ARCTIC
VOL. 76, NO. 1 (MARCH 2023) P. 60–71
https://doi.org/10.14430/arctic77061

An Examination of Outdoor Garden Bed Designs in a Subarctic Community

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(*Received 7 June 2022; accepted in revised form 18 August 2022*)

ABSTRACT. At the global level, interest is growing in extending agricultural activities northwards to increase future food production. Agricultural activities are emerging at the local level in the subarctic and Arctic regions in order to adapt to climate change, mitigate food insecurities, and build up food autonomy. This pilot crop management study was situated in the Hudson Bay Lowlands within an isolated, Indigenous community garden site surrounded by a mature shelterbelt. The study's purpose was to compare kale growing in three types of low-cost garden bed treatments (four plots per treatment) under ambient conditions in a subarctic climate. The 2019 study measured aboveground biomass and total leaf surface area of kale, monitored soil climate conditions of each treatment, and deciphered, with regards to regional suitability, the benefits and drawbacks of each garden bed treatment. Kale cultivated in the standard boxes (0.25 m height raised bed) and hügelkultur-style boxes (0.50 m height raised bed, including a layer of buried woody debris) resulted in 44–58% more aboveground mass and 52% more total surface area than were yielded in kale cultivated in the ground treatment (not elevated), but these increases did not represent statistically significant differences among treatments (ANOVA, $p \geq 0.12$) because of the large variation likely from a small sample size. The two raised box treatments increased early-season soil temperatures by 0.5˚C to 2.5˚C and reduced soil moisture by 41%–53% compared to the ground treatment. We determined that the standard box treatment is best suited for the study site for improving soil climate conditions, protecting against water erosion, and decreasing the need to bend over.

Key words: subarctic; boreal; climate change adaptation; First Nation; kale; northern agriculture; raised beds; remote community; food security

RÉSUMÉ. À l'échelle mondiale, il y a un intérêt de plus en plus marqué pour pousser les activités agricoles vers le nord afin d'augmenter la production alimentaire future. Des activités agricoles commencent à émerger à l'échelle locale de régions subarctiques et arctiques dans le but de favoriser l'adaptation au changement climatique, d'atténuer les insécurités alimentaires et de rehausser l'autonomie alimentaire. Cette étude pilote de la gestion des cultures a été effectuée dans les basses-terres de la baie d'Hudson, plus précisément dans un potager communautaire autochtone isolé entouré d'un brise-vent arrivé à maturation. La raison d'être de cette étude consistait à comparer la culture du chou frisé de trois types de traitements de plates-bandes à coût modique (comportant quatre cases par traitement) dans les conditions ambiantes d'un climat subarctique. L'étude réalisée en 2019 a permis de mesurer la biomasse épigée et l'aire de la surface totale des feuilles de chou frisé, de surveiller les conditions climatiques du sol de chaque traitement et de déterminer, sur le plan de la durabilité régionale, les avantages et les inconvénients de chaque type de plate-bande. Le chou frisé cultivé dans les jardinières standard (surélevées de 0,25 m) et dans les jardinières de type *hügelkultur* (surélevées de 0,50 m, comprenant une couche de débris de bois enfouis) a donné lieu à une masse épigée supérieure dans une mesure de 44 % à 58 % et à une aire de la surface totale plus grande dans une mesure de 52 % comparativement au chou frisé cultivé dans le sol (non surélevé). Cependant, ces augmentations ne représentaient pas de différences importantes entre les divers types de traitements (ANOVA, $p \geq 0{,}12$) en raison de la grande variance vraisemblablement attribuable à la petite taille des traitements. Les deux traitements surélevés ont permis d'accroître les températures du sol en début de saison dans une mesure de + 0,5 ˚C à + 2,5 ˚C et de réduire l'humidité du sol dans une mesure de 41 % à 53 % comparativement à la culture au sol. Nous avons déterminé que le traitement de la jardinière standard convient mieux au site visé par l'étude sur le plan de l'amélioration des conditions climatiques du sol, de la protection contre l'érosion hydrique et du moins grand besoin de se plier pour jardiner.

Mots clés: subarctique; boréal; adaptation au changement climatique; Première Nation; chou frisé; agriculture nordique; plates-bandes surélevées; communauté éloignée; sécurité alimentaire

Traduit pour la revue *Arctic* par Nicole Giguère.

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INTRODUCTION

Agricultural activities are expanding northwards into the subarctic and Arctic regions (e.g., the boreal and tundra biomes) as a strategy to mitigate food insecurities while adapting to climate change (Chen and Natcher, 2019; Hannah et al., 2020; Altdorff et al., 2021; Friedrich, 2021). On a global scale the boreal zone is perceived as a climate-driven agricultural frontier based on the proposition that, in the future, these lands will become more suitable for agriculture and contribute to food security (Hannah et al., 2020; Altdorff et al., 2021). Meanwhile, food insecurity disproportionately impacts northern Canadian Indigenous (First Nations, Métis, and Inuit) communities compared to the rest of Canada (Skinner et al., 2014; Lamalice et al., 2018; Tsuji et al., 2020; Friedrich, 2021).

Food insecurity among Indigenous communities is directly linked to colonialism and residential schools and their legacy (Spiegelaar and Tsuji, 2013; Isaac et al., 2018). Indigenous peoples endured systemic racism, discrimination, and injustice, causing multi-generational trauma and societal disruption (Coté, 2016). Campaigns used to dismantle Indigenous food security and food sovereignty included, but were not limited to, displacement from traditional lands (Coté, 2016; Isaac et al., 2018); restriction of access to, and suppression of knowledge about, traditional foods (Spiegelaar and Tsuji, 2013; Keske, 2021); and imposition of food rations that were unfamiliar, insufficient, and nutrient poor (Spiegelaar and Tsuji, 2013; Coté, 2016). As an outcome, present-day food systems in northern communities rely heavily on expensive, store-bought, southern-imported foods (Spiegelaar and Tsuji, 2013; Svoboda et al., 2014; Keske, 2021). These imported food supplies are transported far distances via poorly developed infrastructure, with unreliable connections that can delay or cut off supplies from northern communities (Skinner et al., 2014; Friedrich, 2021). Consequently, imported food is expensive, inferior in quality, and at high risk of being unavailable, causing many to resort to highly processed non-perishable foods with low nutritional value (Spiegelaar and Tsuji, 2013; Spiegelaar et al., 2019; Friedrich, 2021).

