EFFECT OF SPACING MANAGEMENT ON GROWTH
AND COMMERCIAL LOGGING OF RED PINE

by

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ABSTRACT

To maximize utilization of the forest resource, spacing management always plays an important role in tree planting. It will influence tree height, diameter, mortality, self-pruning, and most importantly, early growth rate of red pine (*Pinus resinosa Ait.*) which will affect its logging time. Although the general nature of the effects of various spacings is fairly well understood, the magnitude of those effects is not. For example, if the spacing is too wide, reduced self-pruning will result in more and larger knots. Branch pruning may be required as a result and thus increase the commercial cost. However, proper spacing providing maximum growing space and directly affect the early growth rate of red pine, and thus benefit commercial logging. The purpose of this thesis is to use the data collected by the OMNR and USDA to determine the effects that spacing has on the growth and stand yield of red pine at varied spacing distances. We conclude that the abundant spacing provides trees with enough resources to survive and create crown closure.

Key Words: spacing management, logging, pruning, stand yield, crown closure, afforestation density, net present value

CONTENTS

1.0 INTRODUCTION

In most natural stands, red pine (*Pinus resinosa*) reproduces abundantly and dense sapling stands develop at an age of 15 or 20 years. It can contain as many as 5000 trees per acre and in extreme cases up to 20,000 (Eyre,1948). The stand density can directly affect the height, diameter, mortality, self-pruning, and most importantly, early growth rate of red pine, which will affect its logging time (Homagain K, Shahi C, 2011). In general, lower stand density means more growing space, which will produce more wood over time. Since lower stand density forest means the trees have a better utilization of existing resources (e.g., light, water, and nutrition), more trees per unit area will produce more wood in a shorter period. However, greater spacing leads to more and larger branches, so trees produce less lumber (Zhu, J. Y., C.T Scoot, 2007). Therefore, the optimum spacing for planting red pine has been a topic of debate among forest workers for many years. The Thunder Bay spacing trial was established in 1951 by the Department of Lands and Forests, now the Ontario Ministry of Natural Resources (OMNR), on the property of the present Northwest Region Natural Resource Centre. They began an experiment in 1963 to explore the effects of spacing on red pine.

In the experiment, they have two 10x10 m plots of red pine at 1.8 m spacing, two at 2.7 m, and two at 3.6 m. Recording the height and diameter of the trees in each plot and taking several photos so that they can calculate something that tells something about how the trees are developing such as stem taper and volume. Since red pine (*Pinus resinosa Ait.*) is used mainly for poles and saw timber. Large diameters are required with few knots preferred. Finding a space distance that can meet enough large diameters of red pines and can also produce sufficient amounts of lumber is very important.

The U.S. Department of Agriculture (USDA) provides 31 experiments and sets of monitoring plots in both planted and natural forests available for analysis. These contain 3,671 individual growth estimates. (Buckman et al. 2006)

In this study, we selected the red pine forest in the west of Thunder Bay as the study plot, and conducted an in-depth analysis on the influence of red pine planting density on the quality and yield of red pine, aiming to provide for the artificial cultivation of red pine in Thunder Bay and even Canada.

1.1 Objective:

The objective of this thesis is to use the data collected by the OMNR and USDA to determine the effects that spacing has on the growth and stand yield of red pine at varied spacing distances. There are several criteria for determining the optimal planting distance. In this thesis when trees are planted at the best planting distance, they will have great tree diameter, height, crown closure, and proper mortality. Getting stem taper and volume based on these data can tell us the yield and development of red pine. Besides raw data, this thesis will provide more advanced data that can better reflect the growth of red pine with this basic information to help readers understand the topic of this thesis more clearly. This thesis will focus mostly on the growth of red pine and whether the yield of the stand is sustainable in the future.

1.2 Hypothesis:

The amount of growth space initially allocated to each red pine greatly influences the required stand management intensity and the final cost of timber. More spacing makes trees grow thicker, and 550 plants/hm^{-2} of planting density will be the most suitable one for red pine since red pine doesn't grow any taller but thicker in times of abundant resources. An increase in the diameter of the tree has less impact on the yield than a decrease in the number of trees. If any other space distance appears to be more favorable for the growth of red pine and the stand yield is sustainable at the same time, the hypothesis will be held to be incorrect.

