drainage ditches were dug around the fields to maintain suitable soil moisture; during rare dry periods, pails of water from the lake would be used to irrigate (FN 1; FN 4; Honigmann, 1961). Two respondents recall having to throw “some powdery stuff” over the fields to control the bugs or worms (FN 4; FN 1). Respondents did not recall the Mission taking soil, such as peat, from other land to fix the local soil: “they just cleared up the land. They fixed it, ploughed it and everything” (FN 1). Land productivity was enhanced by the use of cattle manure as fertilizer (FN 1; FN 4) and farm machinery, such as ploughs and potato diggers (FN 1). Honigmann (1961) recalled the small addition of coastal suckers to the soil prior to potato planting in Attawapiskat, yet residents in FAFN who had worked in the fields do not recall the addition of fish to soil (FN 1; FN 4). However, it seems that many of the Mission's techniques may have gone unnoticed by the local people. FN 1, who at the residential school and recalled much of the farming period, explained: “They did a lot of things, the Brothers. They did a lot of things, but I didn't see them.”

According to Honigmann (1961), the gardening season in Attawapiskat started when ice blocks melted off the land, the earth thawed at least two feet, which was about the beginning of June. The area that was devoted to field production is known to flood approximately every 10 years. In years of flood, the Mission would wait until after break-up, when the floods receded, to seed or transplant crops (FN 6).

The Mission started seedlings of carrots, lettuce, turnips, onions and tomatoes in a greenhouse and transplanted them into the gardens (FN 4; FN11). Tomatoes did particularly well in the greenhouse (FN 4). Turnips, potatoes and carrots were stored in underground structures earlier in the agricultural movement (FN 1; FN 4) and later stored in the basement of the school where it was cool all year (FN 1). FN 2 says that he does not know how they preserved food, but remembers hearing that they had it all year-round.

During his time in Attawapiskat, Honigmann (1961) observed that the “native” people had lacked motivation to garden and attributed this to the absence of a tradition of plant cultivation and its associated slow return for labour. This might suggest that the common European belief that native cultural values or means of food acquisition were inferior, as exemplified in NW Ontario and Alaska (Waisberg and Holzkamm, 1993; Loring and Gerlach, 2010), were also prevalent in the James Bay region. However, Honigmann did encourage experimentation with palatable dishes from wild willow, wild rose and other buds and claimed that people were not aware of the health values of berries. Honigman (1961) also showed concern as early as 1948 about the decline in wild vegetation and berry harvest over the previous one to two decades and attributed this loss to the increase in imported food.

Large-scale agriculture by the Mission came to an end around 1970 (FN 3; FN 5; FN 6) when Indian Affairs took over the residential school (FN 1) and the grocery store was introduced (FN 5). The government removed the residential school and most of the mission followed (FN 6), halting large-scale agriculture. People got jobs and sourced the local store for food (FN 1). Although Fort Albany never established as an agrarian society, the Mission did have some residual impacts on future cultivation in the area. Some elders kept their own potato and strawberry patches nearby (FN 2). The "Old Post" (old Hudson's Bay Company fur trading post), or "Old Settlement", was also travelled to by FAFN residents to grow potatoes, and possibly other crops, up until about twenty years ago (FN 1; FN 2; FN 4). FN 2 recalls of the Post that "It was all clear and the earth was just dark". Up until about two years ago, one couple maintained large potato gardens utilizing skills learned from the Mission (FN 1). Another individual used to keep a potato patch on what is now called "Potato Island" (FN 2). He travelled there by boat, cut up seed potatoes and planted them around June or July after the ground was thawed. He did not return until late September or October as the patch required no maintenance, but stopped his garden when children began vandalizing it.

C 4.4) Current Food System in Fort Albany First Nation

Although older members of FAFN were raised on canned food during the Mission (FN 3), they try to maintain traditional food harvest and consumption (FN 1). One resident explained that few people harvest or hunt because few have the money to afford a boat and fuel (FN 3). The community tradition is to share the kill, but after spending about $600 per trip, many will eat only for a short period of time (FN 3). Community members explain that most people get their food from the store, especially the new generation which consumes a lot of junk food, particularly pop and chips, and do not care for traditional foods (FN 1; FN 3; FN 7). A previous study of food security in FAFN by Skinner *et al.* (2006) reports that healthy eating is impeded by the isolation of the community and the subsequent high cost, limited variety and poor quality of fresh produce.

However, a tendency of people to shy away from a variety of novel fruits and vegetables has been observed in the grocery store and the school's farmer's market (FN 4). One resident explains that, “life is busy, too busy to experiment with foreign foods”, demonstrating knowledge of food usage as a barrier to consumption of the already “limited variety” that exists (FN 4). She explains: “I'll be standing in the produce section and someone will say, 'what is that?' and 'how do you make it'?”. Though she acknowledges cost and availability as limiting, FN 4 also identifies personal choice or preference as perhaps a more limiting factor: “The education is all around, but sometimes I think we limit ourselves here with those excuses that the cost of food is too expensive at the store. A head of broccoli is the same price as a bag of chips” (FN 4). Skinner *et al.* (2006) noted that FAFN youth were capable of differentiating between healthy and unhealthy foods, and that it was both access and desire that were lacking. One lifetime FAFN resident who is food secure has described this common situation: with the same income every two weeks and no bank to store cash, people use their money quickly, playing cards, poker or bingo (FN 3). They buy on credit from the only store in town which charges 19% interest so that by the time the next cheque comes, half of it may be owed to the store: “they are always indebted to the store” (FN 3). He sums the issue by stating: “If you don't have the means, the knowledge, the education, that's where you're stuck”. Therefore, the capacity of citizens to purchase healthy foods may be limited not only by the by the availability and cost of those foods, but also by the behaviours of the consumers themselves.

C 4.5) Towards Sustainable Food Systems in Fort Albany First Nation

The FAFN community has expressed a desire to:

- Improve dietary habits of its population and become food secure (Skinner *et al.*, 2006)

- Bring back and protect traditional knowledge necessary for subsistence lifestyle and transmission of their culture (Minkin, 2008)
- Regain connection with the land (Minkin, 2008)
- Regain traditional values of land responsibility and community mutualism with respect to resources (Minkin, 2008)

These desires are demonstrated by the school snack initiative which is designed to introduce FAFN children to nutritional snacks. However, according to Skinner (2006), the program is not sufficient and could be complemented by community gardens and increased resources (personnel, time, money and food variety).

Since the Mission ended their agriculture program in 1970, FAFN community members have yet to participate in large-scale agriculture or community gardens. A few elders have maintained family potato gardens until very recently (FN1; FN 6). One elder recalled the work involved in successful potato gardening on the mainland: he used a shovel to remove the grass and then tilled the earth. He planted the potatoes about five or six inches below, covering them later on in the season as they started to come up and recalled the intensive weeding requirements. A garden of 50x100 ft produced about 1000-1500 lbs of potatoes from 100 lbs of potato seedlings.

Two other known gardens of greater diversity are being kept by one long-time resident and one relatively new resident to FAFN. FN 8 has kept her outdoor garden at her home on the outskirts of town for six years. She successfully grows potato, turnip, beet, carrot, radish, lettuce, strawberry, tomato and yellow and green onion, *Cucurbita spp.* (squash), *Leguminosae spp.*(beans), *Pisum sativum* var. *saccharatum* (snow peas), *Solanum melongena* (eggplant), *Apium graveolens* (celery), *Piper spp.* (peppers), *Brassica oleracea var. gemmifera* (brussel sprouts) and *Brassica oleracea var. botrytis* (broccoli). She roto-tilled the garden prior to planting, transplanted tomatoes, peppers, broccoli, onions and grew the rest from seed. She also has a successful garden dedicated only to potatoes.

FN 4 started her first outdoor garden this year at her home in the heart of town. She tilled the land and constructed a raised bed. She had success in growing small snow pea and bean plants, but found her soil to be very clayey and stony. Her garden was also disrupted by curious people and dogs. She also potted flowers, herbs and tomatoes which were somewhat successful. She was concerned about contamination in her garden because of the historical garbage dumps and outhouses of unknown locations.

However, they felt restricted by a lack of knowledge, funds, time, resources and support necessary to implement the plant (FN 1; FN 4). They also found difficulty coming to consensus on garden location and thus found personal gardens seemed more appealing (FN 4).

C 4.6) Community Thoughts on Community Gardens

Several respondents liked the idea of a community garden to grow food in Fort Albany (FN 1; FN 3), stating, “It was done before, why not do it again?” (FN 1). Respondents who were around during the Mission settlement stressed the amount of work that would be needed to garden, especially weeding (FN 1; FN 6). One interviewee demonstrated some hesitation, stating, “you gotta really pick up the weeds. It's an all day thing you really have to look after...one with less maintenance would be better” (FN 1).

Gardens were regarded by community members as a means to acquire produce at a cheaper price, especially potatoes, which are favoured and very expensive (FN 1). Others viewed a community garden as a means to bring youth and elders together to share stories of the past, to conserve traditional knowledge and to unify the community (FN 3; FN 7). Two participants expressed concern for a loss of traditional medicinal knowledge and agree that the garden could host culturally important medicinal plants (FN 7). FN 3 explains that *Abies spp.* (balsam) aroma is healing and would be a nice contribution to community gardens (FN 3). FN 4 would like to see flowers in addition to food because they “do something else holistically and spiritually”. FN 4 also saw community gardens as an opportunity for healing oneself from the land, referring to horticultural therapy concepts introduced at the Food Security Conference; she notes specifically that the community suffers from a lot of post-traumatic stress disorder, which is “getting in the way of being able to lead productive lives” and thinks it may be relieved through land-tenure.

While attempting to develop a community garden committee, FN 4 commonly found that people would rather have personal gardens, closer to their homes because they like to “do their own thing” and feel they can better protect something close by (FN 4). Although FN 3 felt confident in the capacity of a community garden to grow food in Fort Albany, he also felt it is better for a family to have their own private fields. FN 3 added, however, that the community currently lacks enough motivation for private subsistence production to take start. Yards are not commonly landscaped because, as FN 4 explains, “there isn't that pressure, that peer pressure to keep your lawn” and “equipment gets stolen and people become apathetic” (FN 4). FN 3 agreed that a community garden would be an effective way to initiate home-gardening in the area: “You have to start first. You have to teach people by having something in common, how to care for the community garden and then eventually (they) will say, 'well I am going to move a bit further away from here and have my own garden, my own field...I want this and that'. It will spread. You're just planting a seed....they'll talk about the best seed they have found...They'll start experimenting with the local things, and watch them grow (in) what kind of soil they like. And they develop (as) an expert. It's also a good way, I think, for developing a community, a cohesive community, a sociable community, from talking about something in common: our garden" (FN 3).

C 4.7) Proposed Garden Area

Most respondents identified the old Mission fields on the mainland as an ideal location for a community garden because of the known productivity of the land, the man-made drainage ditches and the proximity to a freshwater lake (FN 1; FN 2; FN 4). During her community garden project, FN 4 received a high interest in the area, but was concerned about the ability of the garden to act as an educational tool for elders or children who have a more difficult time accessing it (FN 4). However, while experimenting with her own garden in the heart of town she had many difficulties with dogs, theft and vandalism disturbing her garden and her equipment. Community members have been hesitant to invest in town gardens for fear of contamination by the Mid-Canada radar line or old dumps and outhouses in unknown locations of the town core and because much of the soil in the community is thought to be either clayey or boggy (FN 4). They were also concerned about the financial and labour investments needed to develop suitable soil (FN 1; FN 4). "Potato Island", however, is described as having good soil and being a good place for future potato gardens, which require little care. Since a boat is required to access the island, FN 2 suggests that other crops which require more care should be grown closer to the community in the old Mission fields. Although FN 2 did mention that dust is carried by wind from the airstrip, which is located on the southern portion of the proposed garden area, and may be problematic for crop production.

C 5) DISCUSSION

C 5.1) Fort Albany First Nation Food Systems

Information revealed from interviews with FAFN community members converged with findings from the literature review of isolated FN communities of the far north. Staple traditional foods include wild game and fish and were complemented by several plant species, mainly as teas, medicine, and berries. Agricultural produce provided by the Mission was welcomed and appreciated by community members. However, the Mission's relatively large-scale agricultural efforts were directly tied to operation of the residential school; thus, the initiative lacked respect for the traditional culture and the importance of traditional foods. A lack of equality during the Mission settlement meant that FAFN residents lacked autonomy and self-determination over local food production and that knowledge sharing of agricultural strategies with the people was restricted impacting the local food production effort after 1970. Consequently, traditional harvest and associated knowledge was weakened by the residential schools and time-consuming farm work, and continues to be threatened by rising economic costs and climate change.

C 5.2) Barriers to Food Security

Unhealthy food consumption in FAFN is not entirely attributed to a lack of access due to availability, cost, and a profit-driven food supply. Consumption of healthy market produce may also be impacted by personal choice or preference, lack of food usage familiarity, and monetary issues not directly related to cost of consumables. These additional findings are extremely important to consider in this study if the ultimate agenda is to facilitate healthier food systems in northern communities.
Replacement of grocery store produce with gardens will not eliminate limitations of familiarity of food usage, personal preference (choice) and time availability as barriers; they are likely to persist unless proper support and education are provided in conjunction with local food production.
It is significant that the additional barriers discovered in the present study are congruent with what Skinner *et al.* (2006) identify as the central issue related to healthy eating in FAFN: empowerment. In their study, empowerment was defined by Wallerstein (1992) "social action process that promotes participation of people, organizations, and communities towards the goals of increased individual and

community control, political efficiency, improved quality of community life and social justice" (Skinner *et al.*, 2006, pp. 157). Participants in the Skinner *et* al. (2006) study felt dis-empowered by a lack of access to healthy foods, a lack of capacity to influence grocery store stock and pricing, as well as a lack of trust in the grocery store management and company. Yet in the present study, FN 4 recalls the grocery store manager claiming that his previous attempts to stock more produce were not met with greater purchase of produce, and that as a result, these foods did not sell. While many residents desire greater control and ability to make choices for healthy eating (Skinner *et al.* 2006), the amount of people not making healthy food choices may be sufficient enough in a small population to deem greater produce abundance and diversity unprofitable to a private market. However, local food production would allow the citizens who are interested in having greater food democracy and variety to escape the demand of unhealthy consumers. Provision of relatively inexpensive produce through local gardening would also partially mitigate cost as an access issue; thus, providing another incentive for people to choose healthy foods over imports, despite food preference. It would also help relieve perpetual cycles of store debt and monetary management as barriers to nutritious food. Lack of trust in the grocery store company was also expressed in Skinner *et al.* (2006), emphasizing the need for local food autonomy.

C 5.3) Suitability and Acceptability of Agroforestry Community Gardens

In the present study, community members responded positively to the idea of an AFCG as a means to enhance FAFN food security. Consistent with findings by Minkin (2008), FAFN residents demonstrated a fondness towards traditional values of community mutualism over resources. However, a preference for personal gardens over community gardens was also observed in the present study, due to logistical and other concerns, which was identified as a barrier in previous attempts to introduce a community garden in FAFN. Still, several respondents view the community garden as an important initial step towards food localization that is needed to gain community interest in local food production and to educate the community on gardening strategies. Community plantings and workshops have proven to initiate greater interest in personal gardening in FN communities (Healthy Together Now Chronic Disease Prevention, 2010). FAFN community members also view the gardening initiative as a means to bring the community together, heal oneself from working with the land, share traditional ecological knowledge and preserve traditional ecological knowledge of culturally significant plant species, as well as provide healthy food.

FAFN members report reduced access to wild game and berries due to increasing harvesting activity costs and rapid climatic changes. Thus, AFCGs may assist in augmenting traditional foods impacted by climate change. The nutritional, cultural and social benefits of traditional foods in remote FN communities are evident (Willows, 2005; Stroink and Nelson, 2009; Trull, 2009). Taking lessons from previous food security initiatives by the Mission, future local food developments should complement, and not replace, traditional food systems.

C 5.4) Introduction of a Food Security Program

Previous attempts by FAFN residents to introduce community gardens have been challenged by a lack of leadership and knowledgeable personnel devoted fully to local food production and food security as a whole. A few programs within the Peetabek Health Unit are able to address individual components of the food security issue in FAFN, but a lack of cohesive community effort and common vision have been barriers to successful project implementation. A central body with the necessary knowledge, experience and resources for developing community food security and food sovereignty is required to bridge the associated programs and disseminate complementary projects. FAFN would benefit from government support of a Food Security Program (FSP) lead by trained community members who can devote themselves completely to enhancing food security and unifying current efforts towards similar, mutually reinforcing goals. Considering results of Section C, the program should provide education, support and resources for local food production, local food preparation, food budgeting, financial planning and traditional plant uses.

C 5.5) Barriers to Local Food Production

FAFN residents showed concern for the amount of work and time necessary for a successful community garden; thus, emphasizing the importance of a low maintenance community initiative. In the past, time devoted to agriculture and jobs had interrupted their ability to harvest and prepare traditional foods. Community gardens may limit time devoted to traditional food acquisition, but the seasonality of community gardens may also complement traditional food efforts, temporally. Low-maintenance potato gardens in Newfoundland have supported fishing communities during off seasons or periods of low fielding yield (Omohundro, 1985). Further characterization of traditional food seasonality in FAFN would highlight complementary crops. However, cold climates will make for easy storage of root crops all year, which is known to have been a successful strategy by the Mission in FAFN.

FAFN community members fear contamination of the land by the Mid-Canada Radar Line and old outhouses and landfill in unknown locations, making them more reluctant to initiate local food production. Recalling precautions by Bellows and Hamm (2001), localization of food may not inspire sustainable development and local autonomy if the local area is contaminated. The uncertainty demonstrated by FAFN citizens, indicates that resource development is another factor driving a greater confidence in market foods over local foods, as found by Stroink and Nelson (2009). Soil contaminant analysis of potential gardening areas of FAFN is also necessary to determine if local food production is safe, and if so, to encourage greater confidence in the local land to provide.

C 5.6) Import Substitution Strategy

FAFN has seen successful growth of a variety of garden crops by the Mission until 1970, and by local residents up to present day. The University of Waterloo has provided a greenhouse to FAFN, which is almost completed. Once the greenhouse, which is located on the 100-year flood plain, is completely finished, it will play an important role in starting early crops such as carrots, lettuce, turnips, onions and tomatoes, especially in years when the community garden area floods in early spring. The greenhouse may also play an important role in garden education, notably for schoolchildren and residents who have difficulty accessing the community garden.