The disproportionate impacts of climate change have further compounded northern food insecurity by affecting the availability and access of important local foods (Spring et al., 2018; Friedrich, 2021). For instance, climate shifts have impacted growing conditions for wild plants and the habitat and migration routes of game (e.g., fish, birds, and mammals), causing harvesting expeditions for local foods to become more expensive, challenging, and unpredictable (Hori et al., 2012; Spring et al., 2018; Tsuji et al., 2019; Freidrich, 2021). Concurrently, warming temperatures within the boreal region are extending the growing season, increasing the viability of northern agriculture (Hannah et al., 2020; Altdorff et al., 2021; Apostoli, 2021). Northern Indigenous communities are initiating agricultural activities, such as gardening in outdoor and/or indoor environments, as a strategy for climate adaptation, food insecurity mitigation, and building up food autonomy (Barbeau et al., 2015; Lamalice et al., 2018; Chen and Natcher, 2019; Ferreira et al., 2021). Nevertheless, the development of northern agriculture is often restricted by inadequate infrastructure, economic input, and human resources (Isaac et al., 2018; Ferreira et al., 2021; Unc et al., 2021).

Fort Albany First Nation, Ontario, Canada, is one of the northern communities that has adopted gardening activities. Fort Albany is a remote fly-in community that contends with higher cost of living, a common socioeconomic characteristic in northern and Indigenous communities (Skinner et al., 2014; Deaton et al., 2020; Statistics Canada, 2021). Thus, the community strives to develop regionally suitable gardening techniques with low operational costs. The use of shelterbelts—planting crops among trees (Barbeau et al., 2015)—and application of locally made compost (Wilton et al., 2020) are two strategies Fort Albany First Nation has used to improve soil fertility and crop yield. When used with the shelterbelt, growing crops directly in the ground has shown some early production success in this First Nation (Barbeau et al., 2015). However, the community has needed improvements in order to enhance soil and microclimate conditions and minimize labour and body strain while advancing crop production; to achieve these aims, residents implemented raised garden beds.

Raised beds are a popular and affordable crop treatment utilized by boreal- and tundra-based communities engaged in agriculture activities (Svoboda et al., 2014; Thompson et al., 2018; Chen and Natcher, 2019). Globally, raised beds have been used to enhance yields through water regulation by minimizing waterlogging (Velmurugan et al., 2016; Manik et al., 2019; Fisher, 2020), water deficits (Rady et al., 2021), and conserving irrigation resources (Jat et al., 2013). Moreover, raised beds can conserve thermal energy and extend the growing season (Svoboda et al., 2014; Fisher, 2020).

Fort Albany First Nation has also done a trial with taller raised beds that incorporate hügelkultur techniques, hoping these will offer a better alternative to cultivating on slightly raised beds or directly on the ground. In contrast to the research on raised beds, limited peer-reviewed information exists on hügelkultur (Chalker-Scott, 2017; Petry and Bernardini, 2021), a term that first appeared in a 1962 German brochure written by Herman Andrä. While the origins of hügelkultur are unclear, the technique has been described and used for centuries (Chalker-Scott, 2017). Hügelkultur is a raised bed technique that involves building mounds by burying woody and other organic materials (e.g., leaves, grass, cardboard, compost) underneath a surface layer of soil (Chalker-Scott, 2017). Petry and Bernardini (2021) utilized hügelkultur in their community project study carried out in a subtropical setting. However, their research focused on garden knowledge extension and did not provide empirical evidence on the effectiveness of the hügelkultur technique. There is evidence that hügelkultur

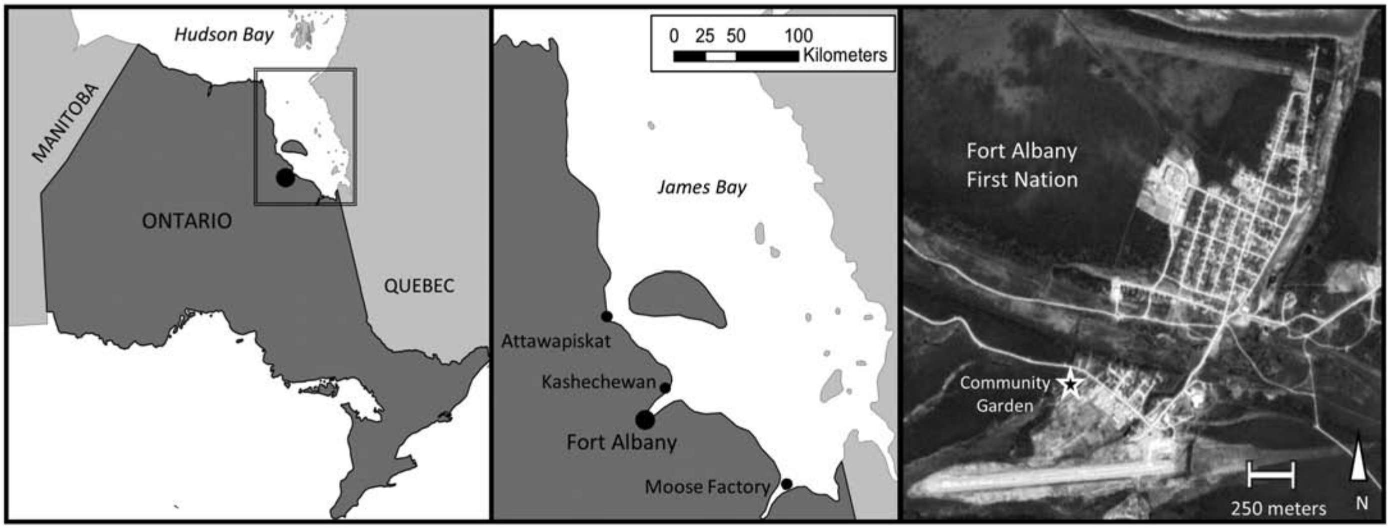

FIG 1. General location of Fort Albany First Nation, Ontario, Canada (left and centre), and the study site within the Fort Albany First Nation Community Garden (right).