2.0 LITERATURE REVIEW

2.1 Factors Affecting the Yield and Quality of *Pinus resinosa*

2.1.1 Site selection

The redistribution of ecological factors by topographical factors will largely affect the yield and quality of *Pinus resinosa*. Analyze the growth status of *Pinus resinosa* plantation from the slope, aspect, and position, we can find that the growth of *Pinus resinosa* standing underground at a lower altitude and a smaller slope is better than that on a sunny slope. Planting *Pinus resinosa* on shady slopes and downhills is beneficial to the growth of *Pinus resinosa* trees. The downslope position has sufficient water, thick soil, and sufficient soil nutrients. The shady slope is less exposed to sunlight and has sufficient water, which is beneficial to *Pinus resinosa* growth. The research of Martin Jeff *et al*. believes that terrain factors such as altitude, aspect, and slope have varying degrees of influence on the growth of artificial *Pinus resinosa* (Martin 1996). It is better to plant *Pinus resinosa* on a half-shadow and half-sun slope than on a sunny slope.

Buckman conducted multiple linear regression of site factors of *Pinus resinosa* plantations and showed that the slope type is the main factor affecting the growth of *Pinus resinosa* (Buckman, 2019). The relationship between soil factors and the growth of *Pinus resinosa* refers to the effect of soil physical and chemical properties on the growth of *Pinus resinosa* under the same climatic conditions. In recent years, there have been more and more studies on the growth of red pine by soil. In the forestation of red pine from the 1960s, red pine showed a trend that they grew well in thick soil areas. The higher growth of *Pinus resinosa* mainly depends on the larger thickness of the "A" layer of soil. The greater the thickness, the greater the growth of the *Pinus resinosa* tree. Larson et al. figured out that soil type, humus layer thickness, and soil dry moisture also play a leading role in the growth of *Pinus resinosa* (Larson 1998). W.C. Bramble et al. believe that the soil type and the thickness of the black soil layer also influence on the growth of forest trees.

In addition, the content of various nutrient elements in the soil also has a certain relationship with the growth of *Pinus resinosa*. The content of total nitrogen and available phosphorus in the soil promotes the high growth of *Pinus resinosa* trees. The higher the content, the greater the growth (Eyre, F.H, 1947). The phosphorus content in the soil significantly affects the height growth of *Pinus resinosa*; The content of cobalt, magnesium, nickel, and manganese is negatively correlated; the content of lead, potassium, copper, zinc, and silver has no obvious effect on high growth. Different tree species have different effects on growth in the same environment, and their effects are different, which may show the opposite relationship (Northwest Region Natural Resource Centre Thunder Bay Spacing Trial Draft Brochure, 2001). *Pinus resinosa* is a shallow-rooted tree species. The root system is usually distributed horizontally and is prone to wind-throw. It is suitable for planting in thick soil areas and well-drained areas (Larocque, 1994). The growth of *Pinus resinosa* forests with bare, morning sun, rushing wind, and steep slopes is the worst. This is because *Pinus resinosa* is prone to physiological drought in early spring, it affects survival and growth.

2.1.2 Afforestation density

Changing the space for competition between trees for sunlight and nutrients may bring about different afforestation densities that have diverse effects on the growth rate of trees and the quality of wood. Generally speaking, density has a great influence on the development of the tree crown, and the structure of the tree crown is composed of branches and leaves at various levels (Lacrocque, 1995). Therefore, forest stands of different densities have disparate effects on the extension and diameter growth of individual side branches of the forest. For example, if the density is too sparse, there are branches throughout the entire length of the stem, and the lower side branches are more developed since the better light conditions, the wood' sharpness will increase, and the material quality of larger knots and young wood will decrease (Dean 1996). During the forest with a high density of forest stands, the individual shades each other, the effective branches of the trees are only locating on the top of the main stem, the growth period of the stem at the top is longer than the base, and the side branches are poor since light (Larocuqe, 1993). Though the trunk shape is better, it will affect the yield of wood.

