1.   Feasibility of producing maple syrup in New Zealand

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Abstract: Maple syrup is strongly associated with North America in the same way that wine was once associated with France. Parts of New Zealand (NZ) have growing conditions suitable for maple trees to grow and exude sap to be used for the production of maple syrup. While traditional production requires mature trees, recent research in the United States suggests that densely planted saplings can produce far more maple sap per hectare than mature trees. In addition, the proposed system allows reduced land and material usage and a much faster start up time than existing practices using mature maple trees.

Densely planted saplings, the so-called plantation method, allows maple saplings to be produced as a row crop, where harvesting in late winter occurs at a unique time compared to other NZ crops allowing for earlier mobilization of the seasonal workforce that typically works on vineyards and fruit crops.

In this paper, we describe intensified maple sap harvesting using a specialized extraction system and the plantation method. We estimate, based on a preliminary design and economic analysis, that the economics of producing sap and processing it into maple syrup are favourable beyond the scale of approximately 10 ha. Furthermore, we demonstrate how deep freeze-thaw cycles are not required to produce a crop of sap from small diameter saplings. Climate, soil and geographical information systems databases were used to develop a figure of merit analysis to compare environmental growth factors and identify regions of the South Island of New Zealand where maple saplings can potentially grow and produce sap for commercial syrup production.

Keywords: maple, syrup, New Zealand, climate, freeze-thaw, saplings, vacuum extraction, heat transfer, plantation method.

1.   Introduction

Maple syrup is produced by concentrating the sugars found in the sap of maple trees, *Acer saccharum*. Maple sap is a transparent liquid, mostly water with approximately 1-3% sugar by weight. The process of extracting sap from the trees, known as tapping, is accomplished by drilling a hole into the sapwood of the tree allowing the natural pressures within the tree to exude the sap. With properties consistent to water, maple sap flows from the trees through extensive networks of tubing (Figure 1) to be collected and processed into syrup. Maple syrup is only classified as such if it has between 66.9-68.9 % sugars by weight, with colour and flavour development having occurred through non-enzymatic browning reactions that take place as sap is concentrated by thermal evaporation [1]. Maple syrup has a range of grades corresponding to varying degrees of colour development as shown in Figure 2, however it cannot be processed in any manner which adds or removes naturally occurring soluble materials. Regulations state that maple syrup must be pure concentrated sap from a maple (*Acer*) tree [2]. Considerable amounts of water must be evaporated off to process maple sap into maple syrup. For example, it would require about 43.78 litres of sap, with 2 % sugars to produce one litre of maple syrup at a standard sugar concentration of 66.9 % sugars [3, 4].
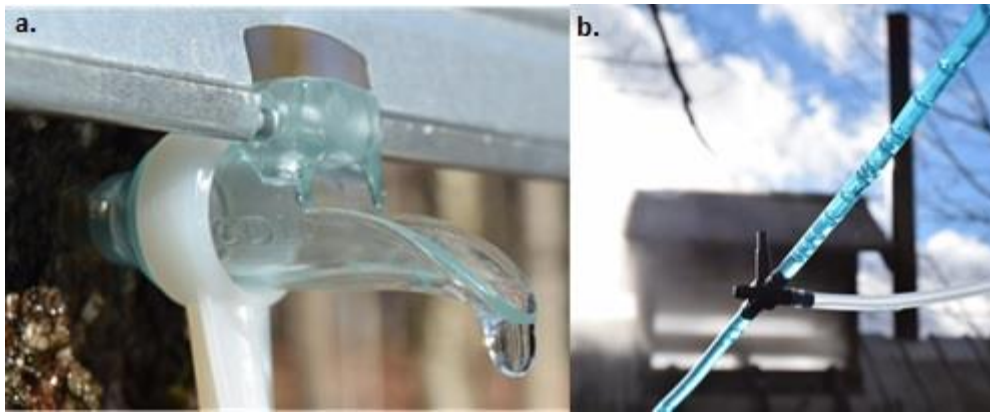
Figure 1: (a) maple sap exudation from tapping a spout into the sapwood. (b) Tubing network for collecting maple sap prior to processing into syrup. Photos are Copyright University of Vermont and courtesy of Mark Isselhardt, used with the permission.

Figure 2: Varying grades of maple syrup, depends to some extent on the degree of colour development. Photo is Copyright University of Vermont and courtesy of Mark Isselhardt, used with the permission.