has been practiced in a boreal community. This evidence comes from a non-peer-reviewed university thesis study by Okorosobo (2017) carried out in the Garden Hill First Nation, Manitoba, Canada, which is located at a similar latitude to Fort Albany First Nation. Okorosobo (2017) found that bush bean productivity improved when the crop was grown in hügelkultur beds compared to cultivation on peat or local clay soil amended with lime.

The present study examines three different garden bed treatments used in the Fort Albany First Nation community: beds directly in the ground, raised beds, and hügelkultur-style raised beds. We compared these treatments during the 2019 growing season by measuring kale aboveground mass and surface area, monitoring soil moisture and temperature, and assessing the benefits and challenges of applying each treatment. This study provides guidance to other high-latitude communities currently considering adopting agriculture, as well as insights for the Fort Albany First Nation as the community continues to develop its agroecosystem.

METHODS

Community Context

Fort Albany First Nation is an isolated Omushkego Cree community located on the west coast of James Bay, Ontario, Canada (52˚20′72″ N, 81˚69′41″W), within the Hudson Bay Lowlands (Fig. 1). This region, which has a subarctic climate, is 14 m above sea level, characterized by flat terrain, and dominated by muskeg or peat moss on limestone bedrock. The community is accessed by plane year-round, by ice roads for six to eight weeks during the winter, and by shallow draft water vessels during the ice-free season (Skinner et al., 2014). The remoteness of Fort Albany First Nation is a contributing factor in the high prevalence of food-insecure households (70.3% from 2009 – 11) within the community, which is seven times greater than the food insecurity rate (9.2%) for total households in Canada (Skinner et al., 2014).

The Roman Catholic Mission formally introduced productivist agricultural activities to Fort Albany First Nation in the 1930s (Spiegelaar et al., 2013). Productivist agriculture seeks to maximize crop ouput through intensive land management and is often associated with biodiversity loss and long-term land degradation (Gordan et al., 2021). The mission's settlement was characterized by a lack of equity, and knowledge of agricultural strategies was not shared with Fort Albany residents (Spiegelaar and Tsuji, 2013). When the residential school in the Fort Albany community closed in the 1970s, agricultural activities were halted, and resources needed to sustain crop production operations (e.g., farm equipment) were removed (Spiegelaar and Tsuji, 2013; J. Metatawabin, pers. comm., 2019). Crop fields were no longer productive once the missions departed because Fort Albany residents did not have autonomy over local food production and were hindered by the lack of resources to manage declining soil fertility and unpredictable cool weather (Spiegelaar and Tsuji, 2013).

The cool seasonal temperatures and short growing season were major biophysical obstacles that restricted the continuity of past agricultural activities in Fort Albany First Nation and other northern communities (Spiegelaar and Tsuji, 2013; Schiff and Brunger, 2013; Svoboda et al., 2014; Friedrich, 2021). The climate of Fort Albany First Nation from 1963 to 2013 had a total mean precipitation of 599 mm with a standard deviation (SD) of 87.6 mm, a mean annual air temperature of −1.0˚C (SD =1.27˚C), and 90.4 (SD =19.28) frost-free days (Climate Atlas of Canada, 2022). However, Hori et al. (2017) determined that temperature trends were significantly on the increase during these past 50 years (1963 – 2013). Furthermore, climate models predict that mean annual temperatures within the region will continue to increase and range from 1.1˚C to 1.5˚C for 2021 – 50, and 2.4˚C to 4.1˚C by 2051 – 80 (Climate Atlas of Canada, 2022).

An Agroecology Approach to Northern Gardening Initiatives

In contrast to past productivist agricultural activities, Fort Albany's garden initiatives, including the garden bed trials, were founded on an agroecology approach emphasizing the values of interdependency, respect, reciprocity, and ecological sustainability (Spiegelaar and Tsuji, 2013). The agroecology approach utilizes holistic perspectives and systems thinking, requires a broad range of participants and actors, and relies on an assortment of knowledge systems (Isaac et al., 2018).

In 2010, the Fort Albany First Nation Chief and Council expressed interest in implementing gardening initiatives. These leaders believed that applying an agroecology approach to such initiatives would be a path towards helping the community collectively find alternative agricultural practices that harmonize with this First Nation's traditional food provisioning activities (Spiegelaar and Tsuji, 2013; Tsuji et al., 2019). Thus, they began work in partnership with us (all authors of this study and affiliated organizations). Members of the team included the leadership of Fort Albany First Nation and university/college personnel, as reflected in this article's authorship. Garden initiatives began in 2012 and included home gardening support (Vanderberg, 2014) and community garden field assessments and trials (Spiegelaar et al., 2013; Barbeau et al., 2015). After 2012, and up to the period of our study in 2019, the garden initiatives involved ongoing reciprocal knowledge exchanges between residents and researchers on food systems, community-based training, community workshops, school field trips, class presentations, and community planting and harvesting events. Crops that were ready early in the season (e.g., bush beans) were shared freely with the community at a locally owned store (Barbeau et al., 2015) and at the locally organized not-for-profit food market. Crops that matured in October were harvested by residents who attended the annual community garden harvest event (Barbeau et al., 2015).