The old Mission fields were selected by FAFN members as the proposed garden area for the AFCG because of the historical productivity of the land, the existing man-made drainage ditches and the proximity to a freshwater lake. Gardeners in the town are concerned about soil contamination from old waste sites and soil fertility, and have had difficulty protecting their plants from being destroyed or stolen by vandals or dogs. Located on the mainland, the proposed garden area is located away from the village proper (but close by), and known to have been protected from waste disposal. Fencing was used by the Mission to exclude children and dogs (Honignmann, 1961), and can be used for the community garden to enhance protection.

The known success and low-maintenance of potato gardens on the islands of the region’s rivers and the capacity of low-maintenance potato gardens to support the bulk of the diet of cold climate communities in Newfoundland and Austria (Omohundro, 1985; Vogl-Lukasser and Vogl, 2004), begs their re-introduction to FAFN. As FN 2 suggested, the majority of potatoes can be left to grow on the islands, while production of diverse crops which require more care can be grown in personal gardens.

Personal AF homegardens are presently not a suitable means of import substitution in FAFN to enhance food security; at present, residents seem to lack interest and education of food production and are challenged by poor soil quality and potential soil contamination within the FAFN town centre. Expansion of food localization in FAFN towards personal home gardens will require soil testing followed by research of inexpensive soil amendments prior to large-scale promotion.

C 5.7) Selection of Study Sites

Based on the community preferences and experiences, as well as the study objectives and literature review of AF, four sites were chosen for biophysical analysis (Appendix 2):

i) Site A, "AFCG" and Site B, "AFCG"

These two sites are located within the proposed garden area on the mainland, easily accessed by road and already support growth of maturing *Salix spp.* (willow) trees. The willows which now dominate the old drainage ditches, border these two sites, allowing for immediate introduction of the AFCG, and the use of naturally existing and adapted tree species. With parallel rows of willow tree species, this location is ideal for research on tree-based intercropping or shelterbelt community gardens. The use of two sites will allow for long-term research of different management strategies for optimal crop production, particularly because the trees rows appeared to differ in terms of willow maturity and density. Initial assessment of soil properties, species composition and willow tree row composition will be discussed in Part 2 of the case study.

ii) Site C, "No Tree"

A site within the proposed garden area that lacks invasion of willow trees was selected as a control. No trees or shrubs are growing within a 58 m radius of this site. Introduction of a community garden on this site, followed by continued research of productivity in this "No Tree" site and the ÀF sites will provide valuable information on the effect of willow trees in subarctic gardens; this will assist in determining the suitability of AFCGs in the subarctic over the long-term. Initial soil sampling of this site will also assist in characterizing the land cultivated by the Mission and identifying any major differences within the proposed garden area.

iii) <u>Site D</u>, "Undisturbed Forest"

A section of forest near the proposed garden area, which remains intact since before Mission settlement, was selected to characterize the more common, undisturbed boreal forest conditions for wider application of AFCGs and to act as a control in determining Mission land modifications. Over long-term studies, this site will also be useful in comparing soil properties to that of the working AFCGs for further research of ecosystem dynamics in AF systems of subarctic regions: tropical and subtropical AF systems are described to have nutrient inputs, outputs and circulation patterns intermediate to that of natural forests and agriculture (Young, 1997). Long-term studies may indicate whether subarctic AF systems behave similarly and thus, if they are a sustainable means of food production.

C 5.8) Land-use of Study Sites and Surrounding Area

Land-use of the selected sites and surrounding area from 1930 to 1970 is described in Section C 4.3, "Introduction to Agriculture in Fort Albany" and geographically shown in Appendix 1: "Land-use During Mission Settlement of Mainland FAFN". Little information was revealed about land-use in the proposed garden area and its surroundings since the end of agricultural production in 1970. Residents claim that the land has been abandoned; however, some areas are dominated by early succession species that appear younger than forty years; ecological land survey of the area is described in Part 2 Section D 4.1. Appendix 2 shows observed land-use in 2010 as well as the location of the study sites. No development can be seen within the proposed garden area, except for the airstrip which runs along the southern portion of the area. In the midst of the proposed garden area, one resident has begun working the land to build a running race track. East of the general site area, “Dike Road” is bordered by a cemetery, residential development, the airport, and a few amenities that have expanded since the Mission’s settlement. Dike Road intersects with a road leading to the Fort Albany First Nation Reserve on the island (not shown in map). Areas immediately north, west and south of the proposed garden area remain as relatively undisturbed forest. A freshwater lake, St. Anne's, is located west of the proposed garden area. An access road running from Dike Road to St. Anne's Lake was created for the construction of a log house along the lake; it allows for easy access to these study sites. The house is located just west of the proposed garden area and is accompanied by a nearby potato garden located just within the proposed garden area, next to Site A. Construction of the home, including use of nearby trees and land excavation, may have caused some recent disturbance to the study sites.

D) CASE STUDY PART 2: BIOPHYSICAL ASSESSMENT IN FAFN

D 1) INTRODUCTION

Considering the meat-based traditional diet of northern FN communities (Guyot *et al.*, 2006; FN 1; FN 2) and low diversity and productivity of high-latitude ecosystems (Elmqvist *et al*., 2004), it is evident that subarctic environments are not naturally conducive to producing large amounts of diverse edible plants. Analysis of site-specific vegetative and soil composition in both undisturbed subarctic ecosystems and previously cultivated lands would provide insight on the potential for these challenging environments to be manipulated into the type of diverse food production sites witnessed in 20th century FAFN.

Extensive analysis and spatial classification of Ontario's northern soils is lacking. The Geological Survey of Canada characterizes all of northern Ontario’s soils around James Bay as peatlands (Natural Resources Canada, 2008). Peatlands are known to have low pH, high levels of organic matter and high levels of stored nutrients due to low decomposition rates (Gardiner and Miller, 2008). The high soil organic matter provides a high water-holding capacity, but this stagnant water results in low root aeration, limiting growth of many plants (Gardiner and Miller, 2008). Soils in the James Bay ecoregion are characterized as predominantly organic Mesisols and Fibrisols with some organic Cryosols and limited areas of dystric and eutric Brunisolic soils on upland sands; they experience sporadic and discontinuous permafrost (MSSC, 1996). Organic Mesisols are composed mainly of organic materials at an intermediate state of decomposition, with some identifiable plant fibres (Soil Classification Working Group, 1998). Organic Fibrisols are composed mainly of relatively undecomposed, well-preserved fibric organic material that can be identified by its botanical origin (Soil Classification Working Group, 1998). Cryosols predominate north of the tree line and experience permafrost within 1 m of the surface (Soil Classification Working Group, 1998). Dystric and eutric brunisols lack a well-developed mineral-organic surface horizon and are found under forest vegetation (Soil Classification Working Group, 1998).

With wetlands comprising 50-75% of the James Bay ecoregion, the dominant vegetation consists of *Cyperaceae* (sedges), *Bryophyta* (mosses), lichens, *Picea mariana* (black spruce), *Larix laricina* (tamarack), *Juniperus spp.* (juniper), Salix spp. (willow), *Populus spp.* (aspen), *Rubus spp.* (brambles), *Myrica gale* (sweet gale), *Alnus spp.* (alders), *Betula spp.* (white birch and bog birch), *Cornus* (dogwood), *Arctostaphylos spp.* (bearberry) and *Vaccinium oxyoccos* (small cranberry) (MSSC, 1996; Hanson, 1953).

Information on soil and vegetative composition of the region is very general, while soil and vegetative conditions of cultivated areas within the region are not documented at all. The following biophysical analysis in FAFN is a site-specific inventory of soil and vegetative composition that will be used to meet the following objectives:

D 2) OBJECTIVES

1) Determine if soil in the proposed garden area (Sites A, B and C) is capable of supporting diverse garden produce and identify if selected soil properties need modification prior to garden implementation
2) Observe spatial variation of soil properties in the crop area in relation to distance to willow trees and identify potential tree-crop competition, as a means to identify ideal crop placement and soil management strategies needed to enhance crop productivity
3) Characterize vegetative and soil composition on each site (Sites A, B, C and D) to make inferences on historical land-use and establish more detailed information on Ontario's

subarctic soils necessary for wide-scale adoption of AFCGs to subarctic communities of the James Bay Ecoregion

4) Establish and analyze baseline soil and vegetative composition to characterize initial site conditions for long-term studies of:

- Soil property dynamics resulting from use of willow in AF community gardens of the subarctic (Sites A and B) compared to gardens in an area of similar historical land-use history, but lacking the tree component (Site C) and an undisturbed forest of the subarctic (Site D)
- The effect of willow tree rows of various geometry and densities (Sites A and B) on spatial and temporal variability of soil properties and on crop success, as a means to determine 1) the suitability of willow AFCGs for subarctic food production, and 2) best willow management practices for optimal production of crop and willow products or services

Refer to Section C 5, parts i, ii and iii for description of Sites A, B, C and D

D 3) METHODS

D 3.1) VEGETATIVE STUDY

D 3.1.1) Species Composition: Sites A, B, C and D

Plant species within the sites were identified to characterize undisturbed and disturbed ecology of the area, provide insight on management history and characterize initial site conditions (Anderson and Ingram, 1989) prior to garden implementation and long-term AFCG studies. Dominant species surrounding these sites were also identified to characterize local ecosystem (Anderson and Ingram, 1989).

D 3.1.2) Willow Tree Inventory: Sites A and B

Further vegetative analysis was performed on the potential AF plots, Sites A and B. Within the tree rows, tree height and width, surface water width, and tree shoot density and shoot basal area, were measured. Typically, AF site characterization includes measurement of stem density and basal area instead of shoot density and basal area, and also includes calculation of wood biomass (Anderson and Ingram, 1989). Willows in these plots developed shoots as low as the base of the tree, making stems a minor proportion of the woody biomass; thus, shoots were a better indicator of willow density and basal area. Calculation of biomass, however, requires destructive willow sampling and more extensive laboratory and statistical analysis than was available in this study.

The adjacent AF plots, Sites A and B were bordered by two willow tree rows and divided by a third willow tree row, each running in the direction from southwest to northeast (Figure 1 and Appendix 2).

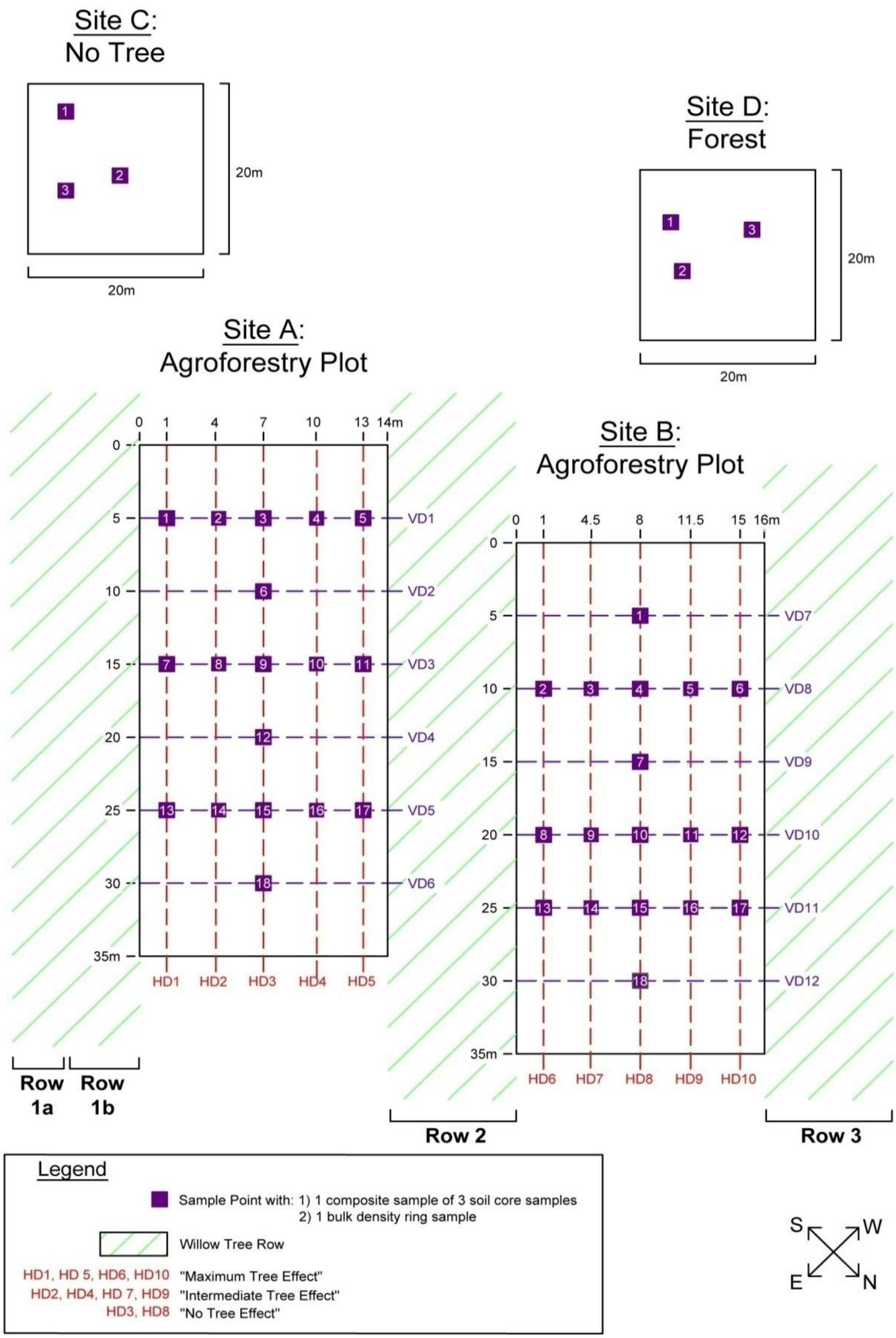

Figure 1: Soil Sampling Design of Proposed Agroforestry Community Garden Sites (Sites A and B), a "No Tree" Control Site (Site C) and an Undisturbed Boreal Forest Control Site (Site D) in Fort Albany First Nation, Ontario. Note: scales differ for A-B versus C-D.

“Row 1” bordered the southeast (SE) length of Plot A; Row 2 was shared by Plots A and B, acting as the northwest (NW) tree row for Plot A and the SE tree row for Plot B; Row 3 bordered the NW length of Plot B (Appendices 2 and 3). Tree height and maturity of Rows 2 and 3 appeared very homogenous within each. Row 1, however, had two distinct generations of willow trees, with taller, more mature trees towards the inside of Site A, labelled stratum 1b, and shorter, less mature trees on the outside, next to the access road, labelled stratum 1a.

A 4-m section along the length of each tree row was sampled for above-ground biomass, tree density and row width. Each tree row was relatively homogenous in width and density and resulted in the selection of a section representative of the majority of the row. Few but large differences in tree height meant that minimum and maximum tree heights were observed from the entirety of each tree row and measured in order to obtain a range of tree height per row. Most trees in a given row were the same height and thus a “majority” tree height was also included. Tree height was measured using an Abney Level and measuring tape, then calculated using trigonometric functions.

D 3.2) SOIL STUDY

D 3.2.1) Sampling Design

a) Sampling Design of Site A and Site B: “AF Plots”

Inventory Study

An inventory study is a general type of soil testing to measure the amount of a property(s) under study and is used in AF research to determine if soil properties are suitable for growing specific crops (Carter and Gregorich, 2008). An inventory study could be random, where coordinates for each sample location are selected using random numbers, or systematic, where the sample sites are selected in a systematic way, typically in a grid pattern (Schroth and Sinclair, 2003). To prepare for long-term studies, flexibility and repeatability were important in the sampling design of Sites A and B and thus, systematic sampling was used; in this way sampling would have greater precision than random sampling, could be replicated within the plots in future studies and would represent the entire plot for continuous studies on soil dynamics over time and space (Schroth and Sinclair, 2003).

Pattern Study

A pattern study can be used to explain spatial and temporal properties of patterns (Carter and Gregorich, 2008). Elements of a pattern study design were included to quantify spatial, and eventually temporal variability of soil properties to measure the effect of the tree row on soil properties and to provide more accurate data for crop placement.

The following is a rationale for selection of a patterned inventory study using systematic sampling:

- Known sample points are necessary for repeatability of the study. Therefore, haphazard and random sampling were avoided (Schroth and Sinclair, 2003; Carter and Gregorich, 2008)
- Homogeneity within the plot suggests that representative sampling is not necessary (Carter and Gregorich, 2008).
- Although the AF plots appear homogeneous within, they are bordered by trees and thus distance to tree effect must be analyzed, especially for long-term studies on the effect of incorporating willow trees in community gardens.
- Spatial variation of soil characteristics within the entire plot must be determined for garden design and crop placement. Thus, smallest representative unit sampling (Schroth and Sinclair, 2003) is insufficient as it would not capture potential gradients along transects parallel to tree row.
- Intercropping plots require stratification of areas from distance to tree row (Schroth and

Sinclair, 2003). This will allow measurement of the spatial variation of soil properties caused by the trees by collecting at different distances from the tree line.

- Future studies may test different crop species and land management practices for optimal production in subarctic AF with willows, and thus broad coverage will provide baseline data of the uniform area.

Type of Inventory and Pattern Studies Used

A grid design is a common type of systematic sampling used in inventory studies that allows for highly detailed information in a smaller area (Schroth and Sinclair, 2003); this extensive sampling style will allow for repeated sampling over a broad area for unknown potential AF studies. The spacing of transects within the grid, however, was dependent on the needs of the pattern study.

Since distance-to-tree effect and overall spatial gradients of soil properties are also sought, a stratified approach was also incorporated in the design (Carter and Gregorich, 2008). In stratification, each plot is divided into homogeneous regions called "strata" (Schroth and Sinclair, 2003). Within each stratum, samples are chosen randomly or systemically. Although a grid provided the basic structure for the design, a stratified approach directed the distance between transects and which grid nodes would actually be sampled in order to measure: the effect of willow at various distances along the width of the plot (horizontal direction) and the effect of unknown factors on soil properties along the length of the plot (vertical direction). The following two paragraphs describe how sampling design was created to satisfy these two measurements; a map of sampling design (Figure 1) and a satellite image of the sites (Appendix 2), can be used as visual aids.

