A COMPARISON OF THE EFFECTIVENESS OF GROUND VERSUS AERIAL CHEMICAL SITE PREPARATION

by

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ABSTRACT

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Keywords: aerial application, chemical site preparation, glyphosate, herbicide, silviculture

Silviculture operations in northwestern Ontario can include the use of chemical site preparation to remove competing herbaceous vegetation to promote the establishment of conifer seedlings. Aerial and ground applications of herbicide are two common methods of chemical site preparation. There is limited literature on site-specific comparisons of these two methods, which can inform management decisions. Data was collected approximately 53 km west of Thunder Bay, Ontario (48°29'04.1"N 89°48'19.7"W) on the Lakehead Forest Management Unit from two adjacent sites. Each site received one of the two methods of chemical site preparation in 2016 and was planted with jack pine (*Pinus banksiana* Lamb.) container stock in 2017. An analysis of the crop species' survival, height, current growth, and the competing species' height yielded no significant difference between methods of chemical site preparation. The results indicate that either method of herbicide application can be implemented with the same degree of effectiveness.

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INTRODUCTION

Chemical site preparation involves the use of herbicides to remove competing vegetation and facilitate conifer seedling establishment. In silviculture operations, herbicides can be applied through numerous methods such as aerial, manual, or ground applications. There is limited literature that explores and discerns the superior method of herbicide application in silvicultural site preparation. The objective of this study is to compare the growth and survival of jack pine seedlings (*Pinus banksiana* Lamb.) on adjacent sites approximately 53 km west of Thunder Bay, Ontario. The sites were treated by ground or aerial application of herbicide. The results provide insight into the effectiveness of common methods of chemical site preparation. The null hypothesis is that there will be no significant differences in the growth and survival of the crop species due to the application method.

HERBICIDE

Herbicide application is an important silvicultural tool in the regeneration of forests (Thompson and Pitt 2011). In Canada, there are five herbicide active ingredients registered for use in forestry, 2,4-D, hexazinone, simazine, triclopyr, and glyphosate (Thompson and Pitt 2011). A glyphosate-based herbicide was used in this study as glyphosate is the most widely used herbicide in forestry for competition control (Sutton 1978; Karakatsoulis *et al.* 1989). Glyphosate is registered for use in forestry in Canada as studies show that at approved application rate as its level of exposure to humans does not cause any harmful effects, and it has low toxicity to wildlife according to Health Canada (Wood and Althen 1994; Government of Canada 2015). Furthermore, no pesticide regulatory authority considers glyphosate to be a carcinogenic risk to humans (Government of Canada 2015).

The application of herbicide on Crown land in Ontario follows strict guidelines outlined by the Ontario Ministry of Natural Resources and Forestry and the Ontario Ministry of Environment. For both methods of application, weather conditions at the time of application must fall within several acceptable ranges. For instance, the wind must be no less than 1 km/h and no more than 8 km/h, ensuring the droplets reach the intended target (OMNR 1992). Additionally, the relative humidity must be at a minimum of 50%, and the temperature must be within 5˚C to 24˚C (OMNR 1992). Also, herbicides are not applied over water bodies, and buffer zones are in place to control drift. When herbicides are applied aerially, there is a buffer of 120 m around human habitation and sensitive areas and a buffer of 60 m around significant areas (OMNR 1992).

During chemical site preparation application, glyphosate penetrates the cuticles of vegetation and translocates into the root system. Once inside of the roots, glyphosate causes mortality by inhibiting the enzyme 5-enolpyruvylshikimate-3-phosphate which synthesizes amino acids (Thompson and Pitt 2011). In the soil, glyphosate is rapidly deactivated and broken down by microorganisms into compounds such as carbon dioxide, water, nitrogen, and phosphorus (Wood and Althen 1994). Therefore, glyphosate is not susceptible to bioaccumulation in the food chain (Thompson and Pitt 2011).