Since 2016, Peetabeck Health Services became the lead administrative organization in the Fort Albany First Nation-university partnership to transition the agroforestry-gardening initiative from being university led to community led. Since then, Peetabeck Health Services has hired a community-based garden coordinator and up to four employees each year to manage the community garden space (Fig 1). Residents and researchers mutually agreed upon crop management decisions to ensure that the garden strategies used and tested were environmentally and socio-culturally suitable for the region. The treatments tested in this study were influenced by garden bed designs used by some residents with home gardens.

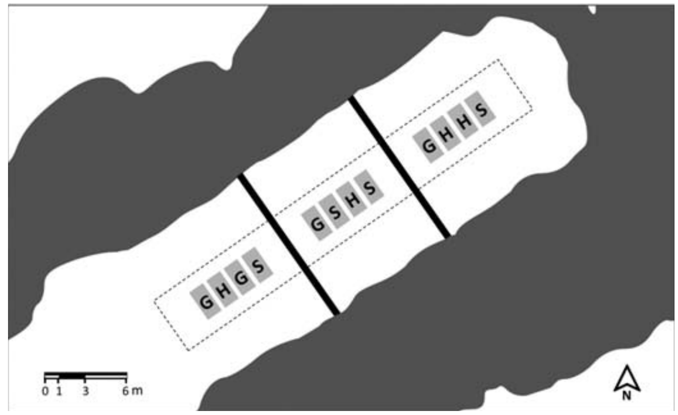

FIG. 2. Depiction of the study site layout located in a segment of the Fort Albany First Nation Community Garden, Ontario, Canada. The 20% grey rectangles represent plots for ground (G), standard box (S), and hügelkultur-style (H) garden bed treatments. The dotted line demarcates the study site area, and the thick black lines represent drainage ditches. The 60% grey area represents the willow (Salix spp.) shelterbelt surrounding the community garden.

For our crop management study, a university researcher who does not live in the community worked alongside the community-based garden coordinator and three employees from 28 May 2019 to 8 July 2019 to set up the garden bed treatment trial. The four Fort Albany residents maintained the site over the growing season. Communication between the community-based coordinator and researchers occurred at least twice a week via telecommunications. The same researcher from our research partnership returned in the fall (28 September 2019 to 11 October 2019) to train the garden coordinator and employees on data collection and to obtain harvest and climate data.

Experimental Site Description

The pilot experimental site was a 30 m x 4.4 m section (Fig. 2) located within the larger 85 m x 12 m shelterbelt community garden. The mostly enclosed shelterbelt consisted of a forested area and two thicket rows of willow *Salix* spp; the thickets, with an average height of 5.2 m, were formed in natural succession over more than 40 years along two human-made drainage ditches. They run parallel from southwest to northeast, meeting forested areas at each end, with two openings (3 m to 9 m wide) per thicket for garden site access (not shown in Fig. 2). The site has drainage limitations owing to a heavy clay layer at 0.50 m soil depth that impedes water infiltration, as well to the site's flat landscape and location < 200 m from a lake. Additional details of the shelterbelt are described in Wilton et al. (2017).

Study partners harvested the soil used for the study from a grassland area 180 m southwest of the experimental site, at a depth of approximately 0 cm – 30 cm. We used harvested soil because i) additional soil within the community garden space was unavailable to fill the raised garden beds, and ii) community members used harvested soil to fill their at-home raised beds (Wilton et al., 2020). Prior to this

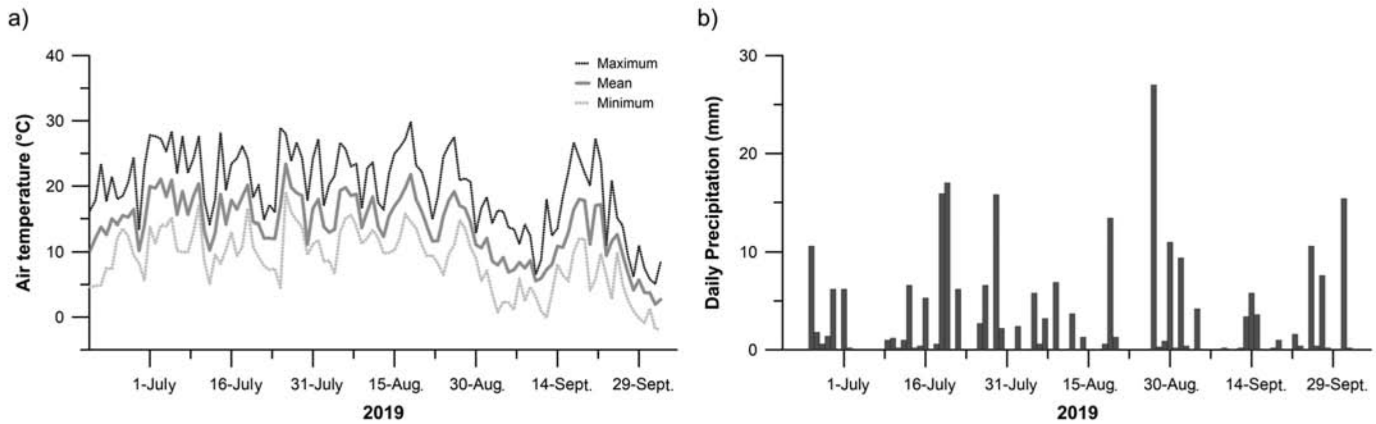

FIG. 3. Air temperature (a) and daily precipitation (b) measured 460 m from the experimental site during the 2019 growing season in Fort Albany First Nation, Ontario, Canada.

study, university researchers tested the garden site and the soil-harvesting location for contaminants and deemed safe for agricultural use in Canada (Reyes et al., 2015). Testing soil for contaminants assured community members access to a safe growing medium—a relevant issue for remote and urban communities developing community gardens (Reyes et al., 2015; Miernicki et al., 2018). The soil used in this study was calcareous, with a silt loam texture (Spiegelaar et al., 2013). The soil had adequate total extractable nitrogen (59.6 mg N kg^{-1}) but low levels of extractable phosphorus (8.1 mg P kg^{-1}) and potassium (34.3 mg K kg^{-1}) for crop production (Barbeau et al., 2018).