2.1.3 Thinning time and intensity

Since changes in the development and growth rate of the canopy, thinning may have an adverse effect on some wood materials. However, the time of thinning can limit this impact to a minimum (Newton, 1997). Early thinning of a stand will increase the range of juvenile timber, cause the juvenile period to be prolonged, the width of annual rings increases, and the transition layer is wider. As a result, the proportion of young wood is increased, the wood must be low density, short fiber, high ratio of lignin, shrink when drying, and reduce the mechanical strength (McClain, K.M., et al.). Delaying thinning until the end of the juvenile period can avoid these problems . Regardless of whether the tree is in the young stage, thinning can reduce the upward trend of the crown, promote the growth of branches, and the development of new branches; as a result, the tree nodes increase, and the sharpness of the trunk increases.

With the increase of thinning intensity, the living space of the canopy is improved, the competition of water and nutrients in the root-soil eased, the sidelight of the trunk becomes more sufficient, and the vitality of the cambium is greatly enhanced. Lemmien et al. (1950) conducted a study on the influence of different thinning intensities on the properties of wood. They selected 16 different thinning intensities, and randomly selected 20 stalks from each forest stand to drill at the breast height, and conduct annual ring width. Timber rate and sapwood analysis, the results show that compared with light thinning and unthinned trees, there are big differences in growth and material quality. The thickness of the sapwood is 31.8 mm and 24.2 mm, respectively, and the proportion of the crown were 40.3% and 35.8%, and their breast diameters were 36.0cm and 28.2cm, respectively.

2.2 Effect of spacing management on the yield and quality of red pine

Density control measures in the process of artificial cultivation of red pine are essential, especially for the later growth process of wood, the stand density should be the lowest. A large number of studies have shown that reasonable spacing management of red pine during the growth process is an important means to improve its output and quality.

2.2.1 Effects of spacing management on growth of red pine

The initial planting density changed the competition relationship in the early stage of seedlings. Most studies showed that the lower the initial planting density was beneficial to the growth of DBH, but had little effect on the growth of height. The effect of different initial planting density on the growth of *Eucalyptus urophylla* in Guangxi showed that the smaller the initial planting density was, the higher the growth rate was and the larger the proportion of large and medium diameter timber is. The higher the initial planting density of *Eucalyptus robusta* Smith plantation is generally controlled at 800-1200 plants.hm^{-2}, which can ensure that a certain individual tree can be obtained during tending and thinning, and has a certain economic source. It is considered that low density is conducive to the growth of DBH. Different planting densities have different effects on *Cunninghamia lanceolata* (Lamb.) Hook.) and Eucalyptus have a very significant impact on DBH growth. The higher the density is, the smaller the average DBH is. However, too low afforestation density will lead to vigorous reproductive growth of trees, thus affecting the vegetative growth, which is not conducive to the cultivation of large diameter timber of *Pinus elliottii*. The initial planting of large diameter timber of *Pinus elliottii* is generally 1100-1600 trees/hm^{-2}, The final density was 1000-1200 plants/hm^{-2}. The initial planting density of larch was 2500-3300 plants/hm^{-2}, and the final density was 525-600 plants/hm^{-2}. The initial planting density of *Pinus massoniana* Lamb. was 1800-2400 plants/hm^{-2}. Finally, 450-650 trees/hm^{-2} are reserved. For the cultivation of large diameter timber of Chinese fir, the site index is generally used to determine the reservation density, thinning time and thinning intensity, which has stronger guiding significance for practice.

2.2.2 The impact of spacing management on the quality of North American red pine

The quality of stem shape is an important issue in forest cultivation. The quality of stem shape directly affects the quality and yield of wood. The poorer shape of the stem means lower economic value. Many scholars consider the height of branches, crown length and height diameters, which is used as the main indicator for evaluating dry shape. The crown length ratio represents the length of the unknotted timber. The existence of dead knots directly affects the quality of the wood. The height-to-diameter ratio represents the straightness and completeness of the trunk, which directly affects the economic value of the wood. The cultivation of plantations is regulated by pruning and density control. Many research results show that the under-branch and height-to-diameter ratio of forest trees increase with the increase of density, while the crown length rate has the opposite law, which is negatively correlated with density (Tian et al., 2021). Research on the stem shape of cork oak (*Quercus variabilis Bl.*) showed that high density is conducive to cultivating good stem shapes on sunny slopes, while shady slopes are suitable for high-density cultivation to cultivate good stem shapes; the research on the wood properties shows that the initial planting density has an effect on the mechanical properties of the wood. And traits such as shrinkage characteristics have a significant impact. Smaller initial planting density can improve the internal density variation of wood, increase the uniformity of mature wood, and improve wood quality. Therefore, controlling the initial planting density can meet the requirements of large-diameter timber for growth, tree shape and mechanical properties.