Collecting sap from maple trees is one of the oldest agroforestry practices in North America, dating back to the 17th century [5]. As the natural foods movement has become increasingly popular, maple syrup has become an increasingly attractive alternative to processed cane sugar. The increasing demand for maple syrup must be matched with increased maple syrup production. Presently, Canada and the United States are the only countries that produce maple syrup on a commercial scale [6]. The maple syrup industry is concentrated in a very small geographical location. It is our aim in this paper to investigate the possibility of commercially producing maple syrup in New Zealand.

Maple trees are unique to other species of trees in that they exude sap during the winter, when the trees are in a leafless state. There is extensive literature addressing the phenomenon of sap exudation in maple trees [7-11], yet the exact mechanisms remain unresolved. The fact that remains constant throughout the literature on sap exudation however, is the need for a freeze-thaw cycle to drive sap flow. Sap flows within the sapwood of the tree in response to temperatures fluctuating about 0°C, this only occurs when the pressure generated in the xylem is above the atmospheric pressure as a result of a freeze-thaw cycle [7]. Sap exudation is only possible when the xylem sap becomes exposed to ambient pressure, through either a wound in the tree or an inserted tap-hole. Sugar, sourced from carbohydrates in the roots and other woody storage tissues of the tree, is loaded into the sap in response to fluctuating freezing and thawing temperatures. Maple trees have raised xylem sap

sugar concentrations after winter dormancy and sap flows from the trees once above-freezing temperatures are reached [12]. Given suitable conditions, sap will flow from maple trees from just after the trees have lost their leaves in autumn until late spring when the trees start to leaf out.

The production of maple sap within a maple tree is regarded as a natural physiological phenomenon, however the basis of the flow and collection of the sap are the result of wounding the tree [13]. Tapping is a simple method that extracts sap from a mature maple tree by drilling a small hole through the sapwood into the xylem of the tree. In traditional maple syrup practices, a hole four to six centimetres deep is drilled into the tree, and a small spout is placed in the hole allowing gravity and pressure within the tree to force the sap out. Small buckets hang from the spout in each tree to collect the sap.

Present day sap-collection systems rely on a dense system of tubing that transports the sap from each tree directly to the syrup processing area. For tubing systems to be successful, maple trees need to be located on sloped land allowing the sap, which is only slightly more viscous than water, to flow with the help of gravity through the tubing. Vacuum extraction systems use a vacuum to enhance the pressure gradient between the inside and outside of the tree, which in turn facilitates faster sap flow rates out of the saplings. The vacuum is especially effective when the pressure level inside the tree only slightly higher than ambient temperatures [9, 12, 13].

One of the underlying assumptions within our analysis is that good maple tree growth corresponds to a high maple sap yield. Extensive literature and data from existing maple syrup practices in northeastern North America was consulted with the goal of identifying climatic conditions, particularly in terms of the freeze-thaw cycle that maple saplings require to achieve a sufficient sap yield. Existing literature states that New Zealand's winter temperatures are too mild for sap exudation from the large, mature maple trees used in the existing syrup industries in northeastern North America. The remainder of this paper demonstrates that New Zealand's warmer winter temperatures will not prevent sap exudation in maple trees.

The following analysis focuses on extracting sap from the top of maple saplings using a specialized sap-collection device and vacuum extraction. Without the need for large freeze-thaw diurnal temperature swings to induce sap flow, maple syrup production can be expanded to regions previously deemed unsuitable for maple syrup production, creating opportunities for growth within the maple syrup industry.

We implicate a numerical model to investigate the heat transfer patterns in maple saplings at historical New Zealand winter temperatures, identifying the temperatures required for sap flow in maple saplings. A figure of merit analysis, based on seven main environmental factors known to affect growth of maple trees was established to locate areas in New Zealand that could support a successful plantation of maple saplings. The figure of merit analysis identified 17 unique locations using soil and climatic data from weather stations across New Zealand. Geographic information system, GIS, technology was used to overlay the figure of merit data across maps of New Zealand. This research has determined that a plantation of maple saplings for use in commercial production of maple syrup is a possible and a promising endeavour in New Zealand.

2   The Plantation Method

The plantation method comprises of three main features: using saplings as opposed to mature trees; using vacuum extraction instead of relying entirely on the pressure that develops naturally inside the tree trunk; a densely planted array of trees similar to a row crop such as grapevines instead of a natural and random distribution of trees found in a forest. These aspects of the plantation method will be discussed in the following subsections.