The field study was restricted to a period from 20 June 2019 to 3 October 2019 because of interruptions due to COVID-19. During the study period, we used air temperature and rainfall data recorded at 30-minute intervals at a weather station (HOBO U30 Series, Onset, Bourne, MA, USA) located 460 m east of the experimental site. Total rainfall for the study period was 231 mm, and the mean daily air temperature was 13.9˚C (SD = 4.7˚C). The maximum air temperature reached during the study was 29.8˚C on 18 August 2019, and the first frost for the growing season occurred on 12 September 2019 (Fig. 3).

Experiment Design and Garden Bed Construction

We used three garden bed treatments—ground, standard box, and hügelkultur-style—in order to mimic designs commonly used in the community (Fig. 4). To permit the same light exposure for all garden bed plots, these plots (n = 4 per treatment) had an inner dimension of 2.40 m × 1.22 m and were constructed in the centre of the site, equidistant from the two shelterbelt rows. Residents of Fort Albany trim branches annually along the inner edge of the treeline to reduce shading within the community garden; they continued this work during the year of our study to reduce shading during daylight hours within the experimental site (centre of the community garden). To determine the layout of the twelve plots (Fig. 2), we randomized the experimental design using the RAND and SORT functions in Microsoft Excel (version 2019) (Fig. 2). We placed the 12 plots in three sections delineated by two manually made drainage ditches approximately 0.50 m wide and 0.40 m deep. In each section, we spaced the four treatment plots 0.30 m apart, except for the plots adjacent to the drainage ditches, which we spaced 4.00 m apart. We constructed the ground bed by removing soil to 0.25 m depth and replacing it with harvested soil. To mimic other gardens in the Fort Albany First Nation, we did not install a fabric permeable barrier between the ground and the added harvested soil (as occurred in the other treatments, described below). We used harvested soil in the ground treatments so that each treatment contained the same growing medium.

The standard-raised beds were rectangular wooden boxes made of untreated spruce lumber. Box height was 0.30 m; we constructed box walls with two 1× 6 nominal-sized lumber (1.9 cm thickness and 14.0 cm width) on each side and 2 × 2 nominal sized lumber (3.8 cm thickness and width) for the vertical supports and corners. We placed a layer of Better Barriers™ water-permeable landscape fabric (Quest Brands Inc., London, ON., Canada) at the open-box bottom (to minimize weeding), then filled it with a levelled 0.25-m layer of harvested soil. The hügelkultur-style raised beds were wooden boxes akin to the standard-raised bed, except the box height was doubled to 0.60 m; we constructed these with four 1 × 6 nominal sized lumber planks on each side (Fig. 5). We also placed landscape fabric at the bottom of the hügelkultur-style boxes, then filled them with organic material, such as decaying logs, dead branches, and leaf litter gathered from the willow shelterbelt, to a height of 0.25 m. We then covered the organic layer with a levelled 0.25 m layer of harvested soil. Traditionally, hügelkultur used tree logs and other organic materials to create tunnel-shaped mounds off the ground and uncontained (Chalker-Scott, 2017). In the present study, we deemed our treatment "hügelkultur-style" because the organic matter and soil layers were contained and cultivation occurred on a flat surface.

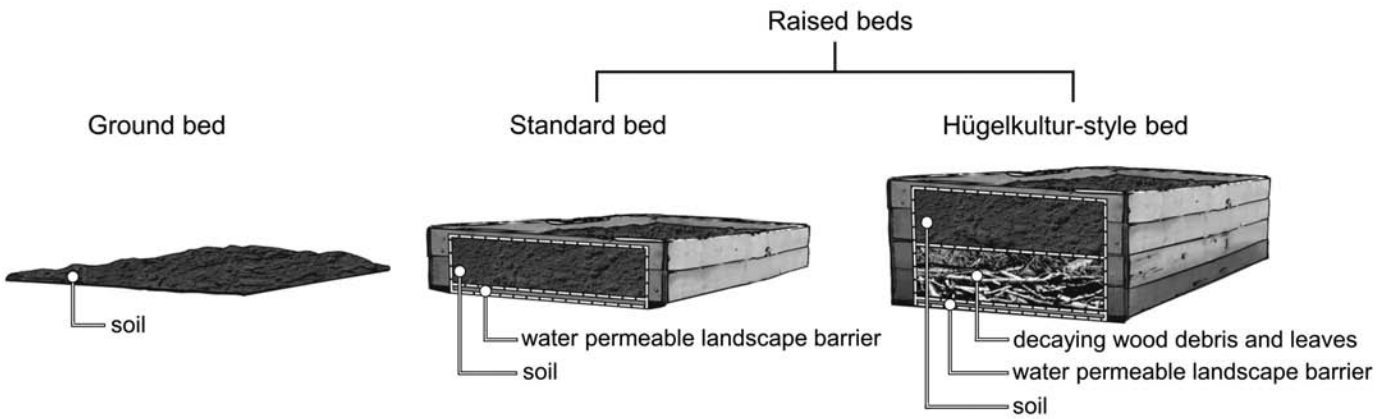

FIG. 4. Cross-sectional illustration of the three garden bed treatments evaluated in outdoor conditions in a subarctic climate.

FIG. 5. Photograph displaying the height difference between the standard box and hügelkultur-style treatments, with willow thicket in the background.