2.2.3 The effect of spacing management on the crown structure of red pine

The canopy is the main place for photosynthesis of forest trees. It plays an important role in the nutrient cycle and nutrient distribution of the whole tree. The size of the canopy is an important indicator of tree growth vitality and productivity, and it also reflects the intensity of competition for forest land. The crown width is used to evaluate the utilization rate of the forest tree crown in the horizontal direction, the vertical direction is expressed by the crown length rate, and the three-dimensional space utilization rate is described by the crown surface area and the crown volume. The greater the density, the greater the crown competition, which seriously affects the growth of trees.

Thinning is the main measure to adjust the competition between forest trees, so as to increase the growth space of reserved trees, and the competition of underground roots will also decrease. The growth space index and the growth space competition index are the main indicators reflecting the intensity of forest competition.

Growth space index is the occupancy or utilization of nutrient space per unit diameter, and reflects the volume of the crown required for each 1cm diameter at breast height to grow and maintain normal vitality.

Growth space competition index is the occupancy rate of the nutrient surface area per unit of breast height or the direct utilization of light. It reflects the crown surface area required for every increase of 1cm2 in the breast height cross-sectional area and to maintain normal life.

The growth space index excludes the influence of diameter at breast height on the volume of the canopy. The larger the value, the better the growth of the tree. The growth space competition index uses the breast height cross-sectional area as a parameter to eliminate the influence of the diameter at breast height on the crown surface area. The relationship between crown width and breast diameter is well known, but relatively few studies have been done. The possible applications and uses of the crown-to-diameter ratio, including the impact on plant spacing decisions, base area per hectare, any given average diameter at breast height, can give a prediction of the ideal stocking level and the degree of thinning. In addition, this index can be used to support decisions on appropriate spacing in mixed tree species stands, management of the upper layer of the shelterbelt system, genetic selection in breeding programs, and prediction of the number of branches used as fuelwood. Newton,. *et al*. (date) studied the crown-to-diameter ratio of 11 common broad-leaved plants in the UK and found that the relationship is very close to linear: between 20-50cm diameter at breast height, and r^2 is greater than 0.8 (Newton, P.F.,1997). The crown-to-diameter ratios of all species were relatively high when they were young, but with the increase of DBH, the crown-to-diameter ratio decreased and began to stabilize at about 30cm. Among the surveyed species, walnut (Juglans spp.) has the highest proportion when young, but other species that require a lot of light, such as birches (Betula spp.) have a very low proportion. There is no strong evidence that the crown-to-diameter ratio can be used to predict species tolerance. For more shade-tolerant species, the crown-to-diameter ratio is higher studied the relationship between diameter at breast height and crown width of Betula platyphylla and found that the crown diameter ratio of Betula platyphylla was larger when it was young, about 71. As the age increases, the ratio of crown diameter gradually decreases. When the diameter at breast height reaches After 45cm, the crown-to-diameter ratio remained at 19.1-22.6.

2.3 Enlightenment of artificial cultivation and management of Red pine

2.3.1 Choose suitable growth environment

According to the investigation and analysis of Red pine growth environment, we found that Red pine should be planted on shady slope or semi shady and semi sunny slope with smaller slope, thicker soil layer, fertile soil and good permeability. In order to prevent the occurrence of physiological drought, Red pine planting should avoid the wind.

2.3.2 Reasonable space management

In the actual planting process of Red pine, the spacing of Red pine should be adjusted reasonably according to the local climate conditions and the growth state of Red pine. For example, in places with abundant rainfall, tree spacing should be appropriately increased, which can promote the increase of wood density. In addition, in the late growth period of Red pine, tree spacing should be increased to ensure the quality and yield of wood. However, the greater the distance, the better. Some studies have shown that too large spacing of trees will also affect the quality of wood.

