Yukon University

Potential for Composting Wood Waste Under Northern Conditions: A Literature Review

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Note to the reader: This document assumes the reader is familiar with the basics of composting and no definitions or process explanations are provided.

1. Introduction

Composting is a well-established natural process (Compost Education Centre, nd). Humans use this process to cycle organic materials within agricultural systems, from large-scale producers to small home gardens. It is also of great use as a method of turning organic waste materials from one industry or purpose into a useful soil amendment and/or safe disposal/remediation method for hazards such as diseased animal carcass composting (Bonhotal et al., 2022; Kalbasi et al., 2005), soils contaminated with hydrocarbons (Tran et al., 2021; Beaudin et al., 1999) ; and soils contaminated with explosives (Scalzo et al., 2000; Darko-Kagya et al., 2010).

As the basic composting process is well understood and ample advisory information is available for successful composting strategies, scientific studies on composting tend to be very targeted towards the specific situations and materials that are being investigated: different organic materials, differing climate conditions, different equipment and methods, different motivations, and different variables and parameters measured. The purpose of this review is similarly focused, with specific materials, climate, and conditions in mind. Previous experiments and observations of others have been reviewed to look for answers that may already exist and to inform and tailor questions and methods for a future field trial.

The interest in this subject originates from a desire for an alternative to slash and burn land clearing practices. Instead of burning the cleared woody materials as a means of disposal, the materials are regarded as a valuable resource which may be converted via composting into a soil amendment to boost the level of soil organic matter, something which is usually very low in freshly cleared Yukon land, which largely consists of poorly developed soils influenced by relatively recent glaciation and a cold, dry climate (Day, 1963). Local circumstance for composting is this very cold climate where ambient temperatures are below freezing for much of the year. As this is intended to be an attainable process for people whose main function is not generating compost, it is desirable to keep this as low-tech and low-investment as possible. The final piece of context is that the material of interest is a very low nitrogen (N) substance, namely wood chips. Woody materials are usually used as a co-material for high N waste streams, providing bulk for aeration and high carbon content to reduce the compost blend's carbon-to-nitrogen ratio (C:N) (Bonhotal & Harrison, 2004).

This targeted review explores existing research illuminating questions around cold climate composting, wood and woody materials composting, high C:N (i.e. low N) systems, measures of quality assessable by the average farm operation, and a limited review of potential additives that might benefit our process. Although thousands of academic papers covering some aspect of composting have been produced over time, there is not a large amount of directly related studies to draw upon for genuinely cold climate (i.e. comparable to Yukon late fall/winter/early spring) composting, nor for composting wood as the primary material; however, what was found is summarized in greater or lesser detail, and analyzed for what can be learned or hypothesized from their results. The intention is to be realistic, not idealistic, concerning what can reasonably be accomplished without delving into complicated equipment and facilities, time-consuming management activities, and designer microbes largely unattainable outside of niche research.

2. Cold Climate Composting

Composting has often been regarded as unviable during winter months in cold regions (Lynch & Cherry, 1996). However, there is interest in the subject, particularly from agricultural operations that generate waste year-round, such as large livestock producers, primarily cattle, as well as food waste generators, such as community waste collection programs. Storing the waste is undesirable as it takes up significant space, produces unpleasant odours, and has the potential for environmental consequences from nutrient leaching (Petersen et al., 2007). What is considered by researchers to be a cold climate does vary, and studies can be found in North America and Europe, where temperatures during the study period are well below freezing, to other regions such as Northern China, where temperatures during the studies were seldom below freezing but generally lower than 10C. The results of all these studies are relevant as the temperatures reflect ambient conditions found in the Yukon from fall through late spring. Of note, most of the studies' main component is a nitrogen-rich material. Most of the studies start with a C:N between 20 and 35, and although generally not mentioned, the materials used contain significant amounts of readily degradable carbon.

In one of the most instructive studies of winter composting, Lynch and Cherry (1996) attempted winter composting in Idaho, USA, using animal manures mixed with straw or wood chips and composted in windrows with passive aeration (perforated pipes running along the bottom of the windrows with ends open to air). The windrows were formed in December, and the pile blends started with a C:N of 20-22. Initially, the materials froze, but within a short time, they began to heat up from the ends of the windrows, notably where they received good solar exposure. The three piles achieved thermophilic conditions 12, 21, and 23 days after formation and maintained internal temperatures around 50C for approximately two weeks. When temperatures within the piles began to drop, they decreased most quickly at the ends, potentially reflecting both more advanced composting as the ends started earlier than the centre of the piles, as well as less insulation at the ends of the piles.

They concluded that winter composting of animal manure is very attainable even during winter months, with ambient temperatures ranging from -27C to 15C throughout the trial period, which lasted from 50-80 days (composting was considered complete when the oxygen level within the pile was maintained at a minimum of 19% indicating minimal biological oxygen demand from microbial processes). The caveat mentioned by the research team was that the lower parts of the windrows where the aeration pipes were located did not reach temperatures over 40C and were thus likely ineffective in destroying pathogens as well as accumulating excessive moisture and signs of anaerobic conditions.

In a trial of food waste composting in Quebec (Sall et al., 2016), food waste collected from grocery retailers was combined with shredded birch bark from sawmills or chopped soybean straw from agriculture. Compost was heaped in covered concrete bays, allowed to heat up, turned when it cooled to ambient temperature and found to reheat after turning. The compost was considered ready for maturation (and moved to an adjacent location on soil) when no further heating occurred upon turning. Maximum temperatures of 68C were reached, and the bark mix was found to have slightly higher temperatures than the straw mix, with an average temperature over six weeks of 41.2C for bark and 37.6C for straw. Composting started in February, and maturation was completed by July. Ambient temperature was not reported in the study. However, as the trial started in Quebec in February and the material was in a covered area outdoors, it can be assumed that the ambient temperature would have been below freezing for much of the six-week thermophilic phase. C:N was 30-35 at the start and 20 at maturity.