Crop Selection and Kale Cultivation

As the community garden evolved over the years, so did crop diversity. Crops selected for the community garden met at least one of the following criteria: i) they were cold hardy; ii) they matured within a short growing season; iii) they currently grew in, or had undergone trials in the subarctic and Arctic regions; iv) they were traditional foods; v) they complimented traditional foods; and vi) they were requested by residents. In 2015, some Fort Albany residents requested kale to help support their dietary iron intake. Following the 2016–18 growing seasons, the community garden incorporated kale cultivation. Based on feedback gathered informally by the research team from community members, we know that some residents have used the kale grown in the garden for roasting to make chips, in smoothies, and as a leafy green in moose stew.

Kale was selected to measure crop production performance in the garden bed treatments because the cool season crop successfully grew in Fort Albany during the 2016–18 growing seasons. Kale is relatively easy to maintain and had been cultivated in other boreal- and tundra-based communities (Svoboda et al., 2014; Stevenson et al., 2014; Lamalice et al., 2018; Chen and Natcher, 2019). Moreover, for beginner data collection training, kale was an uncomplicated crop to measure: no branching, fruit,

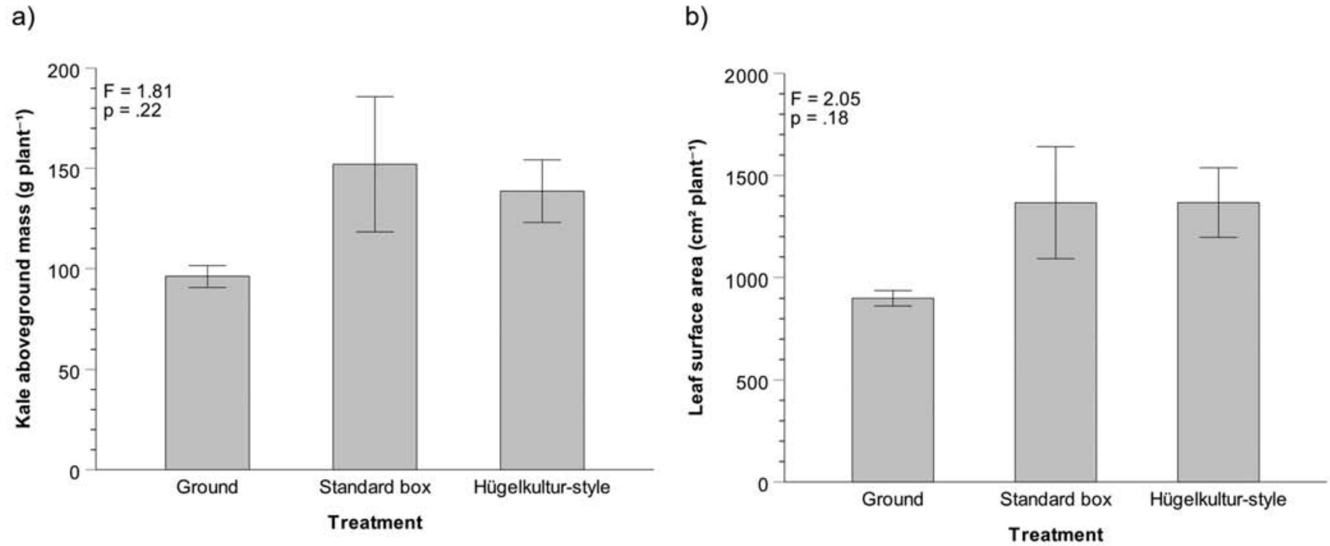

FIG. 6. Mean (± standard error, n=4) aboveground mass (a) and total leaf surface area (b) of kale grown in three garden bed treatments: ground (no elevation), standard box (elevated 0.25 m), and hügelkultur-style (elevated 0.50 m), Fort Albany First Nation, Ontario, Canada, 2019.

or tubers. On 20 June 2019, we sowed kale seeds (Red Russian; *Brassica napus* var. *Pabularia*) at 1 cm depth, spaced 20 cm apart, in a grid pattern that consisted of 12 plants per row in six rows. We then manually irrigated each plot with 30 L for three days after sowing; for the remainder of the season, the plots were rain-fed, without fertilizers or pesticide applications. We manually thinned surplus kale seedlings on 6 July 2019 and manually removed weeds every two weeks.

Measuring Soil Climate Conditions

We inserted moisture sensors and thermocouples at 10 cm depth on 26 June 2019 in each of the four plots per treatment. We programmed six HOBO Micro Station data loggers (Onset Computer Corp., Bourne, MA., USA) to record soil moisture and temperature at 30-minute intervals from 26 June 2019 to 4 October 2019. Each micro station collected data from two plots. One data logger was inactive from 18 August 2019 to 4 October 2019 because of technical issues, but at least three plots per treatment had soil moisture and temperature logging from 26 June 2019 to 4 October 2019. In order to derive the daily mean, minimum, and maximum, we averaged volumetric soil moisture and soil temperature for each treatment.

Kale Harvest

We collected kale samples on 2 October 2019 when the plants had harvestable leaves (ranging from 6 to 18 leaves per plant, with an average of 12 leaves). We randomly selected two plants for harvest from each of the six rows within each plot (n = 12 per plot; n = 48 per treatment) and cut the stem base at the soil surface. We weighed each collected kale plant for fresh aboveground mass. Immediately afterwards, we gently flattened individual leaves of the kale samples onto a white tarp that included references identifying plot and treatment, and a metric-length scale for photographing. We subsequently analyzed the photographs for total leaf surface area using ImageJ software (1.52a, W.S. Rasband, U. S. National Institutes of Health, Bethesda, MD, USA). Once we completed kale measurements, our team distributed the harvested crop to the public for free at the local food market.