1) Unknown Effect: "Vertical Distances"

This stratified systemic division of vertical distances was used to measure geographic variability of soil properties from potential, unidentified environmental and anthropogenic influences over the entire length of the plots. The length of each plot, 35 m, was divided into six equally spaced "vertical distance" (VD) transects, each 5 m apart: VD1-6 for Site A; VD7-12 for Site B. Down the centre of each plot, all six vertical distances were selected as sample points in order to obtain soil property data for non-statistical observation of the variability along the entire length of the plot; this provided one sample point per vertical distance. Due to soil transportation restrictions, only three of these distances within each plot were selected randomly for more extensive sampling sufficient for statistical comparison of vertical distance. This created three single sampling VD points per plot (VD2, VD4, VD6, VD7, VD9, VD12) and three VD transects with five sampling points in each plot (VD1, VD3, VD5 for Site A; VD8, VD10, VD11 for Site B) running perpendicular to tree row. The distance between these five sampling points was dependent on the needs of Distance-to-tree Effect study in order to overlap sampling coordinates on the grid and minimize required number of samples.

2) Distance-to-tree Effect: "Horizontal Distances"

The horizontal distance gradient was used to measure the effect of the tree component on soil properties at various distances along the width of the plots. For soil analysis within a tree-based intercropping system, Schroth and Sinclair (2003) recommend sampling at three strata according to how far each point is from the nearest tree: "maximum tree effect", closest to the tree, "no tree effect", furthest from the tree, and "intermediate effect", at one or two intermediate distances between the tree and the "no tree effect" strata. Tree effect analysis was done for each tree row on each plot, with the shared row (Row 2) having an effect on both plots: Row 1 and Row 2 effect on Site A, Row 2 and Row 3 effect on Site B. With two effect analyses per plot, the centre of a given plot was used as the "no tree effect" stratum for both tree rows. Each tree row within a plot also had a "maximum tree effect" stratum located 1 m from the tree row and an "intermediate effect" stratum, located halfway between the “maximum tree effect” stratum and the centre of the plot. These five strata, two “maximum effect”, two “intermediate effect” and one shared “no effect”, in each plot provided a total of ten “horizontal distance” (HD) transects to be sampled (Table 1). Thus, starting from the SW tree row of each plot, HD transects were placed at 1 m, 4 m, 7 m, 10 m and 13 m from Row 1 in Site A and 1 m, 4.5 m, 8 m, 11.5 m and 15 m from Row 2 in Site B (Figure 1).

Table 1: Horizontal Distance Transects (HD1-HD10), as shown in Figure 1, and Used to Test for Various “Tree Effects” of Rows 1 and 2 of Site A and Rows 2 and 3 of Site B

Tree Effect	Site A		Site B	
	Row 1	**Row 2**	**Row 2**	**Row 3**
Maximum Tree Effect	HD1	HD5	HD6	HD10
Intermediate Tree Effect	HD3	HD3	HD8	HD8
No Tree Effect	HD2	HD4	HD7	HD9

HD transects were placed progressively closer together with decreasing distance to tree row because soil properties tend to change most rapidly closest to the tree (Schroth and Sinclair, 2003). Each HD transect, except for the centre transects HD3 and HD 8, contained three sample points; the centre transects of each plot had six sample points because of the needs of the vertical gradient study; however, this conveniently provided an equal number of six sample points per tree effect of each plot (Table 2).

b) Sampling Design of Site C and Site D: “No Tree Plot” and “Forest Plot”

Site C, “no tree plot”, appeared uniform and homogeneous, yet lacked trees for plot borders and therefore would be very difficult to be repeatedly sampled systematically in the future (Schroth and Sinclair, 2003). Site D, the “forest plot”, was uniform throughout and lacked distinctive physical borders, again making systematic sampling less appropriate. Grid sampling, often used in these instances for broad coverage, was not realistic considering logistics. Additionally, the soil property spatial dynamics of Site C and Site D are not the focus of the study and therefore extensive pattern inventory was not required, allowing greater allocation of effort to sampling AF plots. Thus, both of these sites were sampled randomly, which assisted in eliminating bias and allowed for a general site inventory with low costs (Schroth and Sinclair, 2003; Carter and Gregorich, 2008). Three random sample points per plot were deemed sufficient for general characterization and comparison of sites: R1, R2, R3 for Site C and R4, R5, R6 for Site D (Table 3). Lacking distinct physical borders, a 20 m^2 area was chosen for each of these sites. These 20 m^2 plots were divided into 20 one-square-metre quadrants, from which three quadrants were randomly chosen as sample points. From the centre of the site, Site C was located 58 m from any tree or shrub species and Site D was located 55 m from the westernmost edge of Site B.

D 3.2.2) Sample Collection Methods

As standard procedure for agricultural research, soil samples were taken in the topsoil, up to 20 cm in depth (Anderson and Ingram, 1989; Estefan, and Rashid, 2001; Schroth and Sinclair, 2003). It is relevant to this study to cover more surface layer than depth of soil because the topsoil is where most available nutrients are found and where the soil is manipulated by tillage (Schroth and Sinclair, 2003; Gardiner and Miller, 2008), providing information relevant to crop production. Organic decomposition and soil development is known to be much slower in cool climate soils (Havlin *et al.*, 2005), making topsoil conditions less susceptible to change since the Mission stopped cultivation. Since sampling equipment needed to be transported a long distance via airplane, a small, lightweight soil corer was used. The corer extracted cylindrical samples 20 cm in height by 4.5 cm in diameter. According to Estefan and Rashid (2001), a soil sample should be composed of several sub-samples representing a seemingly uniform area with similar management history (Estefan, and Rashid, 2001). While 5 to 25 sub-samples per composite sample are common, Estefan and Rashid (2001) suggest that fewer sub-samples are needed where little to no fertilizer has been used. At each sample point, therefore, three soil core samples within a 0.5 m radius were removed and bulked in a plastic Ziploc bag to make one composite sample per sample point (Tables 2 and 3).

At each sample point, an additional soil sample was taken with a bulk density ring (Schroth and Sinclair, 2003) within the same 0.5 m radius of each composite sample (Tables 2 and 3). Cylindrical dimensions of the bulk density sample were 5.2 cm in height and 4.5 cm in diameter. A hole was dug about 10 cm from the soil surface and the ring was driven horizontally into the soil about 5 cm below the surface. The ring was carefully extracted and the exposed sides of the ring were trimmed of excess soil to get an exact volumetric sample (Schroth and Sinclair, 2003). Soil from each ring was removed on site and placed into separate bags, labelled with the corresponding sample point ID.

All soil samples were immediately placed in a freezer (Estefan, and Rashid, 2001) in Fort Albany and later transported in coolers to the University of Waterloo for analysis. Samples taken during the crop growth period may give more accurate information about the nutrient status of the soil in which plants are drawing nutrients (Estefan, and Rashid, 2001). Thus, samples were taken from August 6-10, 2010, when the ground was not frozen or water-logged and the growing season appeared to peak.

Table 2: The Number of Sample Points in each Vertical Distance (VD), Horizontal Distance (HD) Transect and Sites A and B, where:
n=Number of Sampling Points**, c**=Number of Soil Cores**, cs**=Number of Composite Samples, and **b=N**umber of Bulk Density Ring Samples

Transect	n	c	cs	b	Transect	N	c	cs	b
VD1	5	15	5	5	VD7	1	15	1	1
VD2	1	3	1	1	VD8	5	3	5	5
VD3	5	15	5	5	VD9	1	15	1	1
VD4	1	3	1	1	VD10	5	3	5	5
VD5	5	15	5	5	VD11	5	15	5	5
VD6	1	3	1	1	VD12	1	3	1	1
HD1	3	9	3	3	HD6	3	9	3	3
HD2	3	9	3	3	HD7	3	9	3	3
HD3	6	18	6	6	HD8	6	18	6	6
HD4	3	9	3	3	HD9	3	9	3	3
HD5	3	9	3	3	HD10	3	9	3	3
Total Site A	**18**	**54**	**18**	**18**	**Total Site B**	**18**	**54**	**18**	**18**

Table 3: The Number of Sample Points in Site C and D, where:
n=Number of Sampling Points**, c**=Number of Soil Cores**, cs**=Number of Composite Samples, and **b=N**umber of Bulk Density Ring Samples

Sample Point	n	c	cs	b	Sample Point	N	c	cs	b
R1	1	3	1	1	R4	1	3	1	1
R2	1	3	1	1	R5	1	3	1	1
R3	1	3	1	1	R6	1	3	1	1
Total Site C	**3**	**9**	**3**	**3**	**Total Site D**	**3**	**9**	**3**	**3**

D 3.2.3) Soil Analysis

At the University of Waterloo, all samples were allowed to defrost in coolers and then to reach room temperature for analysis. The composite soil samples were removed from the bags and spread into shallow aluminum trays to air dry (Anderson and Ingram, 1989). Soil samples were mixed every other day to speed up drying process. About 50 g of dry samples were sent to the Soil and Nutrient Analysis

Lab at the University of Guelph, Ontario for analysis (Appendix 3). Total nitrogen (N), extractable phosphorus (P), potassium (K), and magnesium (Mg), pH, organic carbon (SOC) and inorganic carbon (IC) content were determined for all composite soil samples (n=18 for Sites A, n=18 for Site B, n=3 for Sites C, n=3 for Site D).

Grain size analysis is used to characterize soil texture (percent sand, silt and clay particles) within an area of similar treatment and vegetation (Schroth and Sinclair, 2003). Characterization of soil texture in the undisturbed and modified sites was important since this information is not available for the James Bay area, but less relevant for pattern studies, as it is slow to change temporally and spatially (Schroth and Sinclair, 2003). Thus, only three samples per plot were sent to the Soil and Nutrient Analysis Lab for grain size analysis (Appendix 3). All three composite samples from Sites C and D were analyzed while one vertical distance transect was randomly selected from Sites A and B (VD1 for Plot A and VD8 for Plot B) to obtain three samples per plot.

Bulk density ring samples were used to determine percent soil moisture (SM) and bulk density (BD). SM was determined using the gravimetric method (Gardiner and Miller, 2003): wet samples were removed from the bags, weighed, dried at 105^{o}C for 48 hours and then re-weighed for determination of percent soil moisture (Schroth and Sinclair, 2003). The dry soil mass was also used to calculate BD from the known sample volume (Schroth and Sinclair, 2003).

Soil organic matter (SOM), carbon to nitrogen ratio (C:N), organic nitrogen (ON) and inorganic nitrogen (IN) were estimated from SOC and total N under the assumption that more than 95% of total N in topsoil is organic (Schroth and Sinclair, 2003) and that 58% of SOM is SOC (Schroth and Sinclair, 2003). Structural integrity (s) was determined from percent SOM, silt and clay (Schroth and Sinclair, 2003).

D 3.3) Statistical Analysis

D 3.3.1) Site Characterization

Minimum, mean and maximum levels of various soil properties were compared to known or estimated levels of soil properties needed for optimum growth of mixed garden produce. Known optimal values of soil P, K, Mg and pH and fertilizer N were taken from the Agriculture Analytical Services Lab (AASL) of Penn State University (2010) (Appendix 4). Optimal values of other soil properties were estimated from various literature and are referred to by in-text citations throughout discussion of results.

D 3.3.2) Comparison of Means

PASW Statistics 18 software was used for all statistical analysis. A Test of Homogeneity of Variances and a One-Sample Kolmogorov-Smirnov Test were used to test homogeneity and normality of data within transects and sites, for which on a One-Way ANOVA was used to compare means. Where data were not normal or homogeneous, a non-parametric Kruskal-Wallis Test was used. Soil properties were treated as response variables, site and transect were treated as factors of analysis, and each site or transect was treated as a treatment level. A P-value of 0.05 was used to test for significant differences. A comparison of means was used to determine the amount of variability between Sites A, B, C and D and between transects of AF Sites A and B for select soil properties. Where significant differences were found, post-hoc analysis using a Tukey's Test was followed to compare sites and transects pair-wise. Box-plots were used to show the distribution of data within each site and Means Plots were used to show the distribution of data within transects.

D 4) RESULTS

D 4.1) VEGETATIVE STUDY

D 4.1.1) Species Composition: Sites A, B, C and D

Three visually distinctive strata of vegetation were observed and considered separately for vegetative inventory of Site A:

Stratum 1: within 1.5 m from SE tree row (1.5 m x 35 m)

Stratum 2: area between first and third strata (11 m x 35 m)

Stratum 3: within 1.5 m from NW tree row (1.5 m x 35 m)

Vegetation within these strata of Site A consisted of a mix of early pioneer species (Table 4) reaching up to 45 cm in height, with a few dominant species. Vegetation within Site B was a spatially heterogeneous mixture of early pioneer species (Table 4) reaching up to 86 cm in height, with a few dominant species. The top of Site B, the southwest edge, was dominated by the early pioneer, *Epilobium angustifolium* (fireweed). Site C was composed of a spatially heterogeneous mixture of early pioneer species in approximately equal proportions (Table 4). The dominant overstory species of Site D were identified (Table 4) and were characteristic of a late succession boreal forest.

Surrounding vegetation

In addition to the tree species found in Site D, *Betula papyrifera* (white birch), *Picea glauca* (white spruce), *Thuja occidentalis* (white cedar) and *Abies balsamea* (balsam fir) were common tree species found in undisturbed forests surrounding the study sites. Aspen was common on the outer edges of the forest. Willows dominated disturbed areas such as roadsides and backyards. The most common tree species in the proposed garden area, outside of the study sites, were willow and alder.

Table 4: Vegetative Species Identified in Proposed Agroforestry Community Garden Sites (Sites A and B), a “No Tree” Control Site (Site C) and an Undisturbed Boreal Forest Control Site (Site D) in Fort Albany First Nation, Ontario, where:
A1-A3=Strata 1-3 in Site A, **%**=percent coverage and *denotes non-native species

Site	**Dominant Vegetation**		**Other Vegetation**	
	%	***Species Name***	**%**	***Species Name***
A1	80	*Agrostis Stolinifera** (creeping bentgrass)	10	*Solidago spp.* (goldenrod), *Taraxacum officianales** (dandelion), *Symphyotrichum novae-angliae* (New England aster)
	10	*Symphyotrichum lanceolatum* (panicled aster)		
A2	90	*Galeopsis tetrahit** (hemp nettle), *Erysimum cheiranthoides** (wormseed)	10	*Taraxacum officianales** (dandelion), *Chenopodium album** (pigweed)
A3	85	*Symphyotrichum lanceolatum* (panicled aster)	5	*Vicia cracca** (cow vetch), *Solidago spp.* (goldenrod), *Galeopsis tetrahit** (hemp nettle), *Erysimum cheiranthoides** (wormseed)
	10	*Cirsium arvense** (Canada thistle)		
B	80	*Symphyotrichum lanceolatum* (panicled aster) *Cirsium arvense** (Canada thistle)	20	*Solidago spp.* (goldenrod), *Vicia cracca** (cow vetch), *Galeopsis tetrahit** (hemp nettle), *Erysimum cheiranthoides** (wormseed), *Taraxicum officianales** (dandelion)
C		*Symphyotrichum lanceolatum* (panicled aster) *Solidago spp.* (goldenrod) *Taraxicum officianales** (dandelion) *Vicia cracca** (cow vetch) *Cirsium arvense** (Canada thistle) *Agrostis Stolinifera** (creeping bentgrass) *Eupatorium maculatum* (spotted Joe-Pye weed)		N/A
D		*Picea mariana* (black spruce) *Populus tremuloides* (trembling aspen) *Alnus viriclis* (green alder) *Viburnum edule* (mooseberry) *Larix larcina* (tamarack)		N/A

D 4.1.2) Willow Tree Inventory: Sites A and B

Various measurements of willow tree rows were made (Table 5) and used to calculate total willow density at each site (Table 6). Compared to Stratum 1b, Stratum 1a was composed of shorter and fewer willows with shorter branch length and a higher density of thinner shoots. Row 1 was characterized as a relatively wide tree row at its base with a high shoot and tree density and low branch overhang. The shoot basal area of Row 1 was much smaller than that of Rows 2 and 3. Thus, the relatively large branch and base width of Row 1 can be attributed to a higher number of trees with a high density of thin shoots. In comparison to Row 1, Row 3 had a much higher branch width but similar base width, due to much longer branch overhang of Row 3 into Site B. Row 3 had smaller tree and shoot densities compared to Row 1, but a mean shoot basal area 30 times larger. Thus, the larger width of Row 3 can be attributed to a composition of thick shoots and longer branch overhang, despite the smaller number of trees and shoots.

Row 2 had a much smaller base width, but similar branch width, as Rows 1 and 3. Row 2 had a larger overhang into Sits A and B than either of the other two rows. Row 2 had a moderate shoot density and tree density, as well as an intermediate majority tree height and mean shoot basal area; the values of tree height, trees/ha and shoots/ha were closer to that of Row 3, while the value of shoots/tree and mean shoot basal area were much closer to that of Row 1.

Table 5: Salix sp. (willow) Tree Row Measurements in the Proposed Agroforestry Community Garden Sites (Sites A and B) of Fort Albany First Nation, Ontario, where:

Width (Branch) = Width of row measured from branch tip to branch tip
Row Width (Base) = Width of row measured from tree stem base to tree stem base
Branch Overhang = Distance from branch tip to tree base
Width of Water = Width of water present in the tree row with "consistent" representing a continuous flow of water, and "inconsistent" representing discontinuous patches of water, along the 35 m row length
Shoot Basal Area= Area of shoot measured at the base of the shoot where it meets the stem
Shoots/Tree and Shoots/ha=Number of shoots, counted were base of the shoots meet the stem

Measurement		**Row 1**			**Row 2**	**Row 3**
		Stratum 1a	**Stratum 1b**	**Whole Row 1**		
Row Length (m)		35.00	35.00	35.00	35.00	35.00
Row Width (m)	**Branch**	4.00	7.50	11.50	10.30	15.50
	Base	3.60	5.60	9.20	5.20	9.50
Tree Height (m)	**Min**	1.40	1.79	1.40	1.99	3.35
	Max	1.51	2.89	2.89	5.17	5.89
	Majority	1.51	2.89	2.84	5.17	5.89
Branch Overhang (m) into:	**Site A**	N/A	1.3-3	1.3-3	3.0-4.5	N/A
	Site B	N/A	N/A	N/A	3.0-4.5	1.0-3.0
Width of Water		4 m consistent			1 m inconsistent pools	1.4 m consistent
# Trees/ha		4861.11	4910.71	4891.3	3846.15	3421.05
# Shoots/ha		28472.22	38461.54	65760.87	38461.54	7368.42
# Shoots/ Tree	**Min**	3.00	5.00	3.00	1.00	1.00
	Mean	5.86	18.27	13.44	10.00	2.15
	Max	9.00	48.00	48.00	25.00	5.00
Shoot Basal Area (cm^2)	**Min**	1.40	0.72	0.72	1.27	0.72
	Mean	3.24	4.16	3.93	19.89	92.00
	Max	3.90	9.63	9.63	103.13	336.21

Table 6: *Salix spp.* (willow) Tree and Shoot Density in Proposed Agroforestry Community Garden Sites (Sites A and B) of Fort Albany First Nation, Ontario

Measurement	Site A	Site B
Site Area	994 m^2	1074.5 m^2
Trees/ha*	291.75 trees/ha	223.6 trees/ha
Shoots/ha*	3239.44 trees/ha	1005.12 shoots/ha

*Row 2 was included in the area of both Site A and Site B. Half the number of trees and shoots in Row 2 was used to calculate for density measurements in each site since only half the biomass of Row 2 can contribute to each site.