2.1   Maple Saplings

The basic physiological processes that underlie sap collection from mature maple trees are the same in maple saplings however, with a much smaller radius, sugar storage within a sapling is concentrated into a much smaller area [12]. The collection of sap from maple saplings should show a similar pattern to that of mature trees with the season beginning and ending at similar times.

The use of maple saplings for the harvesting of maple syrup allows for increased sap yields, per hectare compared with mature maple trees as well as shorter start up times between planting the trees and the first harvest. A sapling can be used for maple syrup production after it reaches a diameter at breast height (dbh) of 0.05m, after three to ten years. Alternatively, it takes a mature maple tree around 30-40 years before it is suitable for conventional maple syrup production [13].

2.2   De-topped Sapling Extraction Method

The smaller radius of the saplings along with vacuum extraction could potentially eliminate the requirement for the cold temperatures historically required to induce the freeze-thaw cycle [13]. Researchers at the Proctor Maple Research Centre at the University of Vermont discovered that sap that contains sugar, similar to that collected from mature trees, could be collected from the stem of saplings that had been excised at chest height. They found that the top of the sapling is not essential for sap collection under vacuum-induced flow, and further that de-topping the stem of a sapling is not typically lethal to the saplings [13]. Perkins and van den Berg have established a novel method of sap collection that consists of de-crowning the top of the maple sapling and covering the exposed stem with a specific collection device, seen in Figure 3. Under the sap-collection device, a partial vacuum is applied to each of the interiors of the sap-collecting devices so that sap flows from the top ends of the stems, through the corresponding devices and through the line system to the collecting tank.

Figure 3. A picture of the sap-collection device used to extract sap from the top of maple saplings. Picture used with permission from Sally McCay, Photographer for UVM Photo.

In enabling a freeze-thaw cycle at warmer temperatures, vacuum extraction through the top of a maple sapling will in turn extend the sap-harvesting season [13]. The maple syrup industry has seen increased yields in the production levels of maple sap using vacuum extraction methods [14]. We speculate that using a vacuum and specific sap-collection device to extract sap from the top of maple saplings could entirely bypass the need for deep freeze-thaw cycles, allowing maple syrup to be produced in a much wider range of climates [13].

A key requirement for the long-term perpetuation of this new system is regeneration of new growth from the cut stems. If the tree stem is of sufficiently small diameter (<0.12m dbh) and exposed to a reasonable amount of sunlight, new branches and leaves will sprout from dormant buds located under the bark of the remaining stem during the following seasons [13]. The proposed method of vacuum extraction through a specialized device out the top of a maple sapling proves sustainable, efficient and can be implemented year after year.

2.3   Densely Planted Saplings

 The large land area required for a stand of mature maple trees traditionally used in the maple syrup industry results in relatively low productivity per unit land area. In the plantation method, maple saplings are planted uniformly, spaced 30 to 100 cm apart [13]. A plantation will have up to 12,000 saplings per hectare, over 40 times

greater than a stand of mature maple trees, which usually averages 250 trees per hectare (from Perkins and van den Berg, unpublished). Saplings are shown to produce 7.6-19 litres of sap or 0.07-0.26 litres of syrup per tap [12], while mature trees average 1.5-1.9 litres of syrup per tap [13]. Although each sapling generally has a lower individual sap yield than that of a mature maple tree, the vastly higher density of saplings in a plantation allows for a higher sap yield on a per-area basis than is possible with a stand of mature trees.

The production level of saplings in a plantation system could be up to 3,000 L/ha, compared to conventional plantation systems of mature maple trees producing around 400 L/ha (from Perkins and van den Berg, unpublished). The plantation method allows a much smaller and more efficient land usage that requires much less tubing and infrastructure to install, manage, and maintain. This can substantially reduce the cost of supplies, labour, and time required to produce a given unit of maple syrup. Furthermore, the plantation method allows for a much greater control over the genetic composition and phenotypic traits of crop trees, leaving room for increased profitability and efficiency within the maple syrup industry [13].

3 Maple Syrup in New Zealand

3.1 Economics of Syrup

The World's maple syrup industry is dominated in a very concentrated geographical location. Canada produces 71% of world's pure maple syrup and 91% of that originates from Quebec alone [15]. Canada's maple syrup industry is concentrated in Ontario, Quebec, and New Brunswick, mirroring the maple belt south of the Canadian border are the US states of New York, Vermont, New Hampshire, and Maine [15]. With almost identical climates, the Canadian and United States industries share the same pests, diseases, and environmental concerns. Developing maple syrup in New Zealand could allow the maple syrup industry more geographic diversity, and create a buffer for potential environmental disasters. A maple syrup industry in the Southern Hemisphere allows unique sugaring season and, in addition offer many benefits to New Zealand's economy, including growth of the country's exports.