Statistical Analysis of Kale Productivity

Since kale planted within each garden bed treatment lacked independence, we averaged the 12 measurements from each bed to generate a single value for each treatment of aboveground mass and total leaf surface area per plant. The raw data and data transformations (log; square root; inverse) could not produce homogeneous variances ($p \geq 0.014$, Levene's statistic); thus, we undertook statistical analyses on the untransformed data. We used an ANOVA to compare the mean aboveground mass and mean total leaf surface area per plant among the three treatments (IBM Corp, released 2019, IBM SPSS Statistics for Windows, Version 26.0, Armonk, NY: IBM Corp).

RESULTS AND DISCUSSION

Kale Productivity

Kale cultivated in the ground treatment yielded an aboveground biomass mean of 96.2 g per plant (± 7.52 standard error). In comparison to the ground treatment, the mean aboveground mass in the standard boxes increased by 58% and by 44% when grown in the hügelkultur-style boxes, though these increases were not statistically significant ($F = 1.81$, $p = 0.22$, Fig. 6) because of the large

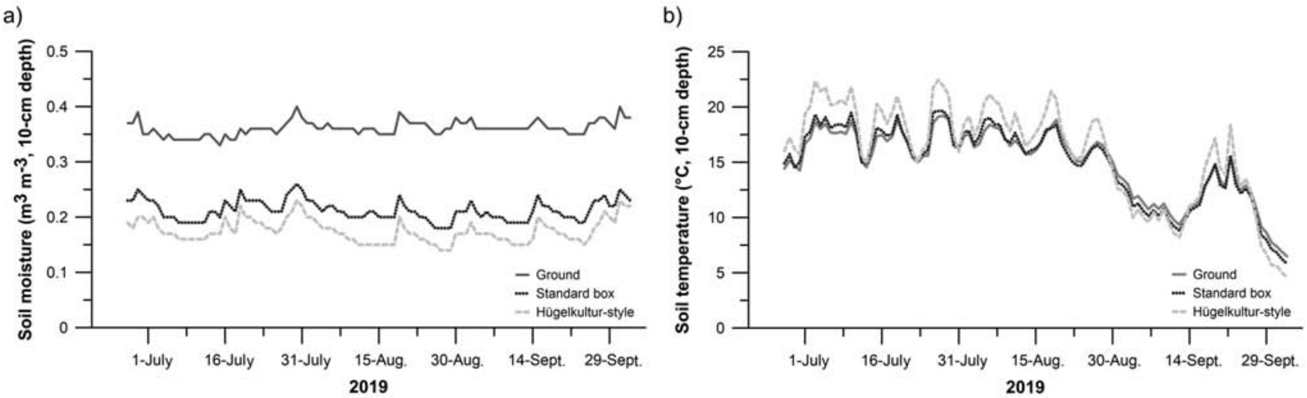

FIG. 7. Mean volumetric soil moisture (a) and mean soil temperature (b) at 10 cm depth for the three garden bed treatments (ground, standard box, and hügelkultur-style) while growing kale during the 2019 growing season, Fort Albany First Nation, Ontario, Canada.

variation likely from a small sample size (n = 4) for each treatment. Similarly, whilst the total surface area of leaves for kale grown in the standard boxes and hügelkultur-style beds increased by 52% compared to kale grown in the ground beds, these increases in leaf area were statistically insignificant (F = 2.69, p = 0.12, Fig. 6).

Soil Moisture and Temperature of Garden Bed Treatments

Moisture and temperature trends from the three treatments displayed differences in soil climate conditions. Daily mean soil moisture content ranged from 0.33 m^3m^{-3} to 0.40 m^3m^{-3} for the ground, to 0.18 m^3m^{-3} – 0.26 m^3m^{-3} for the standard box, and 0.14 m^3m^{-3} – 0.23 m^3m^{-3} for the hügelkultur-style treatment (Fig. 7). The soil moisture grand mean (± SD) for the sampling period was 0.36 m^3m^{-3} ± 0.01 m^3m^{-3} for the ground treatment, indicating moist soil throughout the season. Elevating the garden bed by 0.25 m (standard box) lowered the grand mean soil moisture content by 41% to 0.21 m^3m^{-3} ± 0.02 m^3m^{-3}. A greater reduction of soil moisture was observed in the hügelkultur-style treatment, where the garden bed was elevated to 0.50 m from the soil surface and had an incorporated layer of organic material. The grand mean soil moisture in the hügelkultur-style boxes was 0.17 ± 0.02 m^3m^{-3}, reducing soil moisture by 53% compared to the ground treatment and 19% compared to the standard box.

Mean (± SD) soil temperatures in the hügelkultur-style boxes (15.9˚C ± 4.5˚C) were warmer than in ground (14.9˚C ± 3.1˚C) and standard box (14.9˚C ± 3.5˚C) treatments (Fig. 7). The difference in soil temperature between the hügelkultur-style and ground treatments ranged from −2.7˚C to 5.5˚C, with a mean difference in soil temperature of 1.0˚C ± 1.5˚C. Temperature differences between the standard boxes and the ground were intermediate to that of the hügelkultur-style treatment, with a range of −0.8˚C to 1.9˚C, though the mean difference in soil temperature was 0.0˚C ± 0.5˚C. Both early and late periods in the growing season were notable for soil temperature differences between treatments. Early in the season (27 June 2019 to 6 July 2019), the mean soil temperatures of the hügelkultur-style treatment (19.0˚C ± 2.5˚C) and standard box (17.0˚C ± 1.8˚C) were warmer than in the ground (16.5˚C ± 1.7˚C). Conversely, during the late summer to early fall, the elevated beds did not retain heat as well as the ground. After 29 August, the mean air temperatures were frequently below 10˚C (with minimum air temperatures below 5˚C; Fig. 3), and mean soil temperatures were 10.9˚C ± 2.6˚C in the ground, 10.5˚C ± 3.5˚C in the hügelkultur-style treatments, and 10.5˚C ± 2.7˚C in the standard boxes.