2.3.3 Timely pruning

Regular pruning can improve the quality of Red pine. Pruning can improve the degree of success of the main tree trunk and control the occurrence of dead section by removing the branches with weak growth and dying under the trees, and then cultivate the non-conforming and good materials with good dry shape. Pruning can also improve the environment and health of the stand, and also has a positive effect on the prevention and control of forest diseases and insect pests and the stability of the stand.

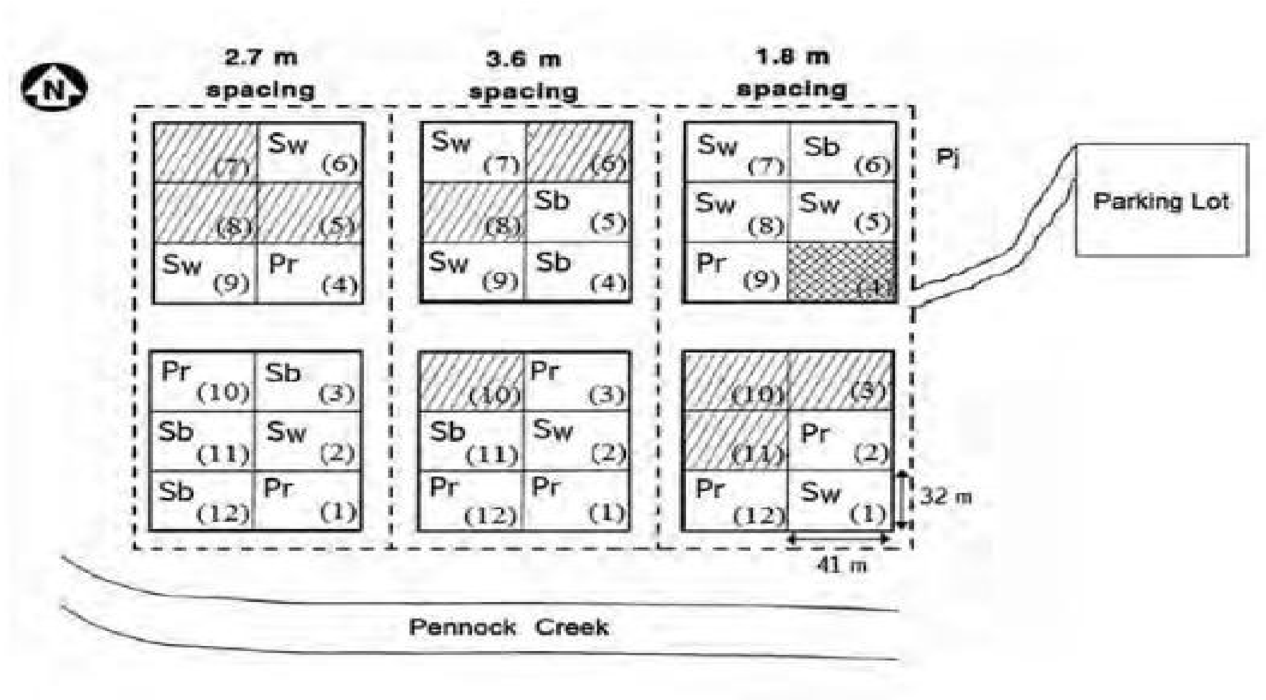
3.0 MATERIALS AND METHODS

In order to explore the effect of spacing management on the growth and quality of red pine, five artificial planting plots with different planting densities were set up. Firstly, the growth indexes of DBH and tree height of red pine under different planting densities were measured to determine the influence of planting density on the growth of red pine. At the same time, we also measured and calculated the height under branch, the ratio of height to diameter and the ratio of crown length, in order to get the effect of planting density on the quality of Korean pine. Considering the growth and quality of red pine, the optimal planting density of red pine was determined to verify the hypothesis.

3.1 Study Area Setting

The Thunder Bay Spacing Trial is located on the western edge of Thunder Bay, 48°32′N latitude and 89°23′W longitude (Homagain *et al*. 2011). The sample plot is located on a shady slope, with a slope of 0-30 degrees, a large soil layer, fertile soil, and good permeability. According to the hypothesis that the optimal planting density of red pine is 500 plants / hm^{-2}, we set density gradients around 500 plants / hm^{-2} to verify the hypothesis (see Table 1).