New Zealand's primary industry is agriculture and horticulture, contributing to over 50% of the country's total export earnings and 6% of New Zealand's GDP [16]. New Zealand has a strong agricultural industry that can support the commercial production of maple syrup. Additionally, the maple syrup harvesting season takes place in late winter, a season completely different from the harvesting seasons of the rest of New Zealand's vineyard and fruit crops. This will extend the working season by allowing for earlier mobilization of the seasonal workforce that typically works on vineyards and other crops. However, the socio-economics effects of this require further investigation.

Two final-year, undergraduate, team-based process design projects investigated the farm-to-table economics of producing maple syrup in New Zealand [17, 18]. They found that the economics involved in establishing a plantation of maple saplings for maple syrup production in New Zealand are far more favourable at larger scales. A plantation of maple saplings in the South Island would be profitable on scales of ten hectares and larger, with onsite processing. It is important to minimize transportation costs, which can be accomplished with processing on-site. The tubing and sap collection devices were found to be the most costly aspect of the initial start-up of a maple sapling plantation. However, the cost of the land required and the storage of large amounts of sap proved a large investment. There is an extended payback period for this project, due to a minimum two-year latency between the planting of maple saplings and the first harvest. The payback period for investing in the start-up of a plantation of maple saplings and the required vacuum harvesting, processing, and packaging equipment was seven years for a ten-hectare plantation [18].

The process of converting maple sap into maple syrup requires an extremely large amount of energy. In many commercial maple syrup operations, the evaporation of sap took place using thermal evaporation in an evaporator fuelled by typically fuel oil or wood, an extremely energy intensive task. If syrup was concentrated purely by evaporation of maple sap it would take to 110MJ to convert 43 litres of maple sap, at 2% sugar, into one litre of maple syrup [1, 19].

To reduce energy usage, reverse osmosis systems are implemented in many present-day maple syrup industry to initially concentrate the sap prior to boiling. Reverse osmosis can only be used to remove up to 75% of the

water in maple sap, the remaining water is removed using evaporation [1]. In using a reverse osmosis unit, the entirety of the concentration process still takes up some 85% of the sap to syrup processing plant's total energy usage, with 80% of that being from the evaporation unit itself [18]. A large single-site plantation of maple saplings using vacuum extraction from de-topped maple saplings, reverse osmosis and wood pellets for evaporation was found to have the lowest overall operating cost and the most favourable economics in the South Island.

3.2   Promising Climate

Extensive literature on the factors known to affect the growth of maple trees was consulted and the climates and growing conditions that currently support mature maple trees in northeastern North America and New Zealand were heavily analysed. The main factors known to affect the growth and management of sugar bushes include temperature, soil properties, climate and light intensity [9, 20-23]. The freeze-thaw cycle is an essential part of the traditional maple sap collection process. Below-freezing winter temperatures must last long enough for the tree to begin the de-hardening process necessary for the beginning of sap production [24]. Freeze-thaw cycles, with a 0°C threshold, are necessary to induce sap flow for sugar maple [7, 8, 11, 13, 21]. Daniel Houle, however, showed that sap exudation could occur at temperatures around 3°C [23], indicating that fluctuations around temperature close to 0°C are sufficient for sap flow to occur.

The climates in northeastern North America and New Zealand are extremely similar in precipitation and warmth criteria however differ in winter temperatures. In northeastern North America, the winters are harsh with deep freezes and consistent overnight lows of approximately -10˚C. Most of New Zealand experiences overnight lows of approximately 2˚C with colder regions experiencing temperatures as low as -2˚C. The warmer temperatures seen in New Zealand indicate that a deep freeze is unattainable in most parts of New Zealand for mature sugar maple trees. Despite this claim, there are existing maple trees used in the traditional forestry method to successfully produce maple syrup in New Zealand.

A man named Dave DeGray has unknowingly become an extremely valuable resource to researchers interested in maple syrup production in New Zealand. In 1984, DeGray planted the first of 200 adolescent sugar maple trees, in a sheltered hollow on his 4-hectare property. His property is located in Nelson, the northern tip of the South Island of New Zealand, a region that historically has heavy rain followed by extended frosts. The maple trees in Nelson have grown at exceedingly high rates, reaching a tappable girth of 25cm within 20 years, almost double the growth rates documented in northeastern North America. DeGray's success in growing mature maple trees in Nelson is held as a standard for our analysis of successful locations in New Zealand to produce maple syrup.