Another Canadian winter study from Lethbridge, Alberta (Larney et al., 2000) composted cattle manure from feedlots over the winter months and compared it to composting over the summer months. The researchers were interested in mass and volume reductions through composting to decrease the transportation costs of delivering manure to fields. The manure contained barley straw bedding from the pens, but no additional bulking materials were added. Windrows were approximately 15m long, 1.6m high and 3.6m wide at the base. Active aeration windrows were turned with a tractor-pulled compost turner at a frequency dictated by the temperature within the piles and varied from 7 to 23 days between turnings. Passive aeration windrows were constructed over perforated passive aeration pipes. Winter composting started in late October, and the summer trial started in late May. Thermophilic temperatures (here defined as over 40C) peaked at 65C for the winter trial, and the thermophilic phase lasted 132 days from late October to early March, while the peak temperature for the summer trial was 71C and the thermophilic phase lasted 98 days from late May through late August. Regarding ambient temperature, the mean monthly temperatures for December and January were -10C and the materials were turned during this period. Temperatures in the piles dropped to ambient temperatures with turning but returned to >45C within two days (it is not clear what the specific ambient temperature was when the piles were turned) and 12 days in total (not in a row) during the winter trial were below -30C with a minimum of -38.9C. Active turning was associated with greater reductions in moisture and volume and higher bulk density, and summer composting showed greater reductions than winter. C:N started at 19.9 for the summer trial and 15.3 for winter and ended at 12.3 for summer and 12.1 for winter.

McCartney & Eftoda (2005) experimented with composting biosolids with wood chips as the bulking agent (1:2.5 by volume) in Winnipeg, Manitoba, trialing four different strategies: starting in late autumn, starting in winter, mixed and stored over winter, then started in spring and finally, mixed with leaves to improve heat generation. Although all trials were deemed successful eventually, the winter pile did not reach thermophilic temperatures (defined in this study as >55C) until the following summer. However, the pile generated heat and appeared to have remained active throughout the winter. These results indicate that even if composting activity slows over the winter, the composting processes will accelerate as environmental conditions allow, but this extends the required time significantly. The research also flagged external factors such as ambient temperature while turning and wind speed as having detrimental effects on maintaining temperatures within the piles. The fourth treatment, with leaves added, is of interest in that the leaves added a readily degradable substance and were found to increase the heat generated within the pile, increase the speed at which temperature recovered after turning, and increase the rate of the composting process. This method is of interest in our context as there is expected to be a lack of readily available nutrition within wood chip piles. Thus, trialing different additives in the lab (such as sucrose solution or beet pulp) is being considered to examine their effects on temperature.

Margesin et al. (2006) experimented with co-composting sewage sludge with shrub clippings in an alpine region in Europe, creating windrows (40m l x 4m w x 2m h) with forced ventilation. Ambient temperatures varied from -3.6C to 10.1C, similar to temperatures in the fall in Yukon. Their experimental variable was the frequency of turning with pile A turned after three weeks and then once a week after that and pile B turned twice a week throughout the experiment. Maximum temperatures were found after 34 days, with pile A reaching 66C and pile B reaching 48C. The team concluded that both heat loss and moisture loss from the more frequent turning of pile B were the factors affecting the lower temperatures in that pile, and the pile also had lower microbial activity and less degradation over time, as indicated by no change in C:N (C:N should reduce as materials decompose). Although the study was ended due to external constraints at a point where the researchers did not consider the compost in either pile to be fully mature, the pile A compost could germinate seedlings and stimulated growth by 25%, while the pile B compost showed an 80% inhibitory effect on seedlings, indicating that pile B compost was far less mature than pile A.

These studies confirm that winter composting in piles or windrows is possible, even with active turning, and at temperatures approaching those experienced in the Yukon although not quite as low and for shorter periods. However, it is important to be aware that the primary materials in these studies are all nitrogen-rich and have been mixed with low-N materials, such as wood chips, to raise the C:N of the system. High-N materials are likely to significantly differ from composting with primarily low N wood chips and may strongly influence how a pile might continue composting as ambient temperatures drop. However, the available studies have not found how large the ambient temperature effect is on a low N system and how it might be mitigated (or if mitigation is necessary).

Additional studies from other regions of the world which are not quite as cold, have confirmed that cool weather composting, even starting at temperatures slightly below zero, is possible, and have focused on microbiology with an eye towards identifying, understanding, and inoculating piles with cold-adapted microbes. Xie et al. (2017) used a microbial inoculant of cold-adapted microbes in compost started at 10C and found that the inoculant addition increased the heat generation and the degradation rate in the composted food waste. Shi et al. (2022) successfully composted cattle manure and corn stalks in spring and fall (ambient temperatures generally between 0-10C) and identified dominant bacteria genus they felt could act as indicators during the various phases of the composting process. Abdellah & Li (2020) reviewed challenges and factors in cold climate composting, noting a relationship between heat loss and aeration, a need for adequate moisture, and a desirable C:N, mentioning that a higher C:N (very relevant to our interests) does not provide adequate nutrition for the composting microbes. They also suggested that biochar addition may lead to temperature increases in the pile and prolong the thermophilic phase but noted that biochar is an inconsistent product and the appropriate application rates were unclear. Wang et al. (2013) demonstrated that loss of heat from the pile will be affected by the ambient temperature in that heat loss will be greater when the difference between pile temperature and ambient temperature is greater and is also influenced by the activity within the pile which generates heat. They also stated that the characteristics of the pile and its material which affect heat are the water content and readily degradable organics content, external factors such as ambient temp, humidity and precipitation, and management strategies of turning, aeration (affected both by turning and by the physical structure of the materials), and the physical dimensions of the compost pile.

None of these studies directly address our particular interests and circumstances given their low C:N materials. However, in the context of essentially 'disposing' of wood waste through composting, there is less concern with speed as it is presumed that low N wood chips containing a large amount of recalcitrant (hard to degrade) carbon will be much slower to compost than something like food waste which degrades quite readily. The above research is concerned with using composting as a waste management strategy addressing waste streams which are repeated or continuous, and thus maximizing speed of the process is desirable as more waste is on the way. For land clearing, the waste stream is limited and will not be substantially or swiftly regenerated while the land remains under production.