Figure 1.0. Locations of the study plots in the Thunder Bay Spacing Trial. (Adapted from McClain et al. 1994) Where, Pr = red pine; Sw = white spruce; Sb = black spruce; and Pj = jack pine bordering the Spacing Trial. The cross-hatched areas were originally planted with Pw = white pine, and the



double cross-hatched area was a failed Sb plot replanted with Pr in 1956 (not included in the analysis). Numbers in the parentheses are plot numbers

3.2 Index detection

For each site, 100 samples were randomly selected, and their diameter at breast height, tree height, height under branches, and crown length were measured. Each sample test was repeated three times.

3.2.1 Growth index detection

In each plot, 100 samples were randomly selected to measure their DBH and tree height. Each sample was tested three times.

3.2.2 Quality index detection

In each plot, 100 samples were randomly selected to measure the branch height and crown length. Each sample was tested three times.

3.3 Data analysis

After obtaining the survey data, input the data into excel in the computer to check the abnormal data with plus or minus three times the standard deviation. Calculate basic single tree and stand information, including average diameter at breast height (cm) and average height (m) 、Height to diameter ratio, crown length rate and other indexes. The formula for calculating the ratio of height to diameter: ratio of height to diameter = tree height/diameter at breast height. Crown length rate calculation formula: Crown length rate = crown length/tree height. Crown length is tree height-branch height (Ishii et al., 2000) .

4.0 RESULTS

4.1 Effect of planting spacing on tree diameter at breast height

The results of variance analysis of the influence of different densities on the average DBH of Red pine (Table 1.0) show that the influence of planting density on DBH of Red pine is reduced with the increase of density, which is a standard negative correlation.

Table 1.0 Analysis on the Differences of Basic Growth Control Indexes of Red pine Stands with Different Density for 20 Years

Stand density/hm-2	Mean breast diameter/cm	Average tree height/m	High under branches/m	Height-diameter ratio	Height-diameter ratio
320	13.07±0.35a	5.97±0.15a	0.58±0.03b	0.48±0.00c	0.90±0.01a
370	12.99±0.35a	6.20±0.06a	0.59±0.03b	0.51±0.01b	0.90±0.01a
470	12.83±0.19a	6.47±0.12a	0.59±0.02b	0.52±0.01b	0.91±0.01a
550	12.79±0.19a	6.10±0.06a	0.59±0.02b	0.52±0.01b	0.90±0.00a

1050	12.27±1.20b	6.60±0.31a	1.21±0.06 a	0.55±0.00a	0.82±0.01b

4.2 Effect of density on tree height growth

According to the data in Table 1, there is no obvious linear correlation between planting density and tree height of Red pine.

4.3 Effect of density on tree quality

The crown length rate is also one of the important indicators reflecting the quality of forest trees. A smaller crown length rate indicates that the dry wood without joints is longer and has higher economic value. The larger the crown length rate indicates that the dry wood without joints is shorter and the economic value is lower. It can be seen from Table 1 that the effect of stand density on the artificial canopy length rate of Red pine is not obvious. Only when the planting density changed from 550 plants.hm-2 to 1050 plants.hm-2, the crown length rate dropped significantly.

The height-diameter ratio is also one of the important indicators reflecting the quality of the forest, which can reflect the level of tree trunk fullness. The smaller the tree height-diameter ratio indicates the greater the sharpness of the dry timber, the larger the height-diameter ratio indicates the smaller the sharpness of the dry timber. The more complete the dry wood. By comparing the height-diameter ratio of Red pine plantations with different densities, it is found that the density is positively correlated with the height-diameter ratio, that is, as the planting density increases, the height-diameter ratio will increase.

According to the changing trend of crown length rate and height to diameter ratio, we concluded that when the planting density reaches a certain level (1050 plants/hm^{-2}), it will have a greater impact on the quality of wood. Therefore, we suggest that the planting density of Red pine should be around 550 trees/hm^{-2}, which can maintain the yield and quality of red pine.