3.3   Heat Transfer Model

It is both a possible and promising endeavour to establish a plantation of maple saplings in New Zealand. The climate of New Zealand with the proposed de-topped sapling extraction method will allow high sap yields to be extracted from maple saplings without freezing temperatures that have been historically required for sap exudation. We provide a one-dimensional, radial, transient, heat transfer model showing the temperature within both maple saplings and mature maple trees. The model provides evidence that average New Zealand winter temperatures can successfully freeze sap within maple saplings.

Smaller diameters of the sugar maple saplings allow for much quicker heat transfer effects through the sapling trunk when compared to mature maple trees. A sapling will cool, freezing the sap within the trunk in a shorter time than a mature maple tree due to the shorter conduction path length, heat must travel from the outside diameter of the trunk to the centre [12]. A heat transfer behaviour model was created to determine the maximum ambient temperature that will still sufficiently freeze the sap within a sapling trunk. Both convection at the surface of the tree and conduction within the tree, are responsible for cooling of a tree, which is driven by cold overnight ambient temperatures. Conduction heat transfer originates from the surface of the tree and extends radially towards the centre. Additionally heat from the soil extends axially up the trunk of the tree however, for the simplicity of this model, it was assumed that heat transfer in the axial direction would have a minimal effect on the sap freeze-thaw cycle and could be neglected. It was assumed in our model, that there was no internal heat generation inside the tree trunk, as well as a constant and isotropic thermal diffusivity, α. The transient radial heat transfer model through an infinite cylinder is given in equation 1,

$$\frac{1}{\alpha}\frac{\partial T}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right) \tag{1}$$

This model describes the temperature, $T(t,r)$, within the trunk of the maple tree as a function of time, t, and radial distance, r. Convection at the outer surface of the trunk is modelled with convective heat transfer coefficient, h, and thermal conductivity, k. Thermal properties of wood are dependent on many factors including density, moisture content, and structural irregularities. Living trees have higher moisture content and therefor higher thermal conductivity, density, and specific heat when compared to dry wood [25, 26]. The parameters used in the model can be found in Table 1, below. It should be noted that the parameters used are based on known properties of dry wood and are not specific to living maple trees. Further research should be conducted to analyse the thermal properties of living maple trees however. To roughly estimate the thermal properties, for the purpose of this research, the highest values within the range given in Janna, 2009 [27] were used for the density, thermal conductivity and heat capacity of wood to establish a value for the thermal diffusivity, where $\alpha = \frac{k}{\rho c_p}$.

The initial condition is given by equation (2) and boundary conditions are given by equations (3), showing symmetry at the centre $r = 0$, and equation (4), matching the convective and conductive heat fluxes at the outer surface, $r = R$, of the maple tree trunk of radius, R.

$$T(0,r) = T_0 \tag{2}$$

$$\frac{\partial T(t,0)}{\partial r} = 0 \tag{3}$$

$$k\frac{\partial T(t,R)}{\partial r} = h\left(T_\infty - T(t,R)\right) \tag{4}$$

Table 1: Model Parameters [27].

Parameter Description	Symbol	Value	Units
Thermal diffusivity	α	9.91×10^{-08}	m^2/s
Thermal conductivity	k	0.19	W/(m*K)
Convective heat transfer coefficient	h	6.00	W/(m²*K)
Radius of sapling	R	0.05	m
Radius of mature tree	R	0.13	m
Initial temperature	T_∞	-1.59	ºC
Initial temperature	T_0	12.0	ºC

Along with the assumptions stated earlier, the unsteady state conduction model assumes that the ambient temperature is constant and that the change from the daily maximum and daily minimum temperature is instant at time t=0. The initial ambient temperature was set at 12 ˚C and the daily minimum temperature was set at -1.59 ˚C. The temperatures chosen represent the average high and average low temperatures, respectively, for a temperatures recorded from a weather station in Hanmer Springs, New Zealand. A period of six hours was chosen as a representation of the night time cooling period before the temperatures start to rise again at dawn. It is important to note that sap inside the tree trunk was considered frozen if the temperature at the centre of the tree was at or below 0˚C. The phase change of water was not accounted for in the calculations of the heat transfer model. In this report, saplings are defined as 6-10 year old trees with a chest-height trunk diameter of approximately 0.10 m whereas mature trees, are more than ten years old with a minimum chest-height trunk diameter of at least 0.26 m. The heat transfer equation was solved using the numerical method of lines, whereby finite difference approximations are used for the spatial derivatives over 51 nodes in the radial direction. The

resulting system of 51 ordinary differential equations (ODEs) was integrated in time using Matlab's stiff ODE solver, `ode15s`. In applying the unsteady state conduction model, the stated assumptions, and the imposed boundary conditions, the inner trunk temperatures were determined over a period of six hours, for maple saplings as well as mature maple trees, as shown in Figure 4 below.