D 4.2) SOIL STUDY

D 4.2.1) Inventory Study: Sites A, B, C and D

D 4.2.1 a) Productivity of Proposed Garden Area (Sites A, B and C)

Measured and estimated values of soil properties (Appendix 5) from each sample point (Figure 1) were used to calculate minimum, mean and maximum levels of soil properties at Sites A, B, C and D (Table 7 and Table 8). The soil in each site was classified as a silt loam by the University of Guelph Soil Analysis Laboratory. Compared to the ideal loam texture, the sites of the proposed garden area (Sites A, B and C) had much lower sand content, more silt, and near the optimal proportion of clay (Table 7). The entire range of soil P, K, Mg and pH levels of each site were compared to known optimal levels determined by the AASL (Appendix 4): K and P levels were too low, Mg levels were too high and pH levels were slightly too high, for optimal mixed garden productivity (Table 7). When compared to optimal range of IN fertilizer additions recommended by the AASL, the range of estimated IN levels in each site were much higher than crop requirements (Table 7). The estimated “s” value”, structural integrity, for each site was well above the critical level, indicating sufficient SOM, and thereby SOC, to maintain soil structure (Table 7). The range of C:N and BD values of each site were sufficiently lower than the maximum critical values crop production (Table 7). Mean moisture levels of each site were much higher than estimated levels for agricultural production in a silt loam soil (Table 7). Optimal values for total N could not be found (Section D 5.2.1a.ii).

D 4.2.1 b) Comparison of Sites A, B, C and D

The forest had slightly higher levels of sand and clay and slightly lower levels of silt, compared to the previously cultivated sites (Table 7). Significant differences among sites were found for all soil properties except K. Post-Hoc Analysis revealed that Site D, the undisturbed forest, had significantly higher levels of N, Mg, SOC and SM (Appendix 6: Figures 1, 4, 8, 9) and significantly lower levels of P, pH and BD (Appendix 6: Figures 2, 5, 6), than the cultivated sites.

Sites A, B and C showed similar levels of K, Mg, BD, SM and SOC. Extractable P was significantly different between all cultivated sites: Site A had significantly higher levels than all other sites, while Site B had significantly higher levels than Site C. Site A had significantly higher levels of N than both Sites B and C, which had similar N levels.

Table 7: Minimum, Mean and Maximum Values of Measured Soil Properties in Proposed Agroforestry Community Garden Sites (Sites A and B), a "No Tree" Control Site (Site C) and an Undisturbed Boreal Forest Control Site (Site D) in Fort Albany First Nation, Ontario, Compared to Optimal Values of these Soil Properties for Agriculture

Soil Property	Site	n	Minimum	Mean	Maximum	Optimal
Sand (%)	Site A	3	16.40	19.03	21.50	40%
	Site B	3	17.50	19.80	22.30	
	Site C	3	13.30	17.23	22.80	
	Site D	3	19.90	20.73	21.90	
Silt (%)	Site A	3	59.20	66.80	71.30	40%
	Site B	3	61.10	62.10	62.70	
	Site C	3	65.80	66.40	67.60	
	Site D	3	49.80	57.03	66.30	
Clay (%)	Site A	3	10.90	14.17	19.30	20%
	Site B	3	15.00	18.10	20.10	
	Site C	3	11.30	16.37	19.10	
	Site D	3	13.60	22.17	28.20	
N (ppm)	Site A	18	5700.00	7400.00	8800.00	N/A
	Site B	18	5200.00	6522.22	7600.00	
	Site C	3	2800.00	5766.67	7900.00	
	Site D	3	8100.00	10900.00	13500.00	
P (ppm)	Site A	18	8.40	15.61	27.00	35-70
	Site B	18	7.70	12.68	19.00	
	Site C	3	7.60	8.17	9.20	
	Site D	3	5.70	6.13	6.90	
K (ppm)	Site A	18	32.00	40.11	50.00	70-200
	Site B	18	31.00	37.50	49.00	
	Site C	3	27.00	32.67	38.00	
	Site D	3	33.00	37.33	40.00	
Mg (ppm)	Site A	18	200.00	292.22	340.00	100-120
	Site B	18	200.00	278.89	370.00	
	Site C	3	240.00	313.33	370.00	
	Site D	3	820.00	960.00	1200.00	
pH	Site A	18	7.60	7.68	7.90	7
	Site B	18	7.60	7.74	8.00	
	Site C	3	7.60	7.77	7.90	
	Site D	3	7.10	7.40	7.60	
BD (g/cm^3)	Site A	18	0.56	0.66	0.74	<1.4
	Site B	18	0.52	0.65	0.80	
	Site C	3	0.60	0.68	0.73	
	Site D	3	0.24	0.39	0.57	
SOC (ppm)	Site A	18	72600.00	101638.89	127000.00	N/A
	Site B	18	67700.00	93227.78	110000.00	
	Site C	3	43600.00	82000.00	110000.00	
	Site D	3	127000.00	211000.00	292000.00	
SM (%)	Site A	18	74.95	92.22	105.92	~40-45
	Site B	18	71.88	87.57	96.85	
	Site C	3	89.73	94.45	102.94	
	Site D	3	118.20	182.59	256.25	

Table 8: Minimum, Mean and Maximum Values of Estimated Soil Properties in Proposed Agroforestry Community Garden Sites (Sites A and B), a "No Tree" Control Site (Site C) and an Undisturbed Boreal Forest Control Site (Site D) in Fort Albany First Nation, Ontario, Compared to Optimal Values of these Soil Properties for Agriculture

Soil Property	Site	n	Minimum	Mean	Maximum	Optimal
IN (ppm)	Site A	18	285.00	370.00	440.00	17.5-100
	Site B	18	260.00	326.11	380.00	
	Site C	3	140.00	288.33	395.00	
	Site D	3	405.00	545.00	675.00	
C:N	Site A	18	13.40	14.46	15.34	<35
	Site B	18	13.58	15.05	16.68	
	Site C	3	14.65	14.97	16.39	
	Site D	3	16.50	20.38	22.77	
SOM (%)	Site A	18	14.00	17.52	21.90	N/A
	Site B	18	11.67	16.07	18.97	
	Site C	3	7.52	14.14	18.97	
	Site D	3	21.90	36.38	50.34	
s	Site A	18	15.46	21.64	25.77	>9
	Site B	18	14.55	20.04	22.36	
	Site C	3	9.08	17.08	22.91	
	Site D	3	27.65	45.93	63.57	

D 4.2.2) Pattern Study: Sites A and B

No significant differences between VD transects were found within Site A for any of the soil properties. Site B showed significant differences between VD transects for K, but not for any of the other soil properties. In Site A, significant differences were found between HD transects for N, P, Mg and SOC; each of these properties decreased towards either tree row (Appendix 7: Figures 1-4). The SE tree row and NW tree row within each site did not appear to have the same effect on N, P, Mg and SOC levels, indicated by a lack of symmetry in means plot curve under each site for each of these properties (Appendix 7: Figures 1-4). Although no significant differences were found between HD transects for the other soil properties, K tended to decrease towards the tree row, while pH tended to increase towards the tree row (Appendix 7: Figures 5, 6). No obvious pattern of BD and SM levels from distance-to-tree could be determined (Appendix 7: Figures 7, 8).

In Site B, significant differences were found between HD transects for N, P, Mg, SOC, BD and SM. N, P, Mg and SOC decreased towards either tree row (Appendix 7: Figures 1-4). BD levels appeared to increase towards either tree row, but were much higher 1m from the NW tree row than 1 m from the SE tree row (Appendix 7: Figure 7). The SM pattern is somewhat inconsistent, but showed a general decreasing trend towards the NW tree row (Appendix 7: Figure 8). Potassium and pH levels were not significantly different between HD transects and do not show any obvious patterns (Appendix 7: Figures 5, 6).

D 5) DISCUSSION

D 5.1) VEGETATIVE STUDY

D 5.1.1) Species Composition: Sites A, B, C and D

The grasses and forbs that dominated the old Mission fields, hemp nettle, wormseed, Canada thistle, panicled aster and creeping bentgrass, are all pioneer species commonly found on recently exposed sites, such as roadsides, wastelands and cultivated fields as well as the shores of water bodies (Chmielewski and Semple, 2001; Government of Saskatchewan, 2008; OMAFRA, 2010; USDA, 2011a; USDA, 2011b). Being tolerant of a wide variety of soil types and environmental conditions, including high moisture soils, most of these species are highly competitive, with the exception of panicled aster which is moderately competitive (Chmielewski and Semple, 2001; Government of Saskatchewan, 2008; OMAFRA, 2010; USDA, 2011a; USDA, 2011b). Hemp nettle, wormseed and Canada thistle are non-native and known to be “weedy” or invasive competitors to crops (Government of Saskatchewan, 2008; OMAFRA, 2010; USDA, 2011b). Creeping bentgrass, has been naturalized in North America since 1750 and used as important forage for livestock; it has become “weedy” or invasive in some areas and can often be found with willows as the dominant overstory (USDA, 2011a). The non-native species which dominated this area may have been introduced by the Mission as forage or garden flowers. As highly competitive species, these grasses and forbs may become a threat to successful crop production, especially without the use of chemical herbicides. Weeds that rapidly spread vegetatively, such as creeping bentgrass and Canada thistle (Government of Saskatchewan, 2008; USDA, 2011a), may be controlled by tillage to break up the perennial roots. The maximum height of vegetation in Site A was 41 cm shorter than that of Site B; however, Site A was covered largely by wormseed and hemp nettle, which were short in both sites. The dominance of these species in Site A, compared to Site B, may be related to the significantly higher P levels in Site A. It may also suggest that Site A has been more recently disturbed, and that the taller pioneer species have yet to colonize Site A. Fireweed at the top (or SW side) of Site B colonized a pile of soil which appeared to have been graded from the area between St. Anne's Lake and Site B, demonstrating recent disturbance by construction in the area.

The mature vegetation found in the forest canopy (black spruce, trembling aspen, green alder and highbush cranberry) was characteristic of mature boreal forests in the James Bay Ecoregion (Hanson, 1953; MSSC, 1996) and no mature non-native species were identified, confirming a lack of disturbance in Site D compared to cultivated sites.

D 5.1.2) Willow Tree Inventory: Sites A and B

Greater tree height and stem basal area, and lower shoot densities, of Rows 2 and 3 may indicate that as the willows age, shoots increase in basal area and decrease in number. Rows 1 and 2 were more similar in number of shoots/tree and mean basal area, while, Rows 2 and 3 were more similar in height, shoot density and tree density; this may suggest that the growth rate of shoot length is greater than that of shoot diameter in younger willow trees and that either growth of shoot diameter is more rapid than tree height in older trees, or shoot diameter continues to increase after tree height stabilizes. This interpretation is supported by Mäkelä's (1986) claim that stem basal area may continue to grow considerably after height grow rates have ceased.

However, a more recent study has identified soil moisture as the major determinant of willow stand composition structure, growth and architecture (or geometry); Rodriguez-Gonzaleza *et al.* (2010) reported that soils with higher moisture content supported willow stands with a higher density of smaller stems, a lower density of larger stems, shorter trees and lower stem basal area. Similarly, other research shows inhibition of stem radial growth (basal area) in some trees with onset of spring rainfall (Oliveira *et al.*, 1994). Row 1 had the most continuous water, 4 m wide, Row 3 had less continuous water, 1.4 m wide, and Row 2 had inconsistent 1 m pools of water; the high density, thin shoots and short height of Row 1 may be a sign of differential growth caused by high soil moisture, rather than a representation of willow age. While the driest row, (Row 2) was slightly shorter and had a lower mean basal area than the most saturated row (Row 3), it must be considered that the surface water of Row 2 was patchy; also, because Row 3 is wider, only 14.7% of Row 3 base width was covered in surface water, while 19.2% of Row 2 base width was covered with surface water. Contrary to findings by Oliveira *et al.* (1994), the surface water within Row 1was found in Stratum 1b and not in Stratum 1a, despite higher shoot density and tree height in the latter. Thus, Stratums 1a can be considered a distinct generation of willows, while, Stratum 1b shoot growth may be limited by the effects of soil saturation.

Overall, the results suggest either that as shoot diameter growth rates increase, tree height growth rates decrease and the number of shoots decrease, as willows age, or that the growth patterns of variables measured in these willows are highly controlled by soil moisture. Results also suggest that the outer stratum of Row 1, near the access road, is a younger generation of willows. It is important to consider that the rows may be comprised of slightly different willow species or varieties, which may also cause differential tree geometry and growth patterns. Willow species were difficult to identify in August when flowers were not present; it is recommended that future studies identify the willow species within these rows in late June or July when flowers may be present. Within the tree rows, some trees had dark green and dull upper leaves, while, others had bright green and shiny leaves; this may indicate that the rows are composed of different willow species or varieties.

Reduced sunlight exposure to the crop area and limited crop production has been observed as a consequence of tree shading in some AF systems (Reid and Ferguson, 1992; Clinch *et al.* 2009). The long branch overhang of Row 2 may inhibit growth near this tree row, particularly the crops of Site B that lie NW of Row 2. The shortest willows are conveniently located on the SE row of Site A which will allow greater sun exposure to crops in this site. This is particularly important in high-latitudes of the northern hemisphere; for example, Omohundro (1985) found that the intense solar radiation of high latitude Newfoundland was able to compensate for a short growing season by stimulating rapid growth. Lower sunlight exposure to the crop area can also be expected to reduce soil temperatures and thereby suppress nutrient mineralization and availability (Chapin *et al.*, 1985; Smith *et al.*, 1998). Tree height and branch overhang will need to be controlled in order to make efficient use of high solar radiation in FAFN.

D 5.2) SOIL STUDY

D 5.2.1) Inventory Study: Sites A, B, C and D

D 5.2.1 a) Productivity of Proposed Garden Area

i) Soil Texture

The ideal soil class for agriculture is a loam, which has 40% sand, 40% silt and 20% clay, allowing for optimal aeration, drainage and root movement (Oelbermann, Personal Comm., 2010). All soil samples from cultivated sites, Sites A, B and C, were classified as silt loam (Table 7); thus, the percentage of each soil separate (sand, silt, clay) was similar between these three sites. Compared to ideal conditions for agriculture, Sites A, B and C had much lower sand content, between 13.3-22.8%, more silt, 55.0-71.3%, and near the optimal proportion of clay, 10.9-20.1% (Table 7). Although this is not the ideal soil class, silt is a moderately sized soil separate between that of clay and sand, and thus would have a moderate effect on soil porosity, drainage, root movement and aeration. However, in contrast to clay, silt has low cohesion and adsorptive capacity (Brady and Weil, 2000); higher proportions of silt in this soil may allow leaching of nutrients. A moderate to optimal clay content is beneficial in this wet area because heavy clay soils are impervious and may easily become waterlogged, leading to surface runoff and loss of nutrients (Turtola and Paajanen, 2000). Dust is made up of very small soil particles, such as silts, fine sands and tiny clay aggregates (Gardiner and Miller, 2008); higher proportions of silt may have drifted from the nearby airstrip. Low sand content in this soil is compensated by a low BD (discussed below), providing the soil with loam-like drainage (Havlin *et al.*2005).

<u>ii) Soil Fertility (N, P, K, Mg, pH)</u>

<u>Nitrogen (N)</u>

Total N includes the organic form (ON) tied up in SOM and the mineralized forms (IN) usable to plants, as ammonium (NH_4^+) or nitrate (NO_3^-) (Gardiner and Miller, 2008). No literature on sufficient amounts of soil N for a given crop, either total or usable forms, could be found; instead, The Ontario Ministry of Food and Agriculture and other Canadian agricultural resources only provide the amount of N fertilizer that needs to be added to soil for given crops. The AASL, which provide optimum values for P, K and Mg, do not address existing N forms, thus, do not have soil optimum soil-N standards; they explain that N is always changing form in the soil, due to moisture and microbe and plant use, and can leach out from one season to the next (Stecko, P. Personal Comm., 2010). Cain *et al.* (1998) confirm the high spatial and temporal variability of N forms within the soil, albeit in coastal dune soils. Therefore, the AASL makes recommendations on optimal N-fertilizer additions, based on the amount of N a given crop requires for the growing season. It appears that conventional agricultural associations in North America assume N deficiencies and thus provide a standard amount of N-fertilizer required, regardless of current soil conditions. This is likely the norm because N is so frequently the limiting growth factor in conventional agricultural systems (Estefan and Rashid, 2001; Schroth and Sinclair, 2003).

Although no comparisons of existing values to optimal values of total N in the soil can be made, initial values can provide useful information about N dynamics in subarctic AF systems over long-term studies. Additionally, an estimate of usable IN in the samples can be compared to recommended N-fertilizer applications required for a given crop to give an approximation of sufficiency of current soil N levels in each plot.