3. Woody Material Composting

Onwosi et al. (2017) found the choice of an appropriate bulking agent to be one of the main challenges addressed in current composting research. When starting with wood chips as the primary material, there is essentially the opposite problem. Wood chips are often used as bulking agents, both due to their coarse structure contributing to aeration and their high carbon content, which is complementary to nitrogenous waste streams (Bonhotal & Harrison, 2004). Few papers were found that specifically refer to the composting of woody materials. This is presumably because wood waste is generally easy to burn in place, which is inexpensive, removes the material very quickly, and doesn't require transportation. The ash can also be spread to add nutrition to the soil (Juo & Manu, 1996). Any continuous or frequent stream of wood waste can be used as a bioenergy source of significant value (Nowak et al., 2019). In the context of a farm with livestock, lesser amounts of wood chips may be used as bedding material which is then incorporated into manure composting (Airaksinen et al., 2001). However, as burning of wood waste becomes less acceptable, alternative disposal methods which create a use out of the waste become worth pursuing (Venner et al., 2011).

Two examples of intentional composting of wood wastes in northern environments were found (central Finland and southern Russia), two relevant studies were found regarding piles of chips stored for bioenergy purposes, one of which was to determine the degree of decomposition occurring while stockpiled for several summer months in a temperate climate (England), and the other in Finland concerned gas emissions from degradation in a bioenergy chip pile. Finally, a Japanese study had a similar purpose in looking for methods of disposing of wood wastes without burning; however, they had very different wood types, used a lab-based reactor, and had different N-amendments available to them. None of these studies perfectly reflect the materials, conditions, and interests motivating this review, but they are still highly relevant. These studies are detailed below, with comments on aspects relevant to our interests.

The Finnish composting study (Veijalainen et al., 2007) explored composting whole (i.e. not chipped or ground) forestry seedlings of birch, spruce, and pine, aged 1-4 years plus sphagnum moss as their container growth medium. They experimented with windrowed material, adding nothing, urea, various levels of horse manure, and horse manure plus both passive and forced aeration. Composting ran for two years, with turning at 3, 12, and 24 months. Samples were taken at the start, and when materials were turned and analyzed for relevant chemical and physical properties. Additional analysis was done for undesirable microbes and wood decomposition. Finally, germination tests were performed on different ages of the composted material using cress and Norway spruce. The highest temperature recorded was 61C in the windrow with forced aeration and 50% horse manure, while maximum temperatures in the piles with 50% and 25% manure were 50 and 48C. The piles with 6% manure, urea, and nothing were 41, 36, and 32C respectively. OM decomposition was tested at the end of year one and year two, with results showing decreases in all the piles after two years, with losses of 32-57% but with little apparent pattern or cause as to which piles lost the most OM. N decreased by approximately a third in the four treatments with nothing, urea, and 6 and 25% manure, while the treatments with 50% manure saw a slight increase. P and K were highest in the treatments with 25 and 50% manure both at the beginning and end of the trial, although those higher treatments saw a decrease in those levels while the other three treatments did not change much in P and K. The overall C:N of the treatments did not vary much between the beginning and the end of the trial, although the 25% manure treatment did see a significant change with a reduction of 20%. pH was only reported at the beginning and end of the trial, and the high manure piles and the urea pile decreased in pH, the nothing and 25% manure stayed roughly the same, and the 6% manure pile increased. The final pH values were between 4.5 (urea) and 6.0 (6% manure). EC at the end of the trial varied widely, with the high manure piles having much higher EC (roughly two to three times) than the lower manure, urea, and nothing treatments. Percolation of precipitation through the piles was minimal and calculated as less than 7% of the annual precipitation. Although the urea pile leached relatively more N than the other piles, the amount leached was considered negligible across the experiment, as was leaching of P. The piles were all found to have an earthy smell after turning except for the urea treatment, which was described as having a "slightly putrid odour" at the three-month turning, and all were observed as dark brown. Shoot and root plugs were visible at three months, but after two years, all materials were uniform except for some of the 4-year-old seedlings, which were still identifiable. Cress seeds germinated successfully with no visual faults in the seedlings, with success rates from 100% (forced air, high manure) to 76% (no treatment). Only the difference between the highest and lowest treatments was statistically significant. Norway spruce germinated successfully (100%) for both high manure treatments, 96% for a control medium of peat, and 92-84% for the other treatments. No seedlings had visual faults, and the difference between germination rates was not statistically significant across the treatments.

The authors attribute the lack of high temperatures to several possible factors, notably a lack of aeration in many of the piles (the forced aeration pile performed best), but not necessarily a lack of N as the urea pile also did not heat up relatively much and this they suggest could be due to either too much moisture and not enough aeration (which could explain the odour at the three month turning) as well as a lack of additional nutrients that are found in the manure but are absent in urea and likely contribute to microbial health. They additionally suggest that the lower pH levels may be affecting microbial life and suggest the potential addition of lime for materials that are acidic and low in N.

A key difference in the interests of this review is that they composted nursery seedlings whole, not actual chipped mature trees and shrubs. The study involved six heaps, each run for two years; however, the heaps were run in groups of two over six years, and thus, the ambient temperature over two years displayed in the paper appears to be an average from three different time intervals which does not allow for observations of the potential direct relationship between pile temperatures and ambient temperatures. The limited lowering of C:N from starting to the end of the trial likely indicates a lack of OM reduction, which suggests lower levels of decomposition or possibly a higher content of hard-to-degrade lignin relative to other waste types, which will be something to consider for compost maturity indicators.

The study has many interesting points and has a very detailed write-up. They experienced lower temperatures in several of their heaps, particularly the ones with urea, no amendment, or very limited manure. It was interesting to see that the urea performed relatively poorly compared to the higher manure treatments and also that the urea and the limited manure treatment ended the two years at a higher temperature than all the other treatments, which suggests they were more biologically active, presumably due to the other treatments being at a more advanced state of compost maturity. They also turned their piles very few times, and the temperature logs do not show much if any, effect from the turning, which is flagged by other studies as highly significant during cooler temperatures (Margesin et al., 2006; Larney et al., 2000; Wang et al., 2013).