COMPETING VEGETATION

Chemical site preparation controls competing vegetation, which is detrimental to the growth and survival of conifer seedlings (Wood and Althen 1994; Wagner *et al.* 1999; Wagner 2000). Competing vegetation can rapidly occupy available growing space within a few months after a disturbance, such as harvesting or fire. As pioneer plants grow, they can outcompete crop tree seedlings for valuable resources such as light, nutrients, and growing space which can cause mortality and smaller diameters, heights, and volumes in crop trees (Greene *et al.* 1999; Chen and Popadiouk 2002; Chen *et al.* 2006; Thompson and Pitt 2011). The impacts of competing vegetation can also be costly as it requires additional silvicultural treatments to manage. Competing vegetation is undesirable in many regards as it requires more resources to protect investments made to ensure a healthy forest.

In northwestern Ontario, competition vegetation can include but is not limited to species like mountain maple (*Acer spicatum*), beaked hazel (*Corylus cornuta*), willow (*Salix spp*.), trembling aspen (*Populus tremuloides*), red raspberry (*Rubus idaeus*), Canada blue-joint grass (*Calamagrostis canadensis*), pin cherry (*Prunus pensylvanica*), and alder (*Alnus spp*.) (Moola and Mallik 1998). The critical period to control these species is in the first few years of stand establishment (Wood and Althen 1994; Wagner *et al.* 1999; Wagner 2000). Competing vegetation can be managed through chemical site preparation. This intensive silvicultural practice can increase conifer productivity and can control tree species composition and stand structure (Walstad and Kuch 1987; Smith *et al.* 1997).

CHEMICAL SITE PREPARATION

Chemical site preparation is an effective way to reduce competition and improve seedling establishment and growth (Addington *et al.* 2011). It enhances conifer seedling growth primarily by reducing the density of competition species, which is especially crucial for jack pine seedlings as they are intolerant of competition (Addington *et al.* 2011). When chemical site preparation precedes planting, jack pine seedlings show greater height, and tree and stand volume (Chen *et al.* 2006). Chemical site preparation can even lead to a shorter rotation age due to significant diameter gains expressed in jack pine seedlings (Chen *et al.* 2006).

When compared to other methods of site preparation such as manual, mechanical, and fire, chemical site preparation results in better crop tree growth, especially on competitive, nutrient-rich sites (Pitt *et al.* 1999; Sutherland and Foreman 2000; Heineman *et al.* 2005). Chemical site preparation can be a more effective silvicultural treatment than other herbicide treatments such as tending (Wood and Althen 1994). Even without subsequent treatments such as tending, chemical site preparation can improve survival, height growth, and diameter of crop trees (Wood and Althen 1994).

HERBICIDE APPLICATIONS

Chemical site preparation can be performed through a manual application, a ground application, or an aerial application. The manual application is the least efficient and most costly method as it requires a person to walk and apply herbicide using a backpack sprayer. However, a manual application is still an effective method for specific applications where other applications may not be suitable. The ground application of herbicide is typically performed using a skidder. The use of skidders for herbicide application is infrequent but still prevalent in northwestern Ontario. Skidders have been used to apply herbicide on the Sapawe Forest, the Black Spruce Forest, the Lake Nipigon Forest, the Lakehead Forest, and the Dog River – Matawin Forest (David Haveman pers. comm. September 17, 2019; Dayna Griffiths, pers. comm. November 8, 2019). When the ground application of herbicide is chosen, it is likely because the target area is small, has an irregular shape, is adjacent to private land, or there are other sensitive or significant areas in proximity to the target area (Jean MacIsaac pers. comm. September 24, 2019). In these scenarios, ground applications are the best method.

When a block is near private land, a sensitive area, or a significant area, aerial application of herbicide must adhere to the buffer restrictions, but the ground application does not adhere to the same buffers. The ground application of herbicide adheres to slope dependent buffers, which are comparatively less restrictive (Jean MacIsaac pers. comm. September 24, 2019). However, there are several economic and practical limitations of the ground application of herbicide, such as lower productivity and uneven coverage due to site characteristics like slope, residual patches of trees, and wet areas that can restrict movement (Campbell 1990). The ground application of herbicide is beneficial under certain circumstances, but the aerial application of herbicides is the most frequently used method. In Canada, the aerial application method is more common as it accounts for 97% of the herbicide applied each year (Campbell 1990). Aerial application is widely used because it has higher production rates and is more costeffective than ground-based applications (David Haveman pers. comm. September 17, 2019).