The AASL recommends about 39-224 kg/ha, or 17.5-100 ppm, of N-fertilizer for a mixed variety of garden crops for one growing season. Measured total N values of the soil samples ranged from 2800-8800 ppm in the cultivated sites (Table 7), and 8100-13500 ppm in the undisturbed forest site (Table 7and Appendix 6: Figure 1). However, fertilizers provide N in the mineralized form (IN), which is available for immediate uptake by plants, while total N includes both mineral IN and stored ON. Since more than 95% of total N in topsoil tends to be organic (Schroth and Sinclair, 2003), the range of usable, mineral IN is estimated to be at most 140-440 ppm for the cultivated sites and 405-675 ppm for the forest site (Table 8), much higher than the recommended fertilizer additions of 17.5-100 ppm.

Excessive levels of mineralized N are hazardous in high-input agricultural systems where N may leach into groundwater, causing eutrophication of water bodies or contamination of potable water sources (Spiertz, 2010). However, hazardous levels of mineralized N are not probable in the study sites, considering that agricultural production halted about forty years ago and that manure was not added to the forest plot. The estimated mineral IN values may be much higher than the optimum N-fertilizer values for several reasons. First, it is likely that these soils have more than 95% of their N tied up in SOM because soils of subarctic regions and boreal forests have shown slower decomposition of SOM and lower mineralization of nitrogen due to low temperatures (Chapin *et al.*, 1985; Smith *et al.*, 1998). Nutrient mineralization can be further retarded in highly saturated soils (Rodriguez-Gonzaleza *et al.*, 2010), such as those in the forest and proposed garden area. Higher proportions of ON would equate lower levels of available IN in the samples, making IN estimates higher than actual IN content. This is further supported by high levels of N in the forest site, which had a mean total N value more than double that of any of the cultivated sites, despite the forest site never receiving manure fertilization. Further, all sites also have relatively high levels of SOM (discussed in Section iv). Secondly, the N-fertilizer values were reported as a mass (kg/ha) and converted to a volume (ppm), while, the measured N values were initially reported as a mass (% dry) and converted volume (ppm). Inaccuracies may have resulted during conversion because different soils have different bulk densities (mass per volume). Third, N-fertilizer values are additions to soil that presumably already contains some mineralized N. Thus, these findings should be treated as loose estimates of “optimum N levels”.

With these considerations, the results suggest that usable N in all four sites is likely near that of “optimum N levels” for diverse crop production, or that excessive amounts of N are stored as SOM. If too much of the N is tied up in the organic form, it may create deficiencies and causes poor plant yields (Gardiner and Miller, 2008). Northern ecosystems are known to have low levels of nitrogen mineralization due to low temperatures and short growing seasons (Flanagan and Van Cleve, 1983; Moore, 1984) and thus natural SOM decomposition in the gardens may be too slow to support mixed garden produce after several years of harvest.

Further soil analysis can be used to determine proportions of soil ON and IN, although annual soil N tests will still be very rough estimates considering that N is always changing form in the soil (Cain *et al.*, 1998; Stecko, P. Personal Comm. 2010). Seasonal studies, or at least annual studies at the same time every year, would help reduce this uncertainty. Test plots of various crops may the best indicators of seasonal N-deficiencies; crops will show yellow colour of older leaves and slow or stunted growth (Schroth and Sinclair, 2003).

Phosphorus (P)

The entire range of inorganic P levels in cultivated sites, 7.6-27 ppm, was less than the optimal range of inorganic P, 35-70 ppm, determined by the AASL (Appendix 4). Low levels of P are common as P is the second most highly deficient plant nutrient (Gardiner and Miller, 2008; Schroth and Sinclair, 2003). Cold, wet springs often retard P absorption (Gardiner and Miller, 2008) and P mineralization is reduced in cold climate regions (Smith *et al.*, 1998), making low P levels in this study site particularly challenging. To optimize P uptake, additions of fresh organic material in the soil can release phosphorus as it decomposes and mitigate P fixation to insoluble forms (Gardiner and Miller, 2008), but Schroth and Sinclair (2003) suggest that P fertilizer is necessary for permanent agriculture. Phosphorus-deficiencies will be indicated by darker green leaf colour, reduced leaf extension and higher root:shoot ratio (Schroth and Sinclair, 2003).

Potassium (K)

High quantities of soil K is common, however, the exchangeable supply required by most plants is often small (Gardiner and Miller, 2008). Such was the case for the proposed garden area, where even maximum exchangeable K levels (50, 49 and 38 ppm for Sites A, B and C) were much lower than the "optimal" range of exchangeable K levels (70-200 ppm) provided by the AASL (Appendix 4). Insufficient exchangeable K reduces plant growth and crop quality (Havlin *et al.*, 2005) and may be particularly detrimental to high K users such as potato (Appendix 4), a highly desirable food in the

FAFN community (FN 1). Deficiencies are expected in soils low in clay, resulting from few exchange sites (Gardiner and Miller, 2008). Low clay content found in about half of the samples within the garden sites (Table 7) may be a problem for K availability. Available K can be enhanced by recycling crop residues and manures (Singh *et al.*, 2002).

Magnesium (Mg)

According to Gardiner and Miller (2008), Mg deficiency is unlikely in soils with moderate to high pH, as found in all potential garden sites. Mean Mg levels for cultivated sites, 292.22 ppm, 278.89 ppm and 313.33 ppm for Sites A, B and C, more than double the upper limit of the optimum range of Mg levels (100-120 ppm) suggested by the AASL for optimum growth of garden produce (Appendix 4). Similar to K, Mg deficiencies are more common in acidic soil with low clay content and high leaching potential (Foth and Ellis, 1997). No negative consequences of excessive Mg could be found in the literature, thus Mg levels in the proposed garden sites appear to be sufficient.

pH

The mean soil pH of sites in the proposed garden area were slightly higher than the optimal of 7 (Appendix 4), with a mean pH of 7.68, 7.74 and 7.77 in Sites A, B and C respectively, but most crops grow well between 5.5 and 8.5 (Gardiner and Miller, 2008). However, maximum efficiency of phosphorus occurs in soils with a pH between 6 and 7, while a pH of 6-6.5 is ideal for potassium uptake (Gardiner and Miller, 2008). Therefore, soil pH in the proposed garden area is likely slightly higher than optimal, but sufficient for a successful mixed garden. Soil acidity increases over time with agricultural use due to loss of cations from leaching and crop removal (Schroth and Sinclair, 2003), which may bring pH to optimal levels. However, AF techniques may decrease soil acidity by decreasing leaching losses and increasing soil organic matter (Schroth and Sinclair, 2003). Monitoring of soil pH in the AFCG test plot over long-term studies can examine this effect.

iii) Bulk Density (BD)

BD represents the density of a known volume of soil as it exists in the study site (Scroth and Sinclair, 2003; Gardiner and Miller, 2008). For good plant growth, BD should be below 1.4 g/cm^3 for clays and 1.6 g/cm^3 for sands (Gardiner and Miller, 2008). The entire range of BD values for each site was well below these limits, with mean BD values of 0.66 g/cm^3, 0.65 g/cm^3 and 0.68 g/cm^3 for Sites A, B and C (Table 7). These low BD levels create sufficient pore space to allow penetration of tiny crop roots and movement of air, water and soluble nutrients (Gardiner and Miller, 2008). If BD is too low, however, it could allow too much leaching of soluble nutrients (Schroth and Sinclair, 2003). A low BD is common in fine-textured soils like silt loams, especially those with higher organic matter, because pores exist both between and within the granules (Brady and Weil, 2000). While cultivated loam soils tend to have an average BD of about 1.1 g/cm^3 to 1.4 g/cm^3, greenhouse potting mixtures support plant growth with BDs as low as 0.1 g/cm^3 to 0.4 g/cm^3 (Gardiner and Miller, 2008). The range of BD values for all sites within the proposed garden area, 0.52g/cm^3 to 0.80g/cm^3(Appendix 5) falls between that of loose potting mixtures and cultivated loams. Therefore, the proposed garden area has suitable levels of BD for crop cultivation.

iv) Soil Organic Carbon (SOC) and Soil Organic Matter (SOM)

Mean SOM was estimated to be 17.52% (Site A), 16.07% (Site B) and 14.14% (Site C) (Table 8). Natural soils of the James Bay Region below the tree line are very high in SOM (MSSC, 1996; Natural Resources Canada, 2008). A critical level of SOM for a given soil can be calculated as "s" based on percent SOM, silt and clay; an s>9 indicates soils with sufficient amounts of organic matter to maintain soil structure (Schroth and Sinclair, 2003). All soil samples in the proposed garden area had s values well above 9 (Table 7 and Appendix 5). Despite 40 years of cultivation by the Mission, the proposed garden area has maintained relatively high levels of SOM in Sites A, B and C. The high levels of SOM make these sites capable of supporting further cultivation without compromising soil structure and other functions of SOM, including regulation of nutrient availability, acidity and water-holding capacity, provision of substrate for biota and acting as a carbon sink (Schroth and Sinclair, 2003).

High levels of SOC relative to ON can reduce SOM mineralization and nutrient availability (Foth and Ellis, 1997). A sufficiently low C:N ratio for SOM ensures that mineral N is produced in excess of the N needs of bacteria involved in the mineralization process (Foth and Ellis, 1997). Substrates with a C:N ratio greater than 35 do not leave sufficient mineral N for plant needs (Foth and Ellis, 1997). With the assumption of at least 95% ON from total N, Sites A, B and C had mean C:N of 14.46, 15.05 and14.97, respectively (Table 8). Thus, SOM and SOC content appear more than suitable for long-term crop cultivation in the proposed garden area.

v) Soil Water Content (SM)

With a mean SM of 92.22%, 87.52% and 94.46%, for Sites A, B and C (Table 7), competition by trees for soil water does not appear to be of concern in the proposed garden sites. No optimal soil moisture values could be found in the literature. According to Crop Advisor, John Hussack (Personal Comm., 2011), soil moisture is highly dependent on environmental conditions, particularly soil type. Hussack (2011) estimated that the ideal soil moisture for crop production in silt loam soils is around 40-45%. Soil moisture is highly spatially and temporally variable (Western *et al.*, 2002), making the one-time sample very limited in characterizing moisture content within these sites throughout the growing season. However, these sites are expected to experience even higher levels of SM; FAFN residents identified early spring as the wettest period in the proposed garden area, particularly during years of floods (FN 1; FN 6).

The high SM found in the proposed garden area is related to the silt loam texture and high SOM content. SOM increases infiltration capacity and retains 20 times its weight in water (Havlin *et al.*, 2005). The optimal water-holding capacity, “field-capacity”, is found in loam soils and is reached when soil is holding the maximal amount of water useful to plants; water in excess will reduce aeration, retarding microbial activity and growth of most plants, and be lost to lower horizons, leaching nutrients from the topsoil (Brady and Wiel, 2000). Silt loams have the highest water-holding capacity, beyond that of field capacity, partially accounting for high SM content. Silt loam texture and high drainage may also be causing low levels of nutrients due to high leaching after floods. Levels of SM measured in early August of 2010 are twice the suggested percentage suitable for crop production in a silt loam soil. It is thus predicted that without modifications to these sites, they will become over-saturated at some point in the season, limiting soil aeration and causing loss of nutrients from leaching and surface runoff (Brady and Weil, 2000; Turtola and Paajenan, 2000).

D 5.2.1 b) Comparison of Sites A, B, C and D

The higher clay content of the forest (Site D) gives this soil better cohesion and adsorptive capacity (Brady and Weil, 2000), which may contribute to the higher nutrient content of forest soils (discussed below). Located much closer to the airstrip, and lacking forest canopy, the cultivated sites (Sites A, B and C) may be accumulating silt from high-silt dust blown from the airstrip.

Lower levels of N in the cultivated areas were expected due to nutrient loss from harvest. Potatoes, which have high N requirements (Appendix 4), were heavily planted in the old Mission fields and thus may have assisted in depleting soil N in the cultivated sites. However, potatoes are also heavy K users, yet no difference in K was seen between cultivated and undisturbed sites.

High levels of N in Site D are suspected to be a result of high SOM and low decomposition rates of subarctic boreal forest (Chapin *et al.*, 1985; Smith *et al.*, 1998). With high proportions of nutrients stored in SOM, inorganic P levels of the forest were low in Site D, but unmeasured organic P reserves may be higher in this site. Low levels of P, however, are common in natural soils that lack fertilizer or additions (Schroth and Sinclair, 2003; Gardiner and Miller, 2008). Mean Mg of the undisturbed forest was more than three times that of cultivated sites, suggesting high Mg use by cultivated plants or high leaching of this cation in low clay soils of the cultivated sites.

Low BD levels are common in organic soils with higher carbon, especially if the area is not cultivated (Brady and Weil, 2000; Havlin *et al.*, 2005). Conventional cultivation increases BD and reduces soil porosity through compaction by machinery, and by replacement of trees and other diverse flora with crops that have smaller root systems (Yamoah *et al.*, 1986; Schroth and Sinclair, 2003).

Higher SOC and SOM in the undisturbed forest were expected due to the lack of cultivation; SOM decreases rapidly within the first 10 years of tillage (Brady and Weil, 2000) and is reduced by approximately 50% after 40-70 years of continuous cultivation (Havlin *et al.*, 2005). With an overall mean SOM of 15.91% in the cultivated sites and a mean value of 36.38% SOM in the undisturbed site, it is estimated that SOM was reduced in the proposed garden area by about 56.27% after the 40 years of cultivation by the Mission. The presence of more trees in the forest site will also contribute to higher SOC, since trees have high net primary production of plant carbon (Young, 1997). The multiple layers of vegetation found in the forest are an additional source of SOC through litterfall. Soils high in organic matter have very high water-holding capacities, thus, much higher SM in Site D can be related to the high water-holding capacity of SOM (Hudson, 1994) and the absence of drainage ditches. The proximity of the forest site to the Sites A and B (Appendix 2) lessens the possibility of differential flooding as a cause.

While mean forest pH was significantly higher than that of cultivated sites, all of the soils were above neutral pH (Table 7). Typically, subarctic forest soils are acidic, due to dominance of conifers that lower soil pH (Abrahamsen and Miller, 1987) and the presence of organic soils, which tend to have low pH (Dunfield *et al.*, 1993; Rodriguez-Gonzaleza *et al.*, 2010). Higher pH in the forest site may be attributed to the presence of inorganic carbon (IC), which has a buffering effect on soils (Yong *et al.*, 1990). Inorganic carbon (IC) does not play a role in plant productivity and is not expected to be found in soil of the western James Bay region, where the Canadian Shield is absent and where organic soils predominate. The source of IC in this area is likely fluvial deposits from James Bay, left by the floods of the Albany River. The proximity of FAFN to James Bay meant that the Mission did not need to significantly modify soil pH prior to crop production.

The range of Mg, BD, SOC and SM levels in the forest samples were also much wider compared to the cultivated sites (Appendix 6: Figures 4, 6, 8, 9); these cultivated sites have been subject to more consistent management and colonized by a more uniform composition of species. The wide range of Mg, BD, SOC and SM levels in the forest is likely a consequence of relatively higher diversity in species and topography, and lack of monotonous anthropogenic influence.

With similar soil textures and BD between the cultivated sites, differential leaching of nutrients between sites is not a probable cause of significant differences in N and P. Lower levels of N and P in Site B, compared to Site A, may be attributed to higher tree and shoot densities in Site B (Table 6), larger pioneer species in Site B (Section 4.1.1) and larger willows in Row 3 compared to Row 1 (Table 5). Greater biomass in Site B would equate to more nutrients stored in this biomass. Higher levels of P in Site B than Site C, may suggest that willows assist in cycling of P. Significant differences in N and P between sites may also be attributed to variable rotation of crops and manure by the Mission. If only one AFCG can be introduced in FAFN due to restrictions in funds or labour, it should be placed in Site A which is known to be more fertile than Sites B and C. Long-term analysis will provide better insights on the effect of willow presence.

D 5.2.2) Pattern Study: Sites A and B

a) Unknown Effect: Vertical Distance Comparison

Potassium levels were significantly higher in the centre of Site B, however, a Box-plot of K within VD transects shows three outliers and a very wide range of data in each transect (Appendix 6: Figure 10). This distribution of data was not common for other soil properties and not observed for K within VD transects of Site A. Significant differences between K levels in VD transects, therefore, do not indicate any geographic trends in soil K along the length of the plots.

b) Distance-to-tree Effect: Horizontal Distance Comparison

Tree-crop interactions, including changes in soil properties, may be complementary, neutral or competitive in AF systems (Young, 1997). Young (1997) refers to several AF studies around the globe where a variety of tree species have increased soil N, P, K and SOC content; under trees, SOC or SOM are nearly always higher, N is often considerably higher and P, K and other exchangeable ions are sometimes higher, as compared to soils beyond the influence of the trees. However, general findings from the current study show that nutrients and SOC increased with distance from willow trees. Post-hoc analysis revealed that N, P, Mg and SOC were significantly lower at “maximum tree effect”, 1 m from the tree row, than at “no tree effect” for each tree row-plot interaction. While there were no significant differences in K levels between HD transects of either site, a general decreasing trend towards Row 1 and Row 2 of Site A can be observed.

It appears that the willow trees may have high N, P and Mg requirements and may compete with crops for nutrients. Young (1997) argued that substantial competition for nutrients is not common. Nwaigbo *et al*., (1997) reported an increase in total N, percent carbon and organic matter with horizontal distance to Scots pine in grazed plots, using treeless grazed plots as a control. Jose *et al.* (2000) observed tree-crop competition for N fertilizer, but explain that differences in phenology and temporal nutrient uptake between the tree species and crops can minimize nutrient competition. However, other studies show that trees can access nutrients from deep soil horizons, returning leached nutrients back into the system (Rao *et al*, 1998), exemplified by higher nutrient concentrations near tree canopy (Gallardo, 2002). Trees can also reduce nutrient losses by protecting the crop area from wind and water erosion (Rao *et al.*, 1998), providing long-term maintenance of nutrient levels in the system.

Typically, SOM and SOC tend to increase near trees, where litterfall is greater (Young, 1997; Rhoades *et al.*, 1998; Gallardo, 2002). Contrary findings in the present study may suggest that the pioneer species within the plots make a greater contribution to soil SOC and SOM. It is important to consider that most AF studies observe soil conditions in developed AF systems where the understory or interior of the system is dominated by crops; within these systems, crops, and thereby organic matter, are removed each year. Sites A and B have been naturalized for about 40 years; while the organic mass of willows remains relatively intact as woody material each year, the grasses and forbs are cycled back into the system. Previous studies have observed an increase in SOM with annual manure application of about 2.5 t/ha (Havlin *et al*., 2005); additions of manure by the Mission may have maintained SOM levels better in the middle of the plot compared to areas closer to the tree row, where the drainage ditches would have lacked manure additions. It is predicted that long-term studies will observe a much greater decrease in SOC and SOM in the “no tree effect” stratum than in the “maximum tree effect” stratum over time, once grasses and forbs are replaced with crops.