The Russian study (Margina et al., 2023) addressed composting of bark and wood waste from the pulp and paper industry. They used old and newer deposits within the dump area but combined the materials before forming their piles. Conditions within the dump tend to be quite wet and densely packed, so the materials were partially anaerobic while stored. They include some relevant points on cold-climate composting within their introduction, including a recommendation to keep piles less than 3m in height when naturally aerated (to avoid excessive compression from the weight of the pile), maintain an appropriate moisture level throughout the composting process, and to start the piles during ambient temperatures high enough to get the microbial activity started. Their research focus was to compost during colder months of the year in open heaps, track the ambient and heap temperatures, and experiment with microbial inoculation to speed up the composting process. They included larger field heaps mixed with mineral fertilizers and smaller amounts of identical blends in a warm laboratory setting. They sourced material from two points within the bark dump representing both older and newer materials, then mixed the materials with a bucket excavator adding in urea (0.71kg/Mg) and diammonium phosphate (0.26 kg/Mg) and built two heaps 1.5m high and 2.7m wide, watered in a commercially available microbial inoculant (EMINEXT) to one heap only, and watered the other heap with tap water. They covered their heaps with polypropylene cloth. The field experiment started when ambient temperatures were 10C (October), and the experiment was left to run for 60 days with no turning, mixing, or additional water. Temperature at 7, 50, and 90 cm depth within the heaps and moisture were recorded every ten days, and various maturity parameters were measured every twenty days. After 60 days, the compost was analyzed for maturity, sanitary indices, and heavy metals. Their parallel lab experiment was undertaken in 8L bioreactors with tap water added as required to keep the material at ideal moisture levels. Moisture and pH were recorded every three days, and decomposition and microbial respiration indicators were examined after 60 days. It is unfortunate that they did not record the temperatures more frequently, particularly at the start of the trial, as their data did not start until day 10 where the temperature at 90cm was 23C, and again on day 20 the temperature at 90cm was also 23C, which is the maximum temperature recorded. However, it cannot be known if that was the highest temperature achieved due to the lack of continuous or more frequent data points. The temperatures then declined over time, although the 50 and 90cm readings stayed well above the ambient temperature while the 7cm depth temperature tracked the ambient temperature fluctuations. On day 60, the temperatures within the heaps had decreased but were still 10, 20, and 25C higher (at 7, 50 and 90cm, respectively) than the ambient temperature, which was then -14C. When the heap was dug into at day 60, the outer 10-13cm of material was frozen. The temperature of the two heaps was determined not to be significantly different and the inoculum did not appear to affect the temperature. Their decomposition and microbial respiration indicator results show a steady near linear decrease from day 0-40 and then little change from day 40 to 60. They attribute the relatively low temperatures of their piles to the materials possibly having already undergone thermophilic composting within the bark dumps and a lack of rapidly decomposing organic matter available within the bark. Although the low temperatures are a concern for not sanitizing the piles (for seeds and pathogenic organisms), the materials did still degrade, particularly from days 0-40. pH and moisture content of the piles were maintained throughout the trial, although pH was only recorded every 20 days. The constant pH may also indicate previous degradation in the bark dumps, as pH during the thermophilic phase has been found to fluctuate due to the biochemical processes taking place (Yu et al, 2019).

Differences between the lab and field trials were found not statistically different. After sixty days, the heap materials, originally found to smell of wood, were described as having a smell of forest humus. They concluded that cold-weather composting was successful and did not differ in result from the parallel laboratory composing. Their end product was suitable for some purposes but did not meet all the Russian regulatory requirements and thus could only be used in situations with an impenetrable base layer and drainage. They did not analyze many factors associated with compost maturity (the focus of the study was more to determine if composting could happen during the winter months) and suggest a follow-up study to test the process over longer periods, including potential freeze and thaw of the piles, and to test the final materials for quality and phytotoxicity.

The applicability of their work to our situation is the use of woody waste as the primary material and the cool-to-cold ambient conditions of the compost piles. However, they were using a local waste product that had already been decomposing for decades in a dump, some of which showed evidence of contamination with chemicals associated with pulp and paper processing (low pH from acids). They were also using bark, presumably from mature trees, and their interest was in finding if they could compost materials over winter and monitor the degradation process over a fixed and relatively short timeframe (two months) with no focus on the quality or use of the product. They also achieved much lower temperatures than would be effective for sterilizing the compost for seeds and pathogenic organisms, but the faster degrading components of the bark would likely have been lost from the time spent in the dump. There was no control pile (i.e. without amendments), and the difference between the piles was with or without the inoculum, which did not show any effect and is not of further interest. However, of interest to our conditions is that they could compost old material at a cool time of year, and the composting continued into the winter. The achievement of further degradation of such an unpromising and already somewhat degraded starting material with only mineral fertilizers as an addition and under cold conditions has positive implications for our purposes, and the lack of higher temperatures and how that might be adjusted is a useful angle for research.

In the Japanese study (Suzuki et al., 2004) the team had similar intentions, to avoid the burning of wood waste from land clearing, and they experimented using wood chips from oak, cedar, and holly mixed with several different amendments and blends of amendments including chicken manure, urea, composted food waste, nitrogenous lime, coal clinker ash, coal fly ash, volcanic ash, and charcoal, with the ash components being cited as potentially reducing heavy metal availability and reducing thermophilic bacteria (there is no explanation as to why these features are necessary or desirable when composting wood waste, nor were those parameters analyzed in the study). The materials were placed in 6m^3 columnar reactors with aerating blower units and dimensions 1.6m high and 2.2m in diameter. After five months, the materials were removed from the reactors, placed in 1m^3 flexible bags, and piled on a concrete floor for a further six months. Samples were tested at 3, 5, 7, and 10 months for various indicators of maturity and found that C:N, pH and total carbon decreased over time, while total nitrogen, nitrate nitrogen, PQ (a measure of humic acid), cation exchange capacity, electroconductivity and ash content increased with composting time. They found, based on a seedling test and evidence of nitrogen deficiencies, that C:N, nitrate nitrogen, and PQ could be used as parameters to estimate compost maturity and then used a statistical technique (multiple linear regression analysis) to identify the compost materials which influenced each parameter, finding that chicken manure, food waste, and charcoal ratio influenced (decreased) C:N; chicken manure and urea increased nitrate nitrogen and PQ; and, fly ash decreased PQ. This paper is not the most clearly written (not suggesting the results or analysis are incorrect, just not well explained), and their results are quite specific to the materials they used but can still be informative. Interestingly, they did not find urea to lower C:N, which could suggest that the N is not being significantly retained within the compost or that the decomposition of the carbon materials is less advanced. However, they do attribute higher nitrate nitrogen to urea which suggests that the nitrogen from the urea is successfully being transformed and retained to some degree. They do not explain how charcoal addition would lower the C:N, but it could be theorized that this is from the charcoal trapping some of the nitrogen compounds as both treatments contained urea in their mixes. Although not mentioned by the authors, the maturity testing results of the various blends do seem to indicate that co-amendments may be a successful approach (e.g. adding some urea with chicken manure) and that lower levels of amendment may take longer to get to maturity but will still get there (e.g. maturity achieved at 7-10 months, but not at the 3-5 month point).