As seen in Figure 4c, the center of a maple sapling reached freezing temperatures of 0°C in 3.5 hours where the mature tree took 22.5 hours to reach a temperature of 0°C. The heat transfer model showed the centre of the maple tree only cooled to 8.95 °C after the six hour time period modelled. The temperature at the sapling centre after six hours was -1.38 °C. At winter temperatures average to Hanmer Springs, NZ the sap at the centre of a mature maple tree will not freeze, however the model confirmed that less extreme overnight low temperatures could successfully freeze the sap within a maple sapling. This finding validates the assumption that winter temperatures common to New Zealand can produce a freeze-thaw cycle within in maple saplings, allowing for successful sap exudation.
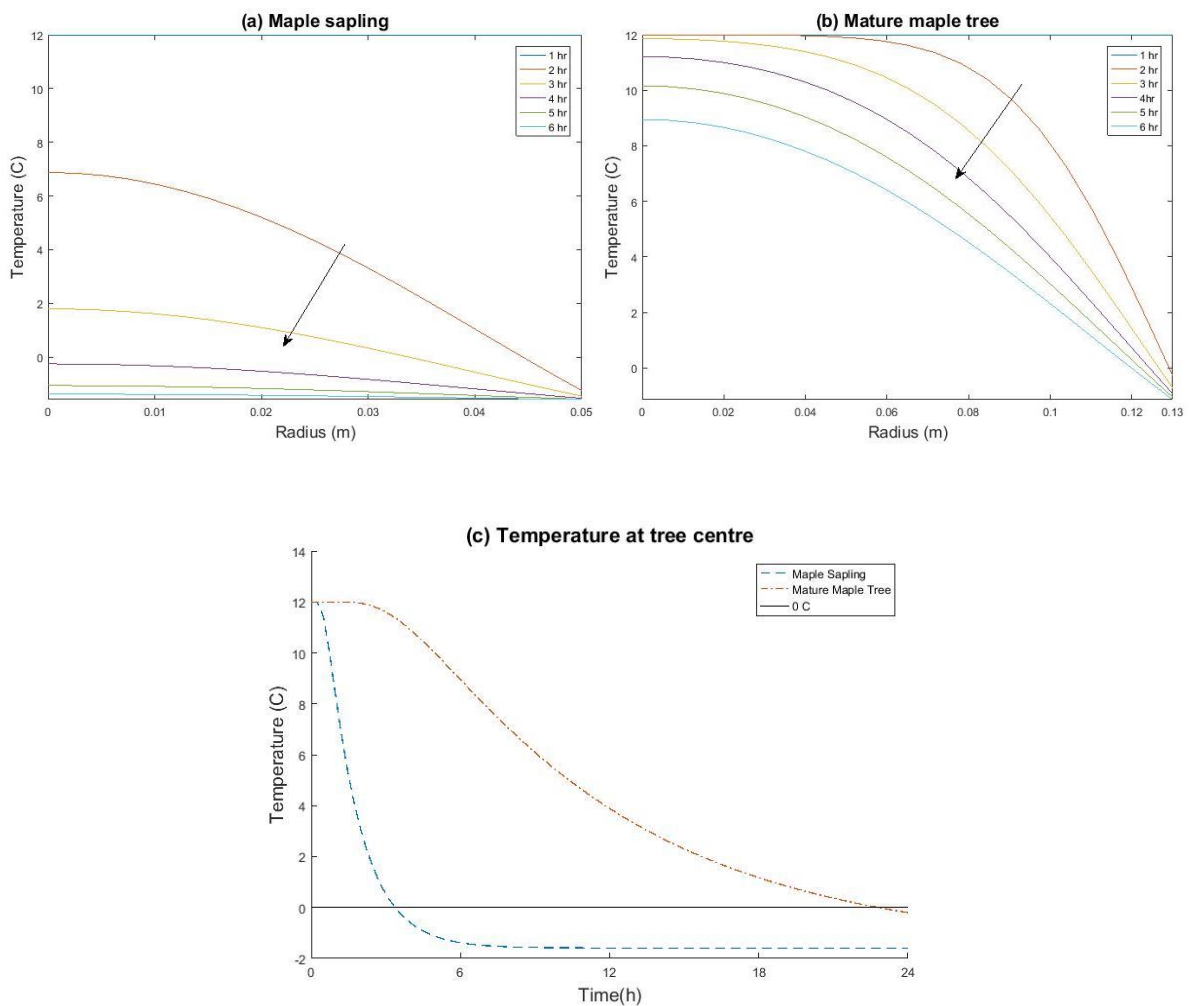