With confirmation of the presence of IC in all soil samples, IC levels along HD transects were plotted. Interestingly, IC and SOC had a completely inverse relationship to the tree rows in both AF sites: IC was much higher at "maximum tree effect" than at "no tree effect" for both sites (Appendix 7: Figures 4, 9). Since IC was deposited by flood, higher IC levels near the tree rows may be a consequence of greater water accumulation and IC deposition in and near the ditches (tree rows). Rivers can deposit substantial amounts of N, P and C (Meybeck, 1982); the presence and distinct distribution trends of IC suggest that flooding of the cultivated area may play a significant role in the quantity and distribution of N and P.

No significant differences in pH were found between HD transects of either site and no consistent patterns could be observed (Appendix 7: Figure 5). Trees in cool climates can sometimes acidify soil, but this is more common of coniferous varieties (Abrahamsen and Miller, 1987). In Sites A and B, SM did not appear to have a consistent trend with respect to tree rows (Appendix 7: Figure 8). High spatial variability of soil water content has been observed in previous studies (Western *et al.*, 2002). Significant differences in SM were found between HD transects of Site B: SM showed a general decrease from Row 2 to Row 3, perhaps due to larger tree size and moisture requirements in Row 3 (Table 5). However, this does not account for low SM in the centre of the plot. Row 3 was situated in a 1.4 m wide ditch with consistent water along the row, while the ditch of Row 2 had inconsistent pools of water only 1 m in width, contrasting what would be expected from higher moisture requirements by Row 3. The deep ditch of Row 3 and variation in topography may be causing accumulation of water into Row 3 from the plot. Previous literature shows that trees may enhance soil moisture through deeper and more extensive root systems, shade effects and protection of understory from wind (Yamoah *et al.*, 1986; Young, 1997; Rao et al. 1998; Clinch *et al.*, 2009). Others demonstrate crop yield reductions resulting from moisture competition by certain tree species (Singh and Kohli, 1992;

Huxley *et al.*, 1994). Trees can access water during periods when crops are not present or when crops have little roots (Schroth and Sinclair, 2003); the presence of willows may mitigate high soil moisture, compensating for short growing seasons and flooding in the AFCG plots.

Elevation surveys followed by continuous monitoring of soil moisture regimes and tree row water content are needed to determine the effect of willow on soil moisture.

Few studies have looked at the effect of trees on physical soil properties, but lower BD under trees has been documented (Yamoah *et al.*,1986). Bulk density is known to vary considerably both temporally and spatially (Schroth and Sinclair, 2003). Although significant differences were found between HD transects in Site B, mean BD in Sites A and B appears to fluctuate sporadically within the range of 0.58 g/cm^3 to 0.68 g/cm^3, with the exception of the HD 10 which reaches 0.76 g/cm^3 (Appendix 7: Figure 7). Post-hoc analysis confirmed that HD 10 caused significant differences in between HD transects of Site B. Within this transect, two of the three samples had a BD of 0.79 and 0.8 (Appendix 5), lessening the possibility of sampling error within this transect. According to Schroth and Sinclair (2003) change in BD is an indicator of changes in soil structure from agricultural management, root growth or soil flora/fauna activity. Having thicker shoots, and subsequently thicker roots, the more mature trees of Row 3 may be increasing BD at their “maximum effect” range. If this is the case, an increase in BD will be greater in “maximum tree effect” compared to the “no tree effect” stratum over time, as the willows age and roots thicken.

E) FINAL DISCUSSION AND RECOMMENDATIONS

Introduction of three gardens, two AFCG test plots and one “no tree” test plot, in the area proposed by the community of FAFN is feasible with a few modifications to the sites, including: enhancement of drainage ditches, additions of peat from the forest, tillage of the garden area, and potentially, pruning of mature willows.

While the higher N, Mg, clay and sand content and lower pH of the forest soils appear to be more conducive to mixed crop production, the shading of understory, low soil temperatures, low decomposition rates and high soil moisture of the forest will not support high crop yields. The forest’s organic soils, however, are recommended for use as an inexpensive, local soil amendment for the AFCG, the “no tree” test plot, and future personal gardens. The higher N and Mg and slightly lower pH of the forest amendment will increase soil fertility of garden soils, which currently have low N and Mg and slightly high pH compared to optimal values. Low nutrient levels in the proposed garden area may be attributed to high silt content, low BD and over-saturated soils. According to Brady and Weil (2000), soil texture can be altered by mixing it with another soil of a different textural class. Addition of forest soils to previously cultivated sites can improve drainage with higher proportions of sand and yet improve nutrient adsorption, reducing nutrient loss from drainage, through increased proportions of clay.

Drying of forest soil amendments will reduce the high moisture content. It is recommended that these dry soil amendments are tilled into the garden plots to increase decomposition of SOM and nutrient availability to plants. Soil analysis results suggest that natural decomposition rates in the area may not be sufficient to support crop produce after several years of harvest. Tillage of organic soils at the beginning of the season, however, can provoke nutrient release before the crops are mature enough to absorb them (Schroth and Sinclair, 2003). Since nutrient release is faster from soil incorporated materials rather than surface applied (Schroth and Sinclair, 2003), it is recommended that some of the soil amendments are tilled into the garden site prior to planting and that more are added to the surface once crops begin to mature. While tillage will increase release of atmospheric carbon (Gordon and Newman, 1997), assisted mineralization of forest soil amendments is likely necessary for optimal crop production; high productivity of local foods will reduce high carbon emissions associated with food imports from the south, likely more than compensating carbon release from tillage.

Tillage may also be a strategy to increase BD and reduce SOM (Havlin *et al*., 2005; Brady and Weil, 2000), thereby reducing nutrient loss and risk of crop failure from over-saturated soils. Current levels of BD and SOM in the proposed garden site suggest that soil structural integrity can be maintained for many years. Monitoring of BD and the "s" value (soil structure) over long-term studies will ensure that optimal BD and SOM levels maintained at suitable levels. Inclusion of the tree component and lack of large machinery use in AFCGs should allow maintenance of sufficiently low BD and high SOM levels. If field production is expanded and livestock are introduced to FAFN, SOM and BD levels can be maintained by adding manure or crop residues and by rotating crops (Havlin *et al.*, 2005). However, initiation of crop rotation in the community gardens is recommended after the first year of cropping due its additional benefit of weed control (Wright, 1984; Liebman and Dyck, 1993) and the presence of highly competitive weeds found in the proposed garden area. Initial tillage of the AFCG sites will reduce competition by these weeds. Further control measures for weeds and other pests will need to be explored during the first few years of cropping when major pests are identified.

Forest soil samples reveal that mineral P levels are naturally low in the area ;therefore, fertilizers or manure may need to be added to the community gardens. However, tillage of forest amendments may potentially release unmeasured organic P. When compared to the proposed garden area, the forest samples also indicate that mission cultivation reduced N, P, and K in the topsoil. Test plots of various crops are needed to identify potential deficiencies of N, P and K or other nutrients in the proposed garden area. AF systems often need fertilizer additions to replace nutrient loss from crop removal (Jose *et al.*, 2000; Schroth and Sinclair, 2003).

Vegetative and soil analysis of the study sites revealed that willows in the AFCGs have a high potential for directly and indirectly competing with crops through shading and nutrient uptake. The willows are expected to reduce soil temperature, soil nutrient mineralization, soil nutrient availability and crop sunlight exposure, in the crop areas immediately adjacent the tree row. Schroth and Sinclair (2003) explain that management can enhance complementary and facilitative interactions between trees and crops and reduce their competitive interactions. Garcia-Barrios and Ong (2004) identify density, spatio-temporal arrangement, fertilization, weeding and shoot and root pruning as means to reduce competition in AF systems. In addition to tillage, weeding of competitive grasses and forbs in the AFCGs may be necessary to reduce competition in the crop area. Pruning of willows may be necessary to reduce light competition, though additions of willow prunings to the crop area can enhance nutrient availability to crops, depending on the tree species, environmental factors and synchrony between organic matter decomposition and crop requirements (Palm, 1995). Considering low decomposition rates in the area, however, it is recommended that prunings are composted separately, rather than added directly to the crop area.

To avoid light, moisture and nutrient competition between trees and crops, Clinch *et al.* (2009) recommend a 2 m wide buffer between trees and crops in willow intercropping systems with tree rows that are 15 m apart. In the present study, nutrient levels were significantly lower 1 m from the tree row. With AFCG plot widths of 14 m and 16 m, it is therefore recommended that crops in these plots are placed about 2 m from the willow tree rows. In consideration of the high latitude of FAFN, crops may need to be placed further than 2 m from the SE tree row of a given plot. However, initial placement of diverse crops 2 m from the tree rows may help identify ideal willow management for optimal crop success in subarctic systems and provide a better understanding of willow-crop interactions in this area.

The presence of a tree-crop buffer allows crops to benefit from the trees without competing with the trees themselves. Willows have a deep root system and extensive branching (Kuzovkina and Volk, 2009); in the AFCG system, they are expected to retrieve nutrients leached from highly porous topsoils, access nutrients inaccessible to crops, enhance nutrient cycling and protect crops from wind, snow and drift of particulates such as airport dust.

The long vegetative season of willow equates to a long period of photosynthetic activity and nutrient uptake as well as a long period of soil protection (Kuzovkina and Volk, 2009), all of which are assets in subarctic regions which have short growing seasons. Therefore, the combination of willows with short-season crops in the AFCG plots is expected to increase annual organic matter production and nutrient acquisition in the system, reduce soil erosion of the crop area and mitigate flooding and high soil moisture, as compared to the no tree control plot.

Periodic flooding helps willow outcompete other tree species, particularly non-native species (Sher *et al*., 2002), but greater flooding can also reduce growth and increase sensitivity to nutrient limitation in willows (Rodriguez-Gonzaleza *et al*., 2010). Management of soil moisture in the tree rows may be an important strategy for regulating tree row density and permeability to wind and snow and limiting willow competition for nutrients, thereby optimizing crop production in the AFCGs. Reduced willow growth may require less labour needed to prune willows and prevent light competition with crops.

Without proper management of soil moisture in the test plots, excessive water in the crop area is predicted to reduce aeration, retard microbial activity and growth of most plants, and cause loss of nutrients from surface runoff, and leaching to lower horizons (Brady and Wiel, 2000; Turtola and Paajenan, 2000). Deepening of drainage ditches within the tree rows, as well as at the top and bottom of the plots, may be necessary to assist the willows in drawing moisture from the crop area. The addition of drainage ditches in the no tree plot will be necessary.

The possibility of FAFN soils being contaminated requires that they are tested for organochlorines prior to any garden introduction. Willows are also known to be resistant to chemical contaminants in soil and water, including chlorinated compounds (Kuzovkina and Volk, 2009). If the site is contaminated with organochlorines, further propagation of willow could be useful for remediation prior to garden introduction. Future research may explore the potential of willows to provide additional products to FAFN, including biomass or biofuel, fibre, timber and fodder (for cattle or sheep) (Kuzovkina and Volk, 2009). It is recommended that future research explores the potential of subarctic AFCGs to provide additional services of carbon sequestration and wildlife habitat that have been witnessed in tropical, subtropical and temperate regions (Quinkenstein *et al.*, Kumar *et al., 2009;* Gordon and Newman, 1997).

Overall, long-term studies of crop productivity and soil property dynamics between sites, relative to distance-to-tree and relative to tree geometry and density are necessary to determine best management strategies for optimal crop and willow production and services, and to determine suitability of willows in subarctic AFCGs. According to Garcia-Barrios and Ong (2004, pp. 234), “managing [AF] systems has to be based more on monitoring, diagnosis, remediation, mitigation and adaptation, rather than on a blueprint predictability of the behaviour of the agroecosystem”.

Soil and vegetative management recommendations of the present study may not be applicable to other subarctic FNs, particularly those that lack a history of settlement and land management by the Mission; decades of manure application and tillage converted boreal forest soils into present conditions of the proposed garden area of FAFN. In the present study, it was found that boreal forest soil fertility and texture are conducive to optimal crop production, but that soil structure is too porous, moisture is too high and P levels are too low, for optimal crop production. With proper tillage and drainage, the implementation of AFCGs in undisturbed areas of the boreal subarctic is feasible and can be expected to become increasingly so with warming climate and subsequently higher soil nutrient availability (Shuur *et al.,* 2008).

Local areas of subarctic forests can be partially cleared as to make use of existing trees in AFCGs, maintaining natural resilience and adaptability. Tree species and AF design in various FN communities will depend on the needs of the area based on local microclimate, soil conditions, cultural and socioeconomic factors, as well as wildlife and carbon sequestration services. With up to 500 species of willow worldwide, predominantly in temperate and arctic zones (Kuzovkina and Volk, 2009), use of willow in other remote FNs communities is highly probable; these willow varieties are adapted to a broad range of climates and site conditions and are suitable for a variety of geographic regions (Kuzovkina and Volk, 2009). The use of conifers, common to the James Bay ecoregion (Hanson, 1953; MSSC, 1996), may make soil in the crop area acidic (Abrahamsen and Miller, 1987). Although this was not the case in the forest site of FAFN, neutral pH in this site is attributed to the presence of IC.

Crop production in subarctic forests that lack oceanic alluvial deposits may be challenged by low pH, particularly in areas dominated by acidic peat bogs (or mushkeg). Inclusion of cattle in subarctic agricultural initiatives can provide manure amendments capable of increasing soil pH and the availability of P and K in acidic soils (Whalen *et al.*, 1999).

Nitrogen-fixing trees can increase available N in immediately surrounding soils, benefitting growth of non-fixing crops in the same system (Young, 1997; Rhoades *et al.*, 1998). Alder, a N-fixing tree (Young, 1997), was found sporadically throughout proposed garden area, the undisturbed forest and flood plains of the FAFN region. Planting rows of native Alder in the proposed garden area of FAFN for long-term research of Alder AFCGs is recommended.

Long-term studies of different tree species in different areas of the subarctic are needed especially in areas where the Mission has not settled and prepared the land. Anderson and Ingram (1989) recommend extensive inventory of land-use within a 5 km radius of an AF system over the previous 20 years. More extensive land use research is recommended for AFCG research in FAFN.

The Mission successfully modified subarctic ecosystems to produce large quantities of diverse foods in a challenging subarctic environment. However, their lack of appreciation for traditional indigenous culture and lack of knowledge sharing with the indigenous community have resulted in devastating losses of autonomy and traditional ecological knowledge in FAFN and other FN communities. Consequently, a lack of leadership, personnel, knowledge and resources were barriers to community garden introduction in FAFN. In addition to food cost, food preference and a lack of food-usage familiarity and time for food preparation were identified as limitations to nutritional food consumption in FAFN. While the AFCG may act as a source of inexpensive and diverse foods, the present study recommends introducing a Food Security Program (FSP), in partnership with the AFCGs, as a holistic means to address the aforementioned barriers. As a means to regain food system autonomy, the FSP needs to be lead by community members and proper educational tools for these leaders need to be provided. The FSP focus should be on community food security and food sovereignty, rather than food security alone.

The present study also revealed that the benefits of healthy foods and knowledge of their use may help community members over-come store convenience during times of social insecurity. The lack of a social security and control experienced by many indigenous peoples should be acknowledged by the FSP. First, the FSP can support the current school snack initiative to increase familiarity of, and confidence in, local foods over exotic imports. Second, the FSP also needs to provided personnel, knowledge and leadership to manage the AFCGs and ensure that they act as a reliable food supply. Continued research on the success and adaptive management of the AFCGs and FSP partnership in FAFN may allow wide-scale adoption of this strategy as a systems approach to community food security and food sovereignty in remote FNs across Canada.

A reintroduction of the potato gardens on “potato” island and Old Fort is recommended for large production of nutritional crop that is easily stored and expensive to import. Potato fields have played a dominant role in local food production of some cold climate communities Austria (Vogl-Lukasser and Vogl, 2004), eastern Canada (Omohundro, 1985) and FAFN, accompanied by smaller subsistence gardens of mixed crops. Similarly, the AFCG can be used in conjunction with mass potato production. Studies on the tree-potato interaction will be particularly important for subarctic AF systems.

While personal gardens are not presently a realistic means of enhancing food security in FAFN, the community garden is expected to increase interest and knowledge of local food production. The accessibility of personal gardens would allow for experimentation with crops that require more care, provision of more diverse crops to complement AFCGs and potato gardens, and increase residents' exposure to land-tenure. Promotion of personal gardening and research on the feasibility of AF homegardens in FAFN are therefore recommended.

Similar to impoverished communities of the tropics and subtropics, remote FN communities of northern Canada face problems of limited productive land and a lack of access to external markets. In the southern hemisphere, AF homegardens are known to enhance food security and provide a larger return of diverse food products with little effort. However, as diverse, multi-strata systems that are designed to emulate tropical and subtropical forests, the traditional AF homegarden design may not be ecologically feasible in subarctic environments, whose natural systems are characterized by relatively low diversity and few vertical vegetative layers. While subarctic conditions will not enable the same level of productivity as tropical and subtropical regions, the underlying concepts behind the success of homegardens can be utilized in the AFCG and personal gardens. Homegardens are described as a "harmonious existence of many species...that embrace(s) the dynamic nature of ecological systems" (Jose and Gordon, 2008). The application of AF in the subarctic will require a better understanding of what areas in the local ecology are highly productive and how they might be emulated with a combination of conventional crops and native species in such a way as to optimize product output per unit area, whilst maintaining the dynamic and resilient nature of subarctic ecosystems in response to environmental change.

Traditional indigenous food systems of the north have been described as a dynamic and flexible response to a challenging and unpredictable environment (Loring and Gerlach, 2010). Traditional indigenous values that encourage resiliency of food systems and ecological systems are also evident in FAFN. Minkin (2008) observed historical and contemporary values of environmental stewardship in FAFN: to never over-kill and to thank the Creator and protect the natural environment. In the present study, one elder (FN 3) described the natural environment as being alive and having rhythm, a purpose and the capacity of being turned into food. He describes indigenous people of James Bay as "harvesters", saying that "they take what is there. Their philosophy is, the Creator provides for us...(and) will put things on the planet we can use...we take what we need (but) we don't grab a handful" (FN 3). "But we don't do that anymore", he says:

> "We are changing behaviour because we have to. It hasn't been the original behaviour of the people here. Now we are in settlement. Back and forth, everybody had their own territory, harvesting off the land what was available and if they are out of that they move to another area within their territory. (They would) harvest all the land eventually within a ten year period...go back to the original spot and by that time things were back. So we just harvested different parts of the territory. But now that we're in settlements, we have to change in behaviour. We cannot move away from this place. This is where we are now".