Two other studies (one a review paper from Finland and one an experiment in England) based on the storage of woody chipped material intended for biofuel use are informative from a materials and conditions standpoint. In these studies, the purpose was to determine the loss due to decomposition and the contributing factors. No amendments were added, but moisture was seen as a key role in material loss and influenced the temperatures within the storage piles resulting from microbial activity. While viewed as a negative for their storage purposes, these results are positive for intentional composting. The Finnish review paper (Wihersaari, 2005) found an increase in dry matter loss from decomposition with increased moisture, as well as finding that temperatures within storage piles rose quickly with a moisture content of 40% but then declined after 1-2 months, while with a moisture content of 50-55% the temperature within the heap stayed high (no indication of how long the storage period was). Wihersaari concludes with recommendations against storing chips intended for biofuels for longer than a week, if possible, and against mixing or moving the heaps as this would increase decomposition. The English study (Whittaker et al., 2016) also found moisture to lead to decomposition and mixing of the materials to be undesirable as it incorporated the wetter outer layer into the heap. Whittiker also noted that the first two months of storage appeared to be undergoing aerobic decomposition but then showed evidence of anaerobic decomposition. However, it is noted that their heaps were of large volume and five meters high, which is above the recommendation for maintaining aeration (3m). The study piles started at a moisture content of 50-54% and decreased by 10-15% over the months of the observation, which indicates a likely need for applying additional moisture throughout the composting process and that from the relatively wet climate of England. Their heaps reached a maximum of 66C at 12 days, stayed above 60C from day 3 to day 30, and experienced a rapid decrease in heat after day 56, where the temperature fluctuated from 20-35C.

One thing to note from these studies is that the materials intended for bioenergy were ‘fresh’ and tended to be either from small diameter wood like willow, branches of larger trees, or bark materials (see Ramial Wood Chips below). Although much of what would be composted in the Yukon is the smaller diameter trees and shrubs, it leans towards being higher in wood and lower in bark, shoots, leaves, needles and sapwood which would contain more readily degradable compounds and have a lower C:N.

3.1 Ramial Wood Chips

Ramial Wood Chips have had some attention as a direct addition (i.e. not composted beforehand) to soil for increased soil organic matter and nutrition, based on a technique developed at Laval University in the late 20th century (Lemieux & Germain, 2001) which is intended to mimic how soil is generated in a forest environment (Germain, 2007). Ramial wood is from the parts of trees and shrubs that are smaller in diameter and produce buds and leaves, which are richer in polyphenols, sugars, proteins, and nutrients that degrade over time and replenish soils as they break down (Lemieux & Germain, 2001). Agricultural experiments using ramial chips have been successful in improving soil structure and nutrition (Fontana et al., 2023) and stimulating biological activity (Barthès et al., 2015), but it is not yet a widely used or studied technique. Another use of ramial wood has some history and interest in permaculture circles, that of a compost-based heating system developed by Jean Pain in France. Pain managed a forested lot, harvesting and chipping brushwood, and using it to create large compost heaps insulated with straw bales and solely consisting of wetted chipped brush in which he embedded water pipes for capturing heat and circulating it through a looped system (*The Jean Pain Way*, 2011). Depending on the size of the pile, the system could run up to 18 months, producing 58C water, which could be used for radiant heating systems (ibid). It was believed by Pain, through his research with the system, that the energy released through composting was greater than that released by burning (Brown, 2014). This subject is relevant to this review in two ways, one as an encouragement that composting woody waste can be very successful with no additional inputs of nitrogenous material; the other that the success might be dependent on the use of ramial wood and not chips or sawdust from larger trees. A further link between this work and our interests is from a field observation during a previous wood chip project undertaken by the YG Agriculture Branch with involvement from Yukon University. That project trialled two different methods of directly applying clearing waste to the newly cleared lands, one of which was to shred and churn the material into the soil, and the other was to chip the cleared material and apply a portion of it each year for three years to the soil surface. What was interesting was the reserved pile of chips that was left beside the trial plots for application in future years. For two years, the pile of chips, with no additional inputs or intentional moisture addition, was found to be hot to the touch within a foot of the surface, moist, and colonized by white rot fungi (*Phanerochete chrysosporium*), which is a main degrader of lignin-dominant materials (Kumar & Shweta, 2011; Singh & Chen, 2008). As it was not part of the trial, the observation remained a curiosity to the research team, and the decomposition of the material was not analyzed further. The observation suggests that a large heap of wood chips and whatever precipitation it receives will start to compost without additional input or interventions. The material that went into the piles was largely smaller diameter aspen, willows, and other shrubs, cut in July, chipped in November, and then stored in the pile until spread. Material of this nature would generally be considered ramial wood, which makes up much of the potential wood waste remaining in Yukon forests after larger timber is salvaged. We do not know when the piles heated up, how long they remained active into the winter, or how much the material decomposed. We also do not know if it was active because it was ramial wood and largely deciduous species or if results would be similar with other materials, such as conifer-dominant chips as well as older cut materials, which have been left in windrows for long periods. If it had not been observed directly, it might not have been believed that a pile of such material would attain notable heat (estimated to be in the 50-60C range based on hand-feel) for such a long a period.