A host of modern technologies is used in the application of herbicide, which creates maximal efficacy and minimal environmental risk (Thompson *et al.* 2007). Both ground and aerial applications involve the use of electronic guidance systems, meteorological monitoring, and experienced applicators. An aerial application can also include technologies such as an automated boom, low drift nozzles, and application control (Figure 1). With this technology, there are high levels of on-target deposition due to precise control over release height, spraying speed and consistent swath spacing (Thompson *et al.* 2007). Herbicide application is a heavily researched silvicultural practice with a high degree of effectiveness.

Figure 1. Application control technology produced by AG-NAV Inc.

METHODS AND MATERIALS

Data was collected on the Lakehead Forest Management Unit, with approval by its managing body, Greenmantle Forest Incorporated. The study site was located approximately 53 km west of Thunder Bay, Ontario (48°29'04.1"N 89°48'19.7"W, 990 m) (Figure 2). The study site was harvested in 2015 and received chemical site preparation in August 2016. The study site received chemical site preparation through a combination of aerial and ground applications of a glyphosate-based herbicide. For aerial application, herbicide was applied by a rotary-winged aircraft, using water as a carrier. For ground application, herbicide was applied by a 1980 Timberjack 480 skidder affixed with a Tjet Evenspray D325 sprayer at a speed of 100 m/h (David Haveman pers. comm. September 17, 2019). The study site was planted with jack pine container stock in 2017 at a spacing of 1.8 m.

In the fall of 2019, twenty 50 m^2 plots were assessed in the 40 ha northeastern section of the block (Figure 3). Plots were distributed evenly amongst both treatment areas with ten plots in each. Circular plots were created by affixing a 3.99 m long plot cord to a stationary shovel in the ground. In each plot, the following data were recorded: the number of crop trees, the average crop tree height in metres (m), the average current year's growth of the crop tree in centimetres (cm), and the number of dead crop trees. Additionally, the average height (m) of three competition species in each plot were recorded.

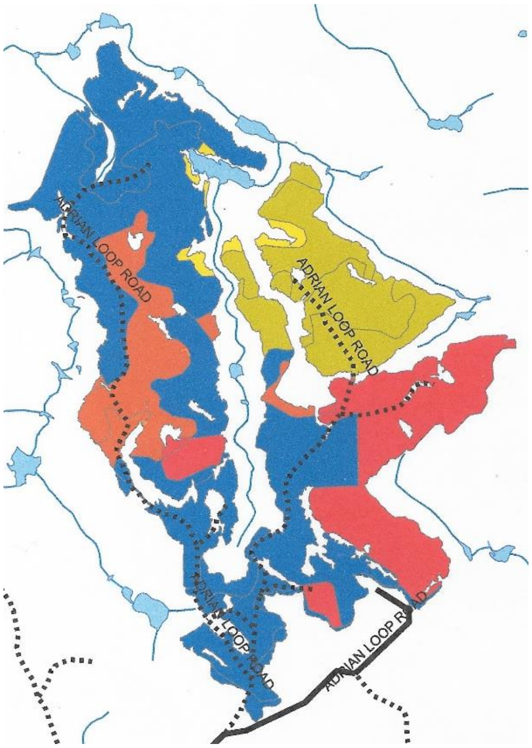

Figure 2. The whole block and the study site in yellow.

Figure 3. Close-up of the study site with the application method differentiated.

The software IBM SPSS Version 25 was used to determine statistical significance in the form of a one-way analysis of variance (ANOVA) tests. The herbicide treatment methods were designated as the independent variable. The average height, the number of trees, the average current year's growth, the mortality, and the average competition height were designated as dependent variables, respectively. Lastly, the densities of the two treatment areas were calculated with the formula:

$$Stems\ per\ hectare\ (SPH) = \frac{Total\ trees}{Number\ of\ plots}\ x\ 200$$

RESULTS

The results show that there was no significant difference in the method of chemical site preparation. The method of application did not significantly impact the height, the number, the current year's growth, nor the mortality of the crop trees nor the height of the competition species. Thus, the null hypothesis fails to reject. There is homogeneity in the data, and the error variance of the dependent variable is equal across groups.