Figure 4. Temperature profiles of (a) a maple tree, radius of 0.13m, and (b) a maple sapling, radius of 0.05m. The arrow represents increasing time over a period of six hours. (c) The temperatures at mature tree and sapling center over the course of 24 hrs.

## 3.4   Identifying Locations for Maple Syrup Production in New Zealand

A figure of merit analysis was used to assess locations for the commercial production of maple syrup from a plantation of maple saplings. This system ranked the various factors that were deemed valuable for the successful

growth of maple saplings gathered from literature and existing maple syrup industries. An underlying assumption of the analysis conducted was that good maple tree growth corresponds to a high maple sap yield. The figure of merit analysis was based on seven main environmental factors; minimum and maximum daily temperatures, annual rainfall, sunshine hours, soil moisture, soil temperatures, and soil type. New Zealand would have a different sugaring season than that of the Northern Hemisphere; it was assumed that maple sap collection would take place from June to August in New Zealand.

For each factor, a scale of zero to four was chosen to rank the factor's performance, zero being the lowest score a location could receive and four being the highest. This was the first attempt to combine many literature based factors in to a single number. It was assumed that each of the seven factors analysed had an equal weight, meaning one factor was not held as more important than the next. With no additional information, this is a valid assumption. The figure of merit analysis was to act as a starting point to evaluate which regions in particular that look promising for the production of maple syrup from a plantation of maple saplings in New Zealand. The particular regions identified require a further detailed investigation.

The total figure of merit score for each location was calculated by summing the figure of merit scores (0-4) of each of the seven environmental factors for each location. With a total of seven environmental factors, each with a maximum value of four, the highest figure of merit score possible in each location is 28. The scale was arbitrarily chosen from the level of interpolation that could be chosen on the Esri ArcGIS Software that was used to map the collected data. The figure of merit scores were overlaid on maps of New Zealand, the South Island map is shown in Figure 5.
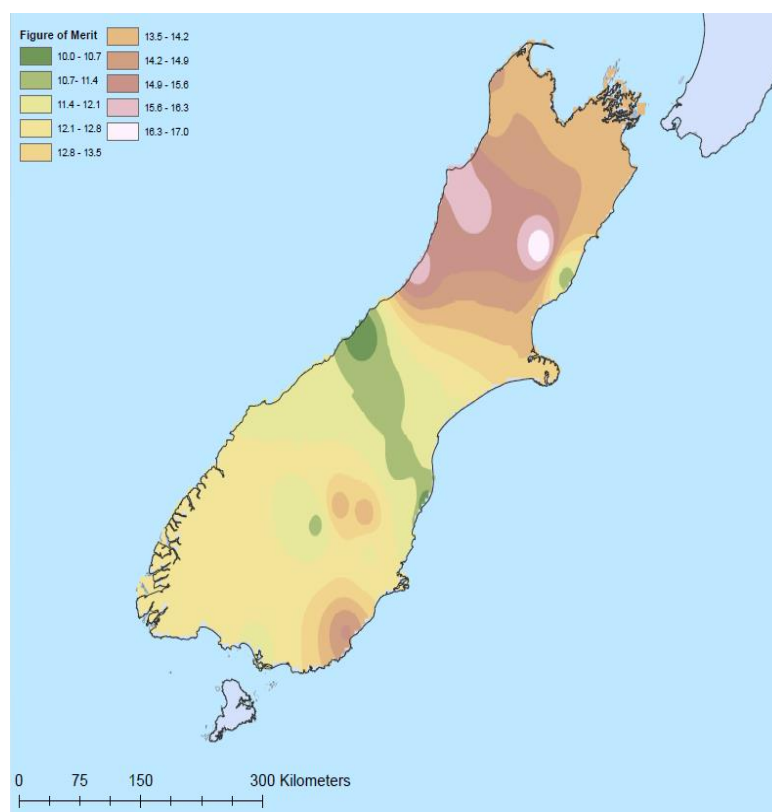
Figure 5. Map of the South Island of New Zealand showing potential plantation sites for sugar maple saplings. Figure of Merit ranking system based on numerous abiotic factors was overlaid using ArcGIS software with higher numbers corresponding to ideal locations. This picture is used with permission from Dane Gandela [28].