4. Compost Pile Construction and Management

4.1 Moisture

Aerobic composting produces water as a decomposition product, which can contribute to maintaining the moisture content throughout the process as moisture is also lost via evaporation (Bartholameuz et al., 2010). However, moisture must be sufficient to get the process started (Shen et al., 2015; Van Der Wurff et al., 2016), and drying of the pile, particularly the outer layer, is potentially quite significant where the pile is exposed to solar radiation and wind and can reduce the effectiveness of the composting process (see Whittaker et al., 2016). Wood chips have much lower intrinsic water content than other wastes such as manure slurries, undried biosolids, food wastes and green wastes, so additional water (ambient precipitation and/or intentionally applied) will likely be necessary to any compost pile constructed primarily of wood chips.

4.2 Turning

Margesin et al (2006) is quite instructive on the effects of turning, where their frequently turned pile (twice a week) was much cooler overall and at their end point was less mature (showed phytotoxicity) in comparison to their pile which was left for three weeks before turning, and then turned once a week after that. Larney et al. (2000) turned their cattle manure compost frequently in winter and found that although the temperature dropped, it returned to thermogenic temperatures within two days. Sall et al (2016) also found their turned piles to return to temperature during winter composting. Tiquia et al. (2002) specifically trialled turned vs unturned windrows and found that although the turned compost was faster, there was a trade off with greater loss of mass, C, K and Na in the turned windrows. N loss varied from 30-67% but did not appear to be affected by turning and instead was affected by initial C:N. Turning is generally required to ensure that materials are mixed throughout the piles, and this may be a regulatory requirement (where applicable) to ensure all materials are exposed to thermogenic temperatures for removal of pathogens and deactivation of seeds (Canadian Council of Ministers of the Environment, 2005). The outer layer may be drier or wetter under the influence of ambient weather, and not have the insultation of the heap to keep temperatures up (see Margina et al, 2023 where temperatures at 7cm track ambient temperature trend, while temperatures at 50 and 90cm retain greater heat and do not appear influenced by external temperatures). In a low-N composting process it is predicted that the slower rate of composting will require less frequent turning, but that occasional turning will be necessary and timing can be indicated by pile cooling after an initial heating period, perhaps every one to two months while the pile is active.

4.3 Heap design/dimensions

Cornell Waste Management Institute (Richard, 1996b) has a brief factsheet regarding windrow design for yard waste windrows, suggesting that windrows be 6-10ft high and 12-20ft wide, with no functional limit to the length. Van Der Wurff et al. (2016) state “the higher the windrow, the coarser the mixture has to be”. Margina et al. (2023) mention keeping piles less than 3m in height when naturally aerated to avoid excessive compression from the weight of the pile, which in their case was constructed of bark waste, which would have similar structural properties to coarse wood chips. The chip pile in Whittiker et al (2016) which was 3m high, initially was aerated and aerobic, but showed signs of anaerobic conditions after two months likely due to chip degradation/compression and collapse of air space within the pile.

4.4 Expected timeframe

Referring back to other studies of wood composting or degradation, two years is a likely timeframe needed to bring woodchip composting to completion. Suzuki et al. (2004) found that ten months starting in a reactor and finishing in bags were required, although several blends were considered mature before the 10-month point. Veijalainen et al. (2007) ran their experimental piles for two years with generally satisfactory results for maturity with the end products, although they were composting seedlings, which would have had a lower C:N than what is found in wood chips. Margina et al. (2023) only ran their piles for two months, starting with already degraded bark material, and did not consider their product fully mature at the end of two months. Given the anticipation that a low N pile will likely not remain active throughout a Yukon winter, utilizing the spring-summer-fall periods over two years is projected to be adequate for achieving fully matured compost, but a temporal buffer might be wise to include in any research plan.

5. High C:N Composting

Ideal C:N for composting is generally agreed as between 25:1 to 40:1 (Amuah et al., 2022), and higher ratio mixed will result in a slower process as the growth of the microbial population is limited (Richard, 1996a). There is not much research focused on differing from that ideal range; however, Pezzolla et al. (2021) found that for optimal composting to achieve temperatures conducive to pathogen removal and complete composting, a ratio of Total Organic Carbon to Water Extractable Nitrogen of 40-80 was recommended. Their experiment utilized a variety of organic wastes combined with a variety of bulking agents, including wood chips, which they characterized as having a C:N of 70 and used at rates of 30-55% in compost blends with higher nitrogen materials. They found compost blends with wood chips were the most successful. Most interesting was the finding that it is the soluble N in ratio to total organic carbon which was correlated with successful composting conditions, not Total Kjeldahl Nitrogen (which is more commonly measured/reported in the C:N) because microorganisms cannot quickly use the non-soluble nitrogen. They suggest that WEN should be more than 0.4% by weight for an optimal amount. An additional relevant finding was that lower levels of OM loss were found with higher values of TOC:WEN, which showed that overly low levels of WEN did not sufficiently support microbial productivity.

6. Compost Quality/Stability/Maturity Measurement (for people without an analytical lab)

Compost quality, stability, and maturity measurement is well represented in research; however, broadly applicable international standards have yet to be established (Brinton, 2000). Criteria can be technical and require analytical equipment or laboratory testing that is not readily accessible to non-specialists, some even venturing into genomic studies of microbial populations (Estrella-González et al., 2020). Several good review papers have been written about compost quality/stability/maturity indicators over the years and will not be duplicated here. Two academic reviews and two additional references are mentioned below, which can be suggested for their breadth while also addressing different angles on the subject and because they are available without a paywall through Google Scholar search or direct link. It should be noted that depending on jurisdiction and intended use of compost (in particular for compost being sold), there may be regulations requiring particular testing prior to sale or use, information which is beyond the scope of this paper and readers are encouraged to inform themselves of any such requirements in their jurisdiction.