In retrospect, the soil climate conditions of raised bed styles should be considered when deciding on what crop type to cultivate. Though kale production increased in elevated beds, this may not be the case for other crops. For instance, a field study in the US Midwest by Miernicki et al. (2018) obtained better yields for kale, radish, and cilantro in raised beds compared to ground beds, while garlic and pepper were not influenced by bed type. Similarly, crop types may have different production outcomes with other management treatments. For example, Das et al.'s (2014) raised-bed experiment in northeastern India found that tomato, okra, and beans yielded best in raised beds, while yields of rice and pea were superior in sunken beds. As well, Svoboda et al. (2014) studied dome greenhouses as a crop management strategy for a single growing season in an Arctic environment. They found that cabbage yielded best results in a non-insulated greenhouse, lettuce was most productive in an insulated greenhouse, and turnip and carrot production was better suited to grow bags in an insulated greenhouse. Studying the effects of different management practices on productivity using a diverse range of crops grown in multiple subarctic locations and seasons would be informative to northern communities. During this single-year and single-site garden bed study, rainfall was sufficient and supplemental irrigation throughout the season was unnecessary. Under drier conditions, the results of kale production within each treatment may have differed.

Space and Time Limitations for Crop Management Trials

In Fort Albany First Nation, this study had a limited area to conduct the trial due to geography, land ownership, partnership agreements, and human resource capacity. As well, we conducted the study for a single year due to interruptions from the COVID-19 pandemic. It is worth noting that long-term published studies on crop management within the subarctic and Arctic are scarce (Sandén et al., 2018; Unc et al., 2021). Ideally, having trials conducted for multiple years and in many locations would provide more reliable information for guiding northern Indigenous communities on management practices suitable to their regions (Altdorff et al., 2021; Unc et al., 2021). One option for achieving multiple-location data would be a larger scale of collaboration with other northern communities and research groups to conduct trials using a common approach in order to achieve replication, scalability, and transferability (Altdorff et al., 2021; Unc et al., 2021). However, these collaborations and arrangements would first need to be established, which brings its own challenges. For instance, a survey conducted by Altdorff et al. (2021) on climate change and northern agriculture expansion found that 79% of researchers working in the boreal and Arctic regions were unaware of any existing research network addressing similar issues.

Garden Bed Selection as a Subarctic Adaptive Agriculture Strategy

Low income is one of the main risk factors associated with the high prevalence of household food insecurity in many remote northern communities (Skinner et al., 2014; Deaton et al., 2020; Friedrich, 2021). Thus, agricultural program initiatives in northern communities need to consider cost-effective strategies (Svoboda et al., 2014; Wilton et al., 2020). The garden bed treatments used in this study are all low-cost options. The ground garden bed is most economical, though it does have perceived drawbacks based on our experience with ground garden beds and raised boxes in the Fort Albany community garden during this study and past growing seasons. The ground garden bed can cause planting delays due to cooler ground conditions in the spring. As well, the ground garden bed requires more weeding throughout the growing season, resulting in greater body strain. Conversely, the hügelkultur-style beds required more building materials. We found that these beds enhanced soil climate conditions and their height provided additional protection to plants from some pests (i.e., dogs, rabbits). In the short-term, the hügelkultur beds minimize body strain when caring for the garden. However, in the long term, the treatment does require additional labour to reconstruct the beds when the lower layer of organic matter decomposes over time (Chalker-Scott, 2017). Some studies mention the biological and nutrient advantages of hügelkultur; these ostensible benefits require future research, however, as they were not examined in the newly built hügelkultur-style beds in this study, nor were they evaluated in other peer-reviewed studies (Chalker-Scott, 2017). Both the ground and hügelkultur-style treatments were shown to be adequate strategies for kale production in Fort Albany First Nation.

Overall, using the standard box treatment was the better strategy, even though increased production of kale was not significant. The standard box improved drainage and reduced some of body strain and labour associated with garden maintenance. Additionally, the standard box was more cost-effective than the hügelkultur-style treatment. The option of having uncontained raised beds (meaning beds constructed by building up existing soil into sustained mounds and amending it before planting) would be as economical as the ground treatment. However, such temporarily raised beds would require annual repair and would be more vulnerable to erosion during early-spring flooding. Contained raised beds, such as the standard boxes used in this study, are a better option for low-lying northern communities surrounded by water bodies, as communities with these characteristics are threatened by increased flooding (Hori et al., 2017; Karegar et al., 2017).

CONCLUSION

The development of subarctic and Arctic agricultural practices is in its early phases in North America. Some northern Indigenous communities have adopted agricultural practices to mitigate food insecurities. As Indigenous communities build up initiatives to restore food autonomy, they must simultaneously find strategies to adapt to a warming climate. The isolated northern community of Fort Albany First Nation has included crop cultivation in their food security plans. Over the years, Fort Albany First Nation has shared and contributed knowledges on cultivating foods at high latitudes by adopting an agroecology approach and undertaking trials of different gardening techniques. For this pilot study, our team examined three different bed types: ground, standard box, and hügelkultur-style box. We found that all three were adequate for kale production. Determining what bed type to use is one of the first decisions when making a garden. These preliminary findings provide insights into how raised beds can reduce excess soil moisture and increase early-season soil temperatures. When accounting for soil climate, construction costs, and labour requirements, the standard box had more advantages than the ground and hügelkultur-style beds for the 2019 growing season in this remote subarctic setting. As agricultural activities continue to move northward, this information provides some guidance to other subarctic and remote communities interested in incorporating crop cultivation into their food systems.

ACKNOWLEDGEMENTS

The authors thank the Fort Albany First Nation Chief and Council, Peetabeck Health Services, and fieldwork assistants Greg Sutherland, Mary Scott, Hillary Sutherland, and Damian

Nakogee. We thank the anonymous reviewers for their helpful comments and suggestions. The Canadian Institutes of Health Research (FRN 169169) and the Indigenous Services Canada, Climate Change and Health Adaptation Program provided funding for this study.

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