The best location for sugar maple sapling plantation, i.e. the locations that displayed identical characteristics to the northeastern North American growing conditions, would have a total figure of merit close to 28. Dave DeGray's site of mature maple trees in New Zealand was ranked on our scale of merit at approximately a 13.5 and has been successfully growing mature maple trees at accelerated rates. A figure of merit score of 14 and above was therefore decided to be the figure of merit standard for a good plantation site. The figure of merit

analysis identified 17 unique locations across New Zealand, with a merit score above 14, that were suitable candidates for a sugar maple sapling plantation.

4   Conclusions and Recommendations

Establishing a plantation of maple saplings for the production of maple syrup was determined to be an economically feasible project that could offer benefits to the New Zealand economy. Plantations of maple saplings in New Zealand, could additionally benefit the global maple syrup industry, offering both agricultural and economic stability as well as a unique climate and sugaring season. Using a dense plantation of maple saplings, a unique sap collection device, and vacuum extraction technology, the production of maple syrup will use less land, less energy, and can be expanded to a broader range of climates.   However, the economic success is highly sensitive to the latency period between planting the trees and the first harvest, and the costs associated with tubing and fittings for vacuum extraction.

New Zealand does not have temperatures that remain cold enough to establish a freeze-thaw cycle in mature maple trees, according to extensive literature and existing syrup industries in northeastern North America. However, the heat transfer analysis in this paper suggests that this is not the case for smaller maple saplings. Moreover, there exists a successful farm of mature maple trees in Nelson, New Zealand and as discussed earlier. The use of maple saplings combined with the vacuum collection method invented by Perkins and van den Berg could replace the need for a deep freeze-thaw cycle in maple saplings allowing the maple syrup to be produced in climates such as New Zealand.

A heat transfer analysis numerically modelled using a cylindrical, one-dimensional, transient conduction model of a maple sapling. Calculations using winter temperatures recorded from a weather station in Hanmer Springs, New Zealand resulted in a maximum overnight ambient temperature required for sap within a sapling to freeze to be 0°C. The interpolation by ArcGIS software used to analyse the temperatures of New Zealand determined that these temperatures were extremely likely to occur during the winter months in large regions of the South Island. Refinements to the numerical model are required to incorporate the different thermal properties of sapwood and heartwood, actual diurnal temperature cycles, and the thermal interaction between the root-ball and ground surrounding each tree.

Extensive data on each of the seven identified abiotic factors shown to have an effect on maple tree growth was collected and interpolated from various weather stations across both islands of New Zealand. Our analysis identified 17 locations throughout New Zealand that we conclude with confidence are sufficient to grow a plantation of maple saplings for the commercial production of maple syrup. More research is needed to understand how the factors affecting the growth of maple trees translates into factors affecting sap yield.

It is important to note that for this research project, each environmental factor had an equal weighting: minimum and maximum daily temperatures; annual rainfall; sunshine hours; soil moisture; soil temperatures; and soil type. An equal weighing of factors means that no factor was held more important than the next in the context of maple sapling growth and sap exudation. It is not known if equal weighing of the chosen environmental factors is the most valid case for the model, and further research is required to understand the correct weightings. For example, the minimum daily temperature might not as important of a factor when the vacuum-collection is implemented compared to the traditional maple syrup tapping practices. Similarly, the soil moisture may hold more importance with the vacuum-collection method as the maple sap yield was found to surpass the expected collection yield. Further analysis of tree growth data, sap yields, biotic, and abiotic data from northeastern North America could include developing a model that can predict tree growth, and more importantly sap yield under New Zealand conditions. Additionally, there is not an existing plantation of maple saplings. To date, the research conducted has been on individual, pre-existing small-diameter trees, and experiments are required in which trees have been planted expressly in a plantation for this type of sap collection and subsequently used for harvest. There are many aspects of methods described in this paper that need further investigation before a system of this type should be implemented.

Acknowledgements

5.   References

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