1. "Compost stability and maturity evaluation – a literature review" by Wichuk & McCartney (2010)
   This review has detailed information on various methods that may be used for assessing composts, as well as presenting guidelines and regulations from various jurisdictions in Europe, Canada, Australia and New Zealand.
2. "Composting parameters and compost quality: a literature review" by Azim et al. (2020)
   This paper is focused less on methods and more on individual criteria and their underlying chemical and biological processes. It is an interesting read but quite technical.
3. "Compost Quality Indicators" by Amery et al. (2020)
   This is a European report written for a non-academic audience. It is straightforward, explanatory, and practical but references European standards.
4. "Guidelines for Compost Quality" by the Canadian Council of Ministers of the Environment (2005)
   These guidelines are intended to be applied to compost in Canada, which is sold or given away and is focused on the quality and safety of the material. The guidelines are intended to provide harmonization and consistency regarding compost quality while leaving flexibility for each jurisdiction which chooses to adopt them (federal, provincial, territorial) to develop any regulatory framework to meet the jurisdiction's specific needs or interests.

Prior to the use of compost, outside testing may be required, particularly for pathogens and contaminants or if there is interest in the nutrient quantity or other soil characteristics of the finished compost. To determine when the compost is stable and mature, it may be helpful to use sensory observations combined with germination and seedling testing before investing in laboratory tests. A stable compost has reached a point where further microbial activity is limited, while maturity is determined by phytotoxicity testing (Wichuk & Mccartney, 2010). Stability comes after a pile heats up due to microbial activity and cools back down, and when turning and remixing the pile no longer causes another heating cycle (Azim et al., 2020) and is tested via indicators of microbial respiration (Barral & Paradelo Núñez, 2011). Maturity is not achieved immediately, and compost is left for an additional period for secondary chemical and biological processes to occur, including humification, often called the curing phase.

Colour and odour will change throughout composting, with material generally becoming darker with maturity (Van Der Wurff et al., 2016) and losing any odours associated with its constituents, volatile chemicals (such as ammonia), or anaerobic processes, and taking on an 'earthy' smell (Wichuk & McCartney, 2010). Margina et al. (2023) observed that bark materials they composted originally smelled woody at the start of their process but darkened and took on an earthy smell at the end of their compost period. Phytotoxicity testing can indicate compost maturity as many chemical components developing in intermediate stages of composting, such as ammonia and various organic acids, are phytotoxic (Barral & Paradelo Núñez, 2011). Although any scientific study will require additional material testing for various parameters, a preliminary assessment of whether or not the compost is likely ready to use can be made in-field by observing whether the materials will heat up if remixed (CCME guidelines suggests any heating be less than 8C over ambient temperature after curing for at least 21 days (Canadian Council of Ministers of the Environment, 2005)), noting the colour (darker than original), and any odour should smell of earth or forest floor and not rotten, chemical, or of its original constituent materials. When these conditions are met, the compost can then be tested for germination and seedling growth.

7. Compost Nitrogen Amendments

7.1 Animal Manures

Animal manures, either solid or liquid slurries, are very common compost ingredients, featured as a primary waste to be transformed into compost, or as a nitrogen-rich amendment to add to carbonaceous materials. Manure varies in C:N both by species, diet of the animals, dilution from rain or wash water, and because manures may be already mixed with bedding materials (Wilson, 2021). Reported values range from 6 or 7 for pig and chicken manures to 15 for cattle and sheep manures to 25 for horse manure (Homestead on the Range, 2018). Manure may harbour pathogenic organisms (such as *E. coli* and *Salmonella*) and parasites; the heat of the thermogenic phase destroys pathogens and can also deactivate undesirable weed seeds (North Dakota State University Agriculture, 2016). Manure is a valuable addition to a compost pile, contributing nitrogen and microorganisms and transforming the waste into a soil amendment.

7.2 Green Manure

Using harvested green manure shoots as a co-composting material is an attractive idea as a method of preparing newly cleared land for a field, as the land could be cleared, planted with a green manure crop, and then instead of turning the entire crop into the soil, the shoot portion would be cut and included in a compost pile with the chipped clearing waste. Choosing a single species or mixed crop which also fixes nitrogen could be an additional benefit as the roots would be cut and left in the soil as the compost is generated for future addition. Such a technique would not require off-site inputs for those who do not want or do not yet have livestock, nor mineral N for those wanting to maintain organic techniques. Personal experience suggests that wood chips and lawn clippings will form a heat-generating compost mix, but not whether the pile can be sustained and reach a matured state in a reasonable timeframe. It was also observed that mixing the lawn clippings and chips was difficult with the grass tending to clump together and anaerobically rot rather than aerobically compost. Literature values of C:N for specific green manures vary, with hay being in the 15-25 range (Van Der Wurff et al., 2016) and for example of some specific crops: fresh-cut alfalfa 12; legume hay 17; mature alfalfa hay 25; and rye cover crop 26 (Homestead on the Range, 2018). Hay is not the same as straw, with straw having a much higher C:N and it is used as a bulking agent. Green manure cuttings might be a challenge to implement, both due to physical structure being difficult to mix in with wood chips, and due to temporal disconnect between having fresh-cut material ready to mix or using stored hay which will have a higher C:N. However, it is a compelling idea for both new farms and organic producers and should be trialed with openness to intervention throughout the process if initial efforts prove unacceptable. It would be desirable to experiment in a lab with additional organic N inputs (such as bloodmeal or offal) if the system appears to be lacking N, as well as experimenting with forage beet (or substituting regular beets) as a potential co-crop for green manure which would also provide readily degradable carbon as sugars and may also benefit the composting process.

7.3 Mineral N

Using mineral N from commercial fertilizers seems a simple way to lower the C:N of a compost system, but is not straightforward. In a review of studies on compost supplementation, Sánchez et al. (2017) analyze both composts supplemented with N fertilizers at the start of the composting process as well as matured composts supplemented with N fertilizers to provide more nutrition in their application. They conclude that both approaches have been shown to be successful, but more research is needed to understand the dynamics and mechanisms involved and the details for optimal implementation. As wood chips are a low N material, natural amendments such as manure may not be available, and commercial fertilizers are relatively inexpensive, using mineral fertilizer is an attractive option for those not committed to organic methods or for those whose land clearing purposes are outside of agriculture. Urea is cheap and readily available and has often been used alone or with additional amendments to improve composting processes. Mirzababaei & Hassani (2024) compared the use of Urea and KOH to enhance the composting process (KOH is alkaline and is intended to increase the breakdown of cellulose and lignin). The highest amount of water-soluble nitrogen was found in the urea treatments and the high C:N of their urea/sawdust mixture (85.8) did not seem to limit the compost process compared to their other blends. Urea was found to be the more successful enhancement. Other studies have found urea to be less successful; in Veijalainen et al. (2007), the results for the urea-amended pile were comparable to no amendment at all and less successful than manure; and (Margina et al., 2023) did not vary the amounts of urea as part of their experiment, but the low level of heating of the system showed limited biological activity. However, that was likely majorly influenced by a lack of readily degradable carbon and does not necessarily indicate a problem with the urea. (Zhao et al., 2022) sought to use urea instead of chicken manure for composting rice straw, to avoid the high EC often found in manure-amended composts and due to a lack of local and reliable sources of manure. Their experiment also used phosphogypsum, intending to reduce NH_3 volatilization and nitrogen loss, and reduce the final compost's alkalinity.