The capacity of traditional food systems to meet nutritional needs and maintain resiliency has been irreversibly altered through settlement and anthropogenic modifications of local cultural and environment. While traditional rotational hunting techniques allowed population replenishment (Elmzvist *et al.*, 2004), the nomadic lifestyle has been replaced by sedentary communities. Access to traditional foods is dependent on fossil-fuel-based transportation and thus traditional rotational harvest is most often not a viable option, resulting in local over-hunting or over-harvesting (Lakehead University Food Security Research Group, 2010).

FN 3 asks for preservation of traditional values, foods and culture, but recognizes that some traditional behaviours are no longer viable. New means of maintaining resilience of food systems and ecosystems of the north are required for geographically fixed northern communities, yet it is also evident that maintenance of traditional food systems and values must be supported. When discussing the interdependence of environmental change and food security, several authors urge towards, what Stroink and Nelson (2009) call, "biculturalism": an integration of traditional knowledge and ecological (western) science (Elmqvist *et al.* 2004; Stroink and Nelson, 2009). Stroink and Nelson (2009) encourage biculturally flexible, holistic, lifelong learning garden programs to help develop a strong local food system in FN communities. In a time and place of ecological and economic uncertainty, sedentary indigenous communities may find resilience by embracing this bicultural approach, sourcing a variety of cultural strategies for securing food.

Wild species associated with FAFN community traditions or a general sense of well-being, such as Labrador Tea, Balsam, flowers and a variety of berries, can be integrated into the community or personal gardens to increase access to the benefits of these plants within the settled community. Native plant species that FAFN members observe to be threatened by climate change could also be integrated into the community garden system. A much more extensive analysis of species composition in undisturbed areas surrounding FAFN is recommended, particularly of native, ecologically-adapted species with edible, medicinal or cultural significance. This should be followed by more extensive research on traditional plant uses and traditional ecological knowledge as well as scientific research of these species to identify additional ecological and structural services that they might provide to AFCGs. Conventional produce of the AFCGs should complement traditional foods; education on meals that incorporate both conventional crop produce and traditional foods by the FSP is advised.

Alaskan gardens of the 1900s are described by Loring and Gerlach (2010) as "innovative responses to rapid ecological, climatic and socioeconomic change"; garden produce filled gaps of variable harvest from wild game and unpredictable food supply. Large-scale introduction of managed AF systems to remote FNs with inclusion of both native and conventional species can complement traditional food systems and mitigate the socio-ecological effects of unpredictable climate change, contaminated ecosystems and the instability of petroleum-based imports. The traditional indigenous values of FAFN described by Minkin (2008) and FN 3 allowed for a resilient and sustainable food system. AFCGs may provide a space where these values can be applied as a means to regain a resilient food system within a sedentary community that is challenged by environmental and cultural change.

F) CONCLUSION

Introduction of AFCG and control test plots in FAFN, for long-term studies of subarctic, subsistence AF systems, is ecologically feasible. Initial site modifications necessary prior to planting were identified. Vegetative and soil sampling methods and design for long-term studies were established. It is anticipated that inclusion of willow trees in subarctic agricultural systems will enhance their long-term productive capacity and that willow AFCG test plots in FAFN are highly transferable to other areas of the subarctic as part of an import substitution strategy to enhance food security in remote FN communities. Community garden initiatives in remote FNs may benefit from the addition of the ecological services, resiliency and dynamism offered by AF systems and the personnel, leadership and knowledge of a FSP, to create a more resilient, adaptable and reliable local food system. Investigation of historical food production in FAFN by Missionaries highlighted the importance of the following: the AFCGs to complement, instead of replace, traditional foods and enhance traditional knowledge sharing opportunities; the FSP to be run autonomously by community members; and the inclusion of community members in the gardening process. Through a bicultural combination of non-native and native plant species and cultivation techniques, AFCGs may provide a space for sedentary indigenous peoples to regain traditional ecological knowledge, tend to a traditional value of connecting harmoniously with the natural rhythms of the environment and nurture traditional forms of spiritual fulfillment, and, thereby, strengthen indigenous identity, connection to the land and sense of social security. Ultimately, this may empower remote FNs to access healthy foods and make healthy food choices in a positively reinforcing, sustainable food system.

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Appendix 1: Land-use During Mission Settlement of Mainland Fort Albany First Nation, Ontario (1930-1970)

Appendix 2: Study Sites A, B, C and D in Mainland Fort Albany First Nation (2010)

Appendix 3: Methods of Soil Analysis by the University of Guelph Soil and Nutrient Lab

(Burr, Personal Comm., 2010)

Texture (Grain Size Analysis via pipette method):

Particle size analysis measures the proportions of the various sizes of primary soil particles as determined by their capacities to pass through sieves of various sizes and by their rates of settling in water using the principle of sedimentation known as Stoke's Law.

Sheldrick B.H., and Wang C. (1993). Particle Size Distribution. Pages 499-507 in M.R. Carter, (Ed.) Soil Sampling and Methods of Analysis. Canadian Society of Soil Science. Lewis Publishers.

pH:

pH is read on a saturated paste, or on an 'as received' basis if the sample is sufficiently moist. Buffer pH is analyzed on soils having a pH of 6.0 or less and is used to determine how much lime is required on farm soils. The pH meter is Thermo Orion 4 Star.

Hendershot,W.H, Lalande, H and Duquette M.1993. Soil Reaction and Exchangeable Acidity. Pages 141 to 142 in M.R. Carter, (Ed.) Soil Sampling and Methods of Analysis. Canadian Society of Soil Science. Lewis Publishers.

Potassium and Magnesium (extractable):

Samples are extracted using 1.0N Ammonium Acetate solution, and the concentration of K, Mg, Ca and Na are determined using an atomic absorption spectrophotometer- Varian SpectraAA. Although primarily used for extracting soils, it can be used for wastes and other materials at the client's specific request. Analysis can be done on a mass or volume basis. Fertilizer recommendations are based on mg/L soil results and therefore Farm Fertility and other Farm tests are always done volumetrically.

Simard, R.R.1993. Ammonium Acetate-Extractable Elements. Pages 39 to 42 in M.R. Carter, (Ed.) Soil Sampling and Methods of Analysis. Canadian Society of Soil Science. Lewis Publishers.

Phosphorus:

Sodium bicarbonate-extractable phosphorus, also referred to as olsen P, is commonly used to measure plant available P in Ontario soils. Samples are extracted using 0.5M sodium bicarbonate solution and the concentration of P in the extract is determined colourimetrically using a Seal Auto Analyser 3.

Reid, K. (Ed.) 1998. Soil Fertility Handbook. OMAFRA Publication.

Carbon (total, organic and inorganic):

The LECO SC444 is used to measure the total carbon content in soil, plant, waste and other samples. Inorganic carbon can be determined by ashing the sample at 475^0C for three hours prior to LECO SC444 use. Organic carbon is calculated from the subtraction of the inorganic carbon result from the total carbon result. The Leco SC-444 method of carbon and sulphur determination is based on the combustion and oxidation of C and S to form CO_2 and SO_2 by burning the sample at 135^0C or 145^0C in a stream of purified O_2. The amount of evolved CO_2 and SO_2 is measured by infrared detection and used to calculate the percentages of C and S in the sample.

Nitrogen (total LECO Nitrogen):

This method, based on the Dumas Method, is routinely used by SNL for the analysis of total N in plant and soil samples. Samples are dried, and ground or sieved prior to analysis. The samples are combusted in a sealed system. Nitrogen compounds released are reduced to N_2 gas, which is measured by a thermal conductivity cell using the LECO FP428. LECO instruction/operations manual for the FP-428 Nitrogen and Protein Determinator version 2.4

Appendix 4: Optimal Levels of Select Soil Properties for Mixed Garden Crops

(AASL of Penn State University, 2010)

	pH	**Mg**	**N**	**P**	**K**
Asparagus (To Plant)	7	120	75	35-70	70-140
Asparagus (Maintain)	6.7	100	75	35-70	70-140
Beans (Kidney, Lima and Snap)	6.5	100	35	35-70	70-140
Beets	7	120	100	35-70	70-140
Broccoli	7	120	100	35-70	70-140
Brussels Sprouts	6.5	100	100	35-70	70-140
Cabbage (Fresh Market and Kraut)	7	120	100	35-70	70-140
Carrot	6.5	100	75	35-70	70-140
Cauliflower	7	120	100	35-70	70-140
Celery	7	120	100	35-70	70-140
Collards	6.5	100	100	35-70	70-140
Cucumbers	6.5	100	75	35-70	70-140
Diakon	6.5	100	35	35-70	70-140
Eggplant	6.5	100	75	35-70	70-140
Endive	6	100	75	35-70	70-140
Escarole	6	100	75	35-70	70-140
Garlic	6.5	100	75	35-70	70-140
Ginseng (To Plant)	5.5	100	50	35-70	70-140
Ginseng (To Maintain)	5.5	100	35	35-70	70-140
Gourd	6.5	100	75	35-70	70-140
Herbs	6.5	100	35	35-70	70-140
Kale	6.5	100	75	35-70	70-140
Kohlrabi	6.5	100	75	35-70	70-140
Leek	7	120	100	35-70	70-140
Lettuce (Head)	7	120	35	35-70	70-140
Lettuce (Leaf and Romaine)	7	120	75	35-70	70-140
Muskmelon (Cantaloupe)	7	100	75	35-70	70-140
Mustard Greens	6.5	100	35	35-70	70-140
Onion	7	120	100	35-70	70-140
Parsnip	7	120	75	35-70	70-140
Peas	6.5	100	45	35-70	70-140
Pepper (Hot and Sweet)	7	120	75	35-70	70-140
Popcorn	6.5	100	60	35-70	70-140
Potatoes	6	100	200	35-55	100- 200
Pumpkin	6.5	100	75	35-70	70-140
Radiccho	6	100	35	35-70	70-140
Radish	6.5	100	35	35-70	70-140
Rhubarb (To Plant)	6	120	200	35-70	70-140
Rhubarb (To Maintain)	6	120	140	35-70	70-140
Rutabaga	6.5	100	35	35-70	70-140
Scallions	6	100	100	35-70	70-140
Spinach	7	120	100	35-70	70-140
Squash (Summer, Winter)	6.5	100	75	35-70	70-140
Sweet Corn	6.5	100	50	35-70	70-140
Tomato (Fresh Market)	7	100	50	35-70	70-140
Turnip Roots	6.5	100	35	35-70	70-140
Tyfon	7	120	35	35-70	70-140
Watermelon	6	100	35	35-70	70-140
Mixed Vegetable Crops	**7**	**100-120**	**35-200**	**35-70**	**70-200**

Appendix 5: Measured and Estimated Values for All Soil Properties at Each Sample Point within Sites A, B, C and D

Sample ID	Site	P (ppm)	Mg (ppm)	K (ppm)	pH	N (ppm)	IN (ppm)	ON (ppm)	IC (ppm)	SOC (ppm)	M (%)	BD (g/cm^3)	C:N	s	SOM (%)
A1	A	14.00	200.00	32.00	7.80	5900.00	295.00	5605.00	34800.00	81200.00	105.92	0.64	14.49	17.29	14.00
A2	A	24.00	320.00	36.00	7.70	7900.00	395.00	7505.00	27600.00	107000.00	83.07	0.65	14.26	22.78	18.45
A3	A	18.00	330.00	40.00	7.60	8000.00	400.00	7600.00	27700.00	107000.00	94.27	0.64	14.08	22.78	18.45
A4	A	16.00	310.00	39.00	7.60	8100.00	405.00	7695.00	25600.00	115000.00	94.98	0.68	14.94	24.49	19.83
A5	A	11.00	250.00	37.00	7.80	6600.00	330.00	6270.00	28100.00	94900.00	84.79	0.70	15.14	20.21	16.36
A6	A	16.00	320.00	42.00	7.70	8100.00	405.00	7695.00	27600.00	110000.00	89.82	0.69	14.29	23.42	18.97
A7	A	8.40	230.00	34.00	7.80	6200.00	310.00	5890.00	33600.00	80400.00	81.03	0.73	13.65	17.12	13.86
A8	A	27.00	330.00	43.00	7.70	7900.00	395.00	7505.00	27900.00	108000.00	80.90	0.70	14.39	23.00	18.62
A9	A	18.00	340.00	40.00	7.70	7900.00	395.00	7505.00	27100.00	109000.00	87.63	0.74	14.52	23.21	18.79
A10	A	16.00	340.00	45.00	7.60	8800.00	440.00	8360.00	24400.00	127000.00	102.25	0.56	15.19	27.04	21.90
A11	A	14.00	270.00	43.00	7.60	7000.00	350.00	6650.00	28100.00	92900.00	101.16	0.65	13.97	19.78	16.02
A12	A	15.00	340.00	41.00	7.70	7300.00	365.00	6935.00	28600.00	99400.00	90.65	0.66	14.33	21.17	17.14
A13	A	9.30	210.00	35.00	7.60	5700.00	285.00	5415.00	33400.00	72600.00	93.81	0.65	13.41	15.46	12.52
A14	A	15.00	290.00	44.00	7.60	7900.00	395.00	7505.00	27700.00	108000.00	91.42	0.63	14.39	23.00	18.62
A15	A	21.00	320.00	49.00	7.60	7700.00	385.00	7315.00	27500.00	103000.00	74.95	0.68	14.08	21.93	17.76
A16	A	15.00	320.00	50.00	7.60	8300.00	415.00	7885.00	23900.00	121000.00	104.36	0.61	15.35	25.77	20.86
A17	A	9.20	240.00	39.00	7.60	6900.00	345.00	6555.00	28200.00	97800.00	105.32	0.61	14.92	20.83	16.86
A18	A	14.00	300.00	33.00	7.90	7000.00	350.00	6650.00	26700.00	95300.00	93.67	0.68	14.33	20.29	16.43
Mean	**A**	**15.61**	**292.22**	**40.11**	**7.68**	**7400.00**	**370.00**	**7030.00**	**28250.00**	**101638.89**	**92.22**	**0.66**	**14.46**	**21.64**	**17.52**

Appendix 5 Continued: Measured and Estimated Values for All Soil Properties at Each Sample Point within Sites A, B, C and D

Sample ID	Site	P (ppm)	Mg (ppm)	K (ppm)	pH	N (ppm)	IN (ppm)	ON (ppm)	IC (ppm)	SOC (ppm)	M (%)	BD (g/cm^3)	C:N	s	SOM (%)
B1	B	12.00	240.00	39.00	7.60	6700.00	335.00	6365.00	26400.00	97600.00	89.69	0.52	15.33	20.98	16.83
B2	B	9.00	200.00	36.00	7.70	6100.00	305.00	5795.00	33300.00	78700.00	91.29	0.66	13.58	16.92	13.57
B3	B	9.70	230.00	39.00	7.70	6100.00	305.00	5795.00	29100.00	92900.00	96.69	0.65	16.03	19.97	16.02
B4	B	16.00	290.00	32.00	7.70	7200.00	360.00	6840.00	24700.00	104000.00	96.52	0.54	15.20	22.36	17.93
B5	B	14.00	270.00	35.00	7.70	6600.00	330.00	6270.00	27100.00	85900.00	89.09	0.62	13.70	18.47	14.81
B6	B	9.20	230.00	36.00	7.70	5600.00	280.00	5320.00	29500.00	79500.00	88.55	0.69	14.94	17.09	13.71
B7	B	13.00	310.00	49.00	7.60	7200.00	360.00	6840.00	25500.00	104000.00	77.39	0.61	15.20	22.36	17.93
B8	B	10.00	220.00	36.00	8.00	6200.00	310.00	5890.00	30600.00	83400.00	90.61	0.72	14.16	17.93	14.38
B9	B	15.00	320.00	42.00	7.60	7600.00	380.00	7220.00	23700.00	110000.00	96.46	0.60	15.24	23.65	18.97
B10	B	17.00	300.00	44.00	7.70	7300.00	365.00	6935.00	25400.00	110000.00	91.70	0.64	15.86	23.65	18.97
B11	B	14.00	350.00	42.00	8.00	7100.00	355.00	6745.00	23300.00	102000.00	84.58	0.74	15.12	21.93	17.59
B12	B	9.60	250.00	43.00	8.00	5600.00	280.00	5320.00	27900.00	74100.00	72.54	0.79	13.93	15.93	12.78
B13	B	11.00	230.00	31.00	7.60	6000.00	300.00	5700.00	30900.00	87100.00	96.79	0.63	15.28	18.72	15.02
B14	B	12.00	270.00	35.00	7.60	6700.00	335.00	6365.00	25400.00	104000.00	96.85	0.64	16.34	22.36	17.93
B15	B	17.00	350.00	31.00	7.70	7400.00	370.00	7030.00	26700.00	101000.00	79.68	0.63	14.37	21.71	17.41
B16	B	13.00	370.00	38.00	8.00	6300.00	315.00	5985.00	23800.00	93200.00	92.22	0.63	15.57	20.04	16.07
B17	B	7.70	230.00	34.00	7.80	5200.00	260.00	4940.00	29100.00	67700.00	71.88	0.80	13.70	14.55	11.67
B18	B	19.00	360.00	33.00	7.60	6500.00	325.00	6175.00	27900.00	103000.00	73.81	0.58	16.68	**22.14**	17.76
Mean	**B**	**12.68**	**278.89**	**37.50**	**7.74**	**6522.22**	326.11	**6196.11**	**27238.89**	**93227.78**	**87.57**	**0.65**	**15.05**	**20.04**	**16.07**
1	C	7.70	370.00	33.00	7.60	6600.00	330.00	6270.00	27600.00	92400.00	90.70	0.72	14.74	19.25	15.93
2	C	9.20	330.00	38.00	7.90	7900.00	395.00	7505.00	26100.00	110000.00	102.94	0.60	14.66	22.91	18.97
3	C	7.60	240.00	27.00	7.80	2800.00	140.00	2660.00	36300.00	43600.00	89.73	0.73	16.39	9.08	7.52
Mean	**C**	**8.17**	**313.33**	**32.67**	**7.77**	**5766.67**	288.33	**5478.33**	**30000.00**	**82000.00**	**94.46**	**0.68**	**14.97**	**17.08**	**14.14**
1	D	5.80	1200.00	39.00	7.60	11100.00	555.00	10545.00	12300.00	214000.00	173.31	0.35	20.29	46.59	36.90
2	D	6.90	860.00	33.00	7.10	13500.00	675.00	12825.00	8930.00	292000.00	256.25	0.24	22.77	63.57	50.34
3	D	5.70	820.00	40.00	7.50	8100.00	405.00	7695.00	19500.00	127000.00	118.20	0.57	16.50	27.65	21.90
Mean	**D**	**6.13**	**960.00**	**37.33**	**7.40**	**10900.00**	545.00	**10355.00**	**13576.67**	**211000.00**	**182.59**	**0.39**	**20.38**	**45.93**	**36.38**