The statistical analyses were performed using the raw data presented in Appendix I and Appendix II. Levene's test for equality of variances was performed for each interaction to verify the assumption that variances are equal across groups. All distributions are normal, according to Levene's test. Also, the density of the study site was determined, and the calculations show that the area which received a ground application of herbicide had a slightly larger density of 1,160 SPH while the area which received an aerial application of herbicide had a density of 1,060 SPH. The density of the area which received a ground application was 100 SPH greater than its counterpart, which is not significant.

Table 1 is a summary of the data of average crop tree height produced by one-way ANOVA. Table 1 includes the count, mean, and standard deviation of heights. Table 2 shows that there are equal variances across groups and a normal distribution as $p = 0.099$. The height of the crop trees showed no statistically significant difference in the method of application as $p = 0.899$ (Table 3).

Table 1. Descriptive statistics of height (m) data.

Application method	Count	Mean	Standard deviation
Ground	10	0.665	0.193
Aerial	9	0.656	0.113
Total	19	0.661	0.156

Table 2. Levene's test of equality of error variances in height (m) data.

F	df1	df2	Sig.
3.054	1	17	0.099

Table 3. Tests of between-subjects effects.

Source	Type III sum of squares	df	Mean square	F	Sig.
Corrected model	.000[a]	1	0	0.016	0.899
Intercept	8.260	1	8.260	320.997	1.79E-12
V1	0	1	0	0.016	0.899
Error	0.437	17	0.026		
Total	8.728	19			
Corrected total	0.438	18			

[a] R squared = .001 (adjusted R squared = -.058)

Table 4 is a summary produced by one-way ANOVA, which includes the count, mean, and standard deviation of the number of crop trees by application method. Table 5 shows that there are equal variances across groups and a normal distribution as p = 0.513. The survival of crop trees showed no statistically significant difference in the method of application as p = 0.947 (Table 6).

Table 4. Descriptive statistics of the number of trees data.

Application method	Count	Mean	Standard deviation
Ground	10	5.80	3.225
Aerial	9	5.89	2.421
Total	19	5.84	2.794

Table 5. Levene's test of equality of error variances in the number of trees data.

F	df1	df2	Sig.
0.446	1	17	0.513

Table 6. Tests of between-subjects effects.

Source	Type III sum of squares	df	Mean square	F	Sig.
Corrected model	.037[a]	1	0.037	0.005	0.947
Intercept	647.195	1	647.195	78.315	9E-08
V1	0.037	1	0.037	0.005	0.947
Error	140.489	17	8.264		
Total	789	19			
Corrected total	140.526	18			

[a] R squared = .000 (adjusted R squared = -.059)

Table 7 is the descriptive statistics produced by one-way ANOVA of the current year's growth, which includes the count, mean, and standard deviation. In Table 8, Levene's test shows that there are equal variances across groups and a normal distribution as $p = 0.333$. The survival of crop trees showed no statistically significant difference in the method of application as $p = 0.983$ (Table 9).

Table 7. Descriptive statistics of current growth (cm) data.

Application method	Count	Mean	Standard deviation
Ground	10	0.195	0.064
Aerial	9	0.194	0.046
Total	19	0.195	0.055

Table 8. Levene's test of equality of error variances in current growth (cm) data.

F	df1	df2	Sig.
0.992	1	17	0.333

Table 9. Tests of between-subjects effects.

Source	Type III sum of squares	df	Mean square	F	Sig.
Corrected model	1.462E-6[a]	1	1.46E-06	0	0.983
Intercept	0.718	1	0.718	224.209	0
V1	1.46E-06	1	1.46E-06	0	0.983
Error	0.054	17	0.003		
Total	0.775	19			
Corrected total	0.054	18			

[a] R squared = .000 (adjusted R squared = -.059)

Table 10 is the descriptive statistics produced by one-way ANOVA of the mortality of crop trees, which includes the count, mean, and standard deviation. Levene's test shows that there are equal variances across groups and a normal distribution as $p = 0.080$ (Table 11). The mortality of crop trees showed no statistically significant difference in the method of application as $p = 0.447$ (Table 12).

Table 10. Descriptive statistics of mortality data.

Application method	Count	Mean	Standard deviation
Ground	5	2