Phosphogypsum (PG) is a byproduct of the manufacture of phosphorous fertilizers from rock phosphate. It primarily consists of gypsum ($CaSO_4$) but with significant and undesirable impurities, usually including elevated radioactive components (Fornés et al., 2024). Outside of areas with unwanted PG dumps, gypsum would be a better choice and is widely available. (Zhao et al., 2022) amended their rice husk base with urea or chicken manure adjusted to bring the C:N to 30 and then added PG in varying quantities. The PG showed a strong effect in reducing the NH_3 emissions from the urea treatment by reducing a spike in NH_3 emission during the early composting stage. Total N loss of the urea with no PG treatment was roughly double that of the manure and the PG-added treatments (45% vs 19-26%), with the majority lost as NH_3. The PG was added at rates of 0, 10, 20, and 30% of the dry weight of the organic materials, and overall results were best with the 10 and 20% additions (they believed the 30% addition reduced the pH of the system too much and negatively affected the composting process). They concluded that a moderate amount of PG is an effective addition where urea is used as the main N source. This study is a valuable reference, with the caveat being that the amount of urea used is unclear, and the amount of PG used is relatively large if applied to a large volume of composting materials. In the situation of a low N compost, it is assumed that a much lower gypsum application rate would be adequate, but this would be a good line of inquiry for a lab trial.

Prochnow et al. (1995) experimented with PG and simple superphosphate fertilizer (approximately 50% gypsum content) to reduce N volatilization losses during manure composting. Although both decreased the loss, the PG was more efficient. They attributed the reduction to the gypsum in the amendments based on regression analysis and the reaction of gypsum with ammonium carbonate, which produces ammonium sulphate. Prochnow et al. recommend that application rates to straight manure blends be at least 100kg/ton, and this might be a recommendation that could be scaled to a low-N system by considering the rough amount of N contained within manures and adapting accordingly and presents another potential line of lab inquiry. Adding superphosphate to urea to reduce volatilization is not a new idea and has long been recommended as a strategy for N retention in a soil application (Gasser, 1964) due to the acidification attributed to superphosphate.

No references were found specifically comparing different N fertilizers for their effects on the composting process. However, one study (Adamtey et al., 2009) was found where urea and ammonium sulphate were trialed as an additive to finished compost to boost the nutritive value of the combined product. They stored the coproducts for two years and found that the N losses at the end of two years were almost double (47%) in the urea blend compared to the ammonium sulphate blend (24%). The pH of the mixtures was different, with the urea blend being roughly one pH unit higher (8-9) than the ammonium sulphate blend (7-8). However, (Gasser, 1964) mentions that ammonium sulphate has high rates of N loss compared to urea when applied to the surface of calcareous soils, which may differ when mixed into the soil. The base saturation of the soil also influences the N loss. The particulars of N fertilizer behaviour in compost and soils are complex and are also influenced by the timing of the applications (Matsushima et al., 2009). Cornell Waste Management Institute at Cornell University has plentiful information for composting; however, their minor information entry for fertilizer nitrogen suggests there is a lack of research on appropriate application rates, but also suggests that the application should be low and applied in a series to avoid volatilization of very soluble sources. Additionally, because the nitrogen is not locked into an organic form, the total application should be half to two-thirds if applied based upon a calculation to raise the C/N (Richard, 1996c). For experimentation on composting wood waste, it is likely best to choose one common fertilizer to use in a field setting, and any additional additives could be trialed in a lab setting.

8. Hügelkultur approach

Initially, this review intended to consider hügelkultur as a possible technique for decomposing larger-sized pieces of woody material. However, upon contemplation, this is not an attractive approach for the scenario we are contemplating as the buried material takes a very long time to decompose (generally a desirable feature for people using this technique) and is in a mound or a trench format. Mounds or trenches may be appropriate for a market garden or a home garden operation. However, for larger-scale field cultivation for which machinery would be used for sowing and harvesting, hügelkultur would be a challenge to navigate around or over and does not make much sense to implement unless there is a specific space dedicated to hügel beds. Hügelkultur is a very valid and interesting technique for the appropriate purpose. A literature review (Hvenegaard, 2021) of its potential for managing forest fuel reduction wastes completed by a consultant for the City of Rossland in southern British Columbia can be read by anyone who wishes to learn more about it, oriented towards waste wood management and wildfire mitigation.

9. Conclusion

Composting of woodchips as a primary compost material is not a well-researched topic. As burning becomes less acceptable, composting presents a potential alternative practice with the added benefit of providing valuable organic matter and nutrition to newly cleared land. This review has presented evidence that cold climate composting is possible (particularly with higher N materials), that woodchip composting is possible (but likely slow), and that several options for nitrogen amendment can be considered which are appropriate for organic and conventional or non-agricultural composting. However, none of the information reviewed specifically addresses the combination of factors of interest in this Yukon context and questions remain regarding the actual potential for success of low-N woodchip composting including the length of time required, the heating potential of the piles (i.e. can it reach a sufficient thermogenic state), which of the potential N amendments work and what challenges do they present, and the degree to which N amendments can be minimized while still achieving a satisfactory result. A field and lab study guided by this information would be of value to northerners, fill a gap in the global body of knowledge on this topic and serve as an example or influence others to undertake similar land stewardship approaches.

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