5.0 DISCUSSION

In this part, we will discuss the growth of the trees shown in each data. Whether they have a positive impact on the economic value of the trees and whether they are conducive to the sustainable development of the stand.

Firstly, we discussed the growth and quality of red pine under different spacing management. Through the detection of growth index and quality index, the relationship between planting density and growth and quality of red pine plantation was studied. We got the following results: (1) with the increase of planting density, the DBH of Korean pine decreased, showing a significant negative correlation. (2) There was no significant correlation between height and planting density of Korean pine. (3) High planting density will lead to a significant decrease in crown length rate of red pine. (4) The planting density of red pine was positively correlated with the ratio of height to diameter. In conclusion, the planting density of red pine will have a certain impact on the yield and quality of red pine, especially when the density rises sharply. We believe that the previous hypothesis is true, that is, the planting density of red pine should be about 550 plants/hm^{-2}, which can not only maintain the yield but also ensure the quality of red pine.

Secondly, we discuss the economic benefits of reasonable spacing management. Reasonable spacing management is an important means to ensure the yield and quality of wood. Pereira et al pointed out in the research that the planting density of wood is directly related to the yield and quality of wood(Pereira et al., 2012). Too low planting density will lead to low wood yield and poor economic benefits. High planting density will affect the growth of wood, resulting in low wood yield and poor economic benefits.

Therefore, reasonable spacing management plays an important role in improving wood economic benefits. red pine is one of the most scarce wood in the market. How to achieve the maximum yield in the limited planting area and produce good economic benefits is an urgent problem to be solved. Lu et al. studied the optimal planting density of Korean pine seedlings, and found that reasonable increase of planting density (1502 plants/hm^{-2}) at seedling stage can not only increase the yield of Korean pine, but also ensure the quality of Korean pine seedlings, and realize the maximization of economic benefits. Because the selected red pine is older, the optimal planting density is much smaller. We think that the planting density of 550 plants/hm^{-2} is the best density to cultivate adult red pine plantation, which can produce the greatest economic benefits.

Finally, we discussed the sustainable development of wood. The sustainable utilization of wood is a hot topic in current research. At present, plantation cultivation is changing from the previous extensive type to intensive cultivation. When cultivating Red pine plantation, the purpose of wood should be considered and oriented cultivation should be carried out. When directional cultivation of timber forests, the most suitable planting density can be determined according to the purpose, and the interval management of red pine of different ages can be carried out to control the time of thinning, while ensuring the quality of red pine, increasing its yield and increasing commercial value. For non-structural materials, such as pulp materials, particleboard and fiberboard materials, short rotations and fast growth are required, and higher initial planting densities can be adopted; for structural materials, such as building materials, electric poles, etc., the trunks are required to be straight and sharp. The taper is small and the structure is uniform. According to the species and purpose, the best forest density is adopted, the appropriate time is cut and reasonable pruning can not only promote the rapid growth of forest trees, but also improve the wood quality.

There are still some deficiencies in this study. The quality of wood varies with tree species, plant-to-plant and intra-plant location. At the same time, it is affected by factors such as tree age, genetics, environment and cultivation measures such as initial planting density, site conditions, thinning intensity and fertilization. And the interaction of these factors together has an impact on the quality of wood, so the law of wood quality changes becomes very complicated. However, this change has brought many difficulties to the production and utilization of wood. Only by fully considering the impact of multiple factors on wood quality and analyzing a large number of measurement data can we truly find the inherent quality change law. If you can grasp the variation law of wood quality and its influencing factors, it has important practical significance for guiding wood production, improving wood quality, and increasing the comprehensive utilization of wood. This article only discusses the impact of planting density on wood quality and yield(Lu et al., 2020). The results of the study have certain limitations, and further efforts are needed to study the impact of comprehensive factors on wood quality and yield.

6.0 CONCLUSION

In this study, 2500 red pine trees in five plots of Red pine plantations with different planting densities in Thunder Bay were used as the research object. Through the analysis of stand density, the basic growth indicators (diameter and height) of red pine, crown growth indicators and the influence of the height-to-diameter ratio shows that the optimal planting density of Red pine plantation is 550 plants/hm^{-2}, which provides a certain theoretical basis for the spacing management of red pine plantation in Thunder Bay area. Our analysis results prove the assumption correct.

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