Appendix 6: Box-Plots of Soil Property Levels in Sites A, B, C and D and of K in Vertical Distance Transects in Site B (*denotes significant differences between sites)

Figure 1: Box-plot of N (ppm) in Sites* A, B, C and D

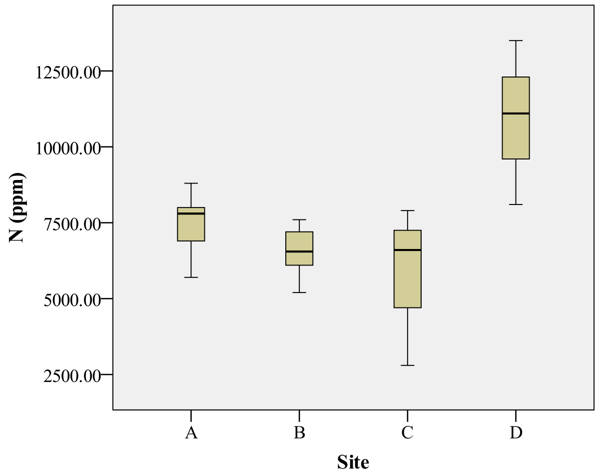


Figure 2: Box-plot of P (ppm) in Sites* A, B, C and D

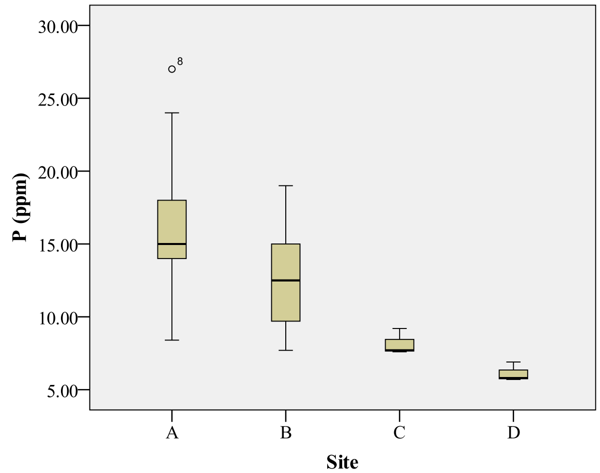


Figure 3: Box-plot of K (ppm) in Sites* A, B, C and D

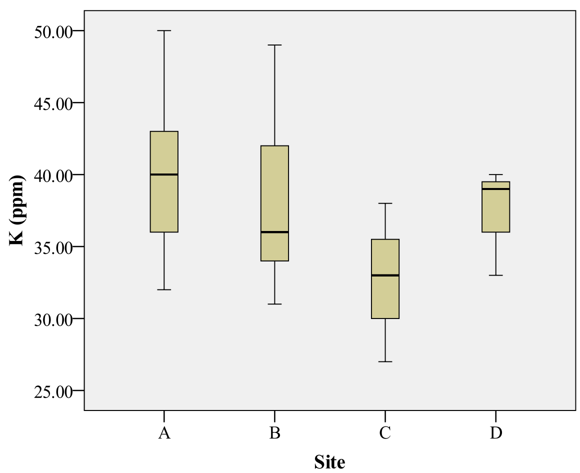


Figure 4: Box-plot of Mg (ppm) in Sites* A, B, C and D

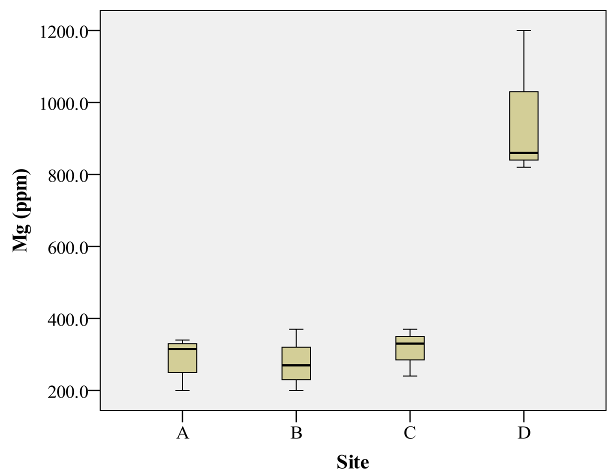


Figure 5: Box-plot of pH in Sites* A, B, C and D

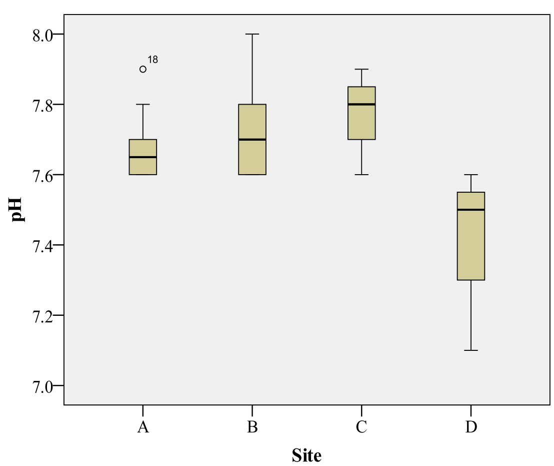
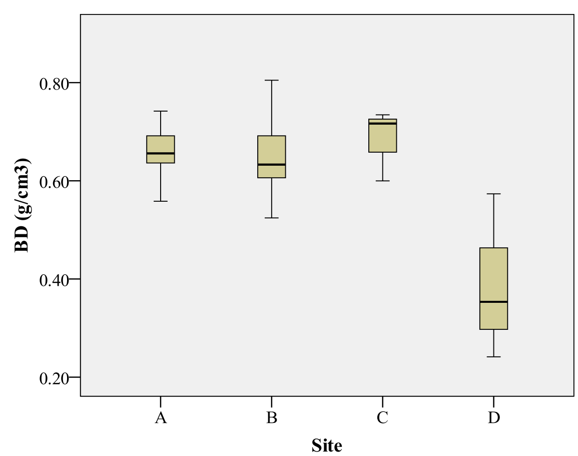


Figure 6: Box-plot of BD (g/cm3) in Sites* A, B, C and D



Appendix 6 Continued: Box-Plots of Soil Property Levels in Sites A, B, C and D and of K in Vertical Distance Transects in Site B (*denotes significant differences between sites or transects)

Figure 7: Box-plot of %SOM in Sites* A, B, C and D

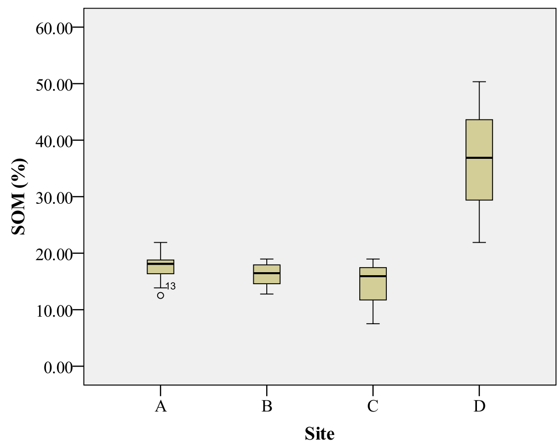


Figure 8: Box-plot of SOC (ppm) in Sites* A, B, C and D

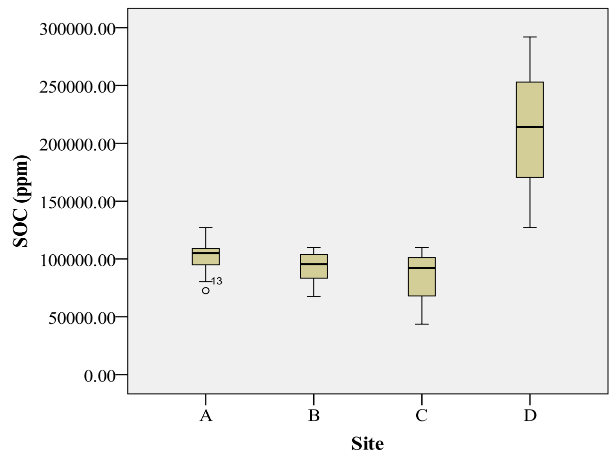


Figure 9: Box-plot of SM (%) in Sites* A, B, C and D

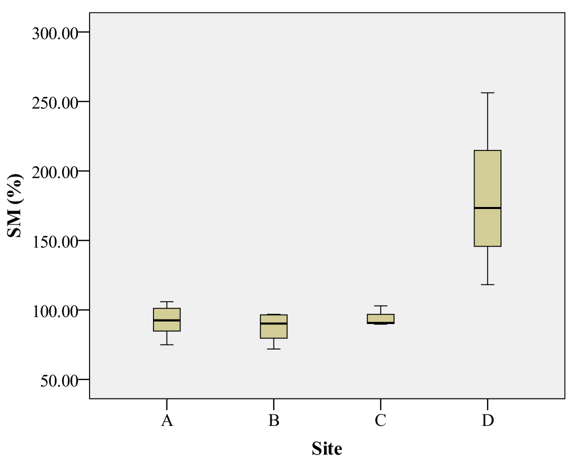
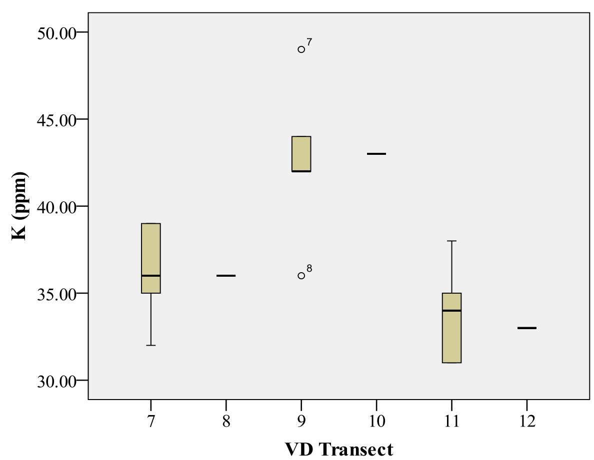


Figure 10: Box-plot of K (ppm) in Vertical Distance Transects* of Site B



Appendix 7: Means Plots of Soil Property Levels at Horizontal Distance (HD) Transects of Site A and Site B (where *denotes significant differences between transects)

Figure 1: Means Plot of N (ppm) at HD Transects of Site A* and Site B*

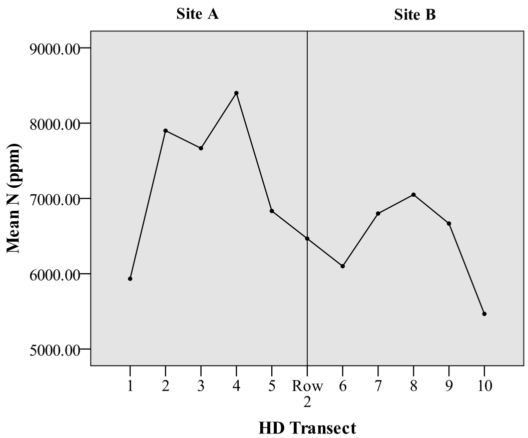


Figure 2: Means Plot of P (ppm) at HD Transects of Site A* and Site B*

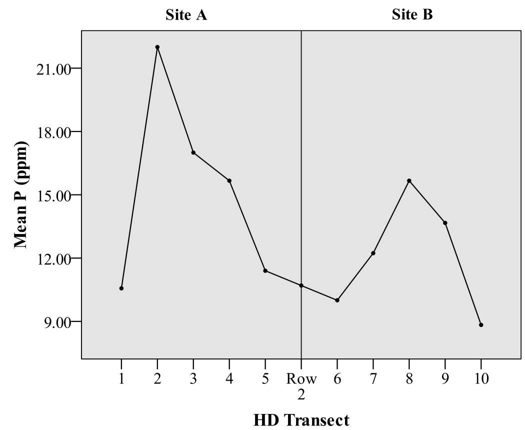


Figure 3: Means Plot of Mg (ppm) at HD Transects of Site A* and Site B*

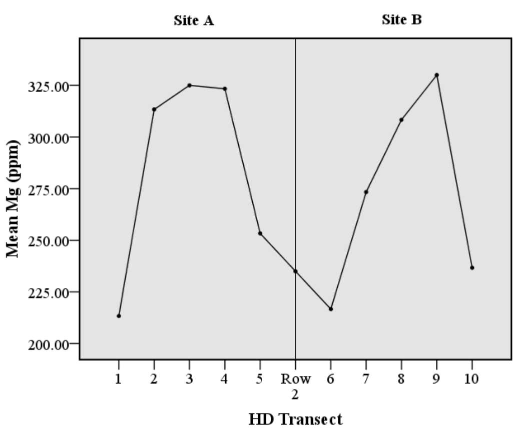


Figure 4: Means Plot of SOC (ppm) at HD Transects of Site A* and Site B*

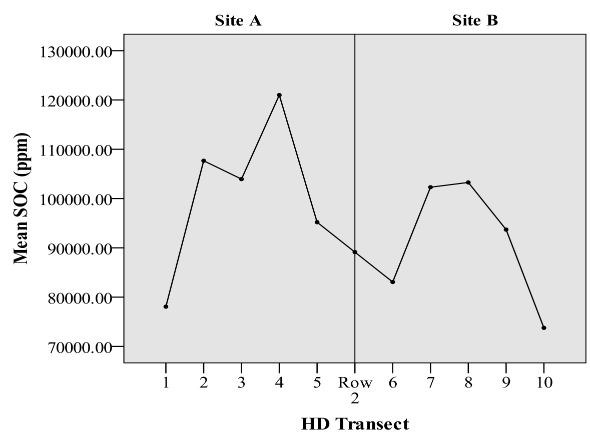


Figure 5: Means Plot of K (ppm) at HD Transects of Site A and Site B

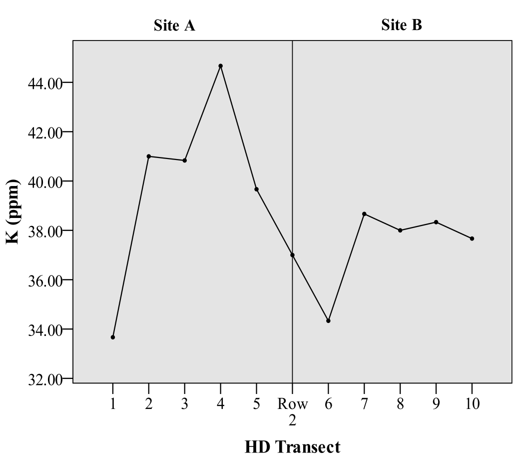
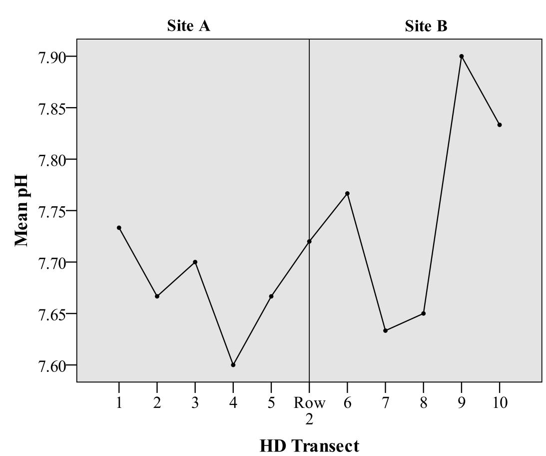


Figure 6: Means Plot of pH at HD Transects of Site A and Site B



Appendix 7 Continued: Means Plots of Soil Property Levels at Horizontal Distance (HD) Transects of Site A and Site B(where *denotes significant differences between transects)

Figure 7: Means Plot of BD (g/cm^3) at HD Transects of Site A and Site B*

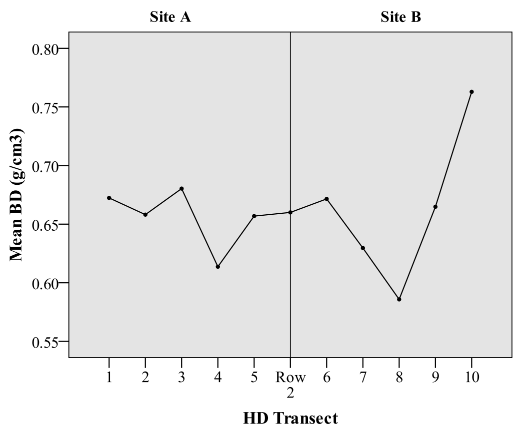


Figure 8: Means Plot of SM (%) at HD Transects of Site A and Site B*

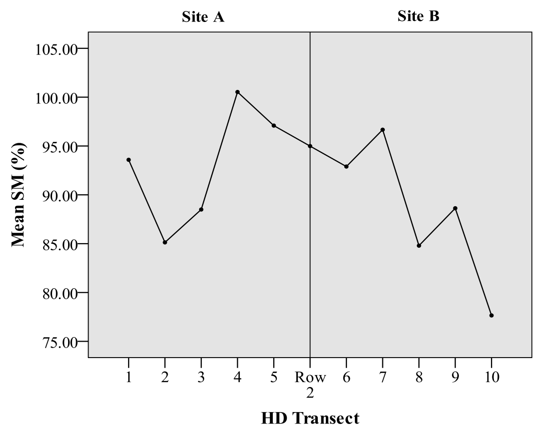


Figure 9: Means Plot of IC (ppm) at HD Transects of Site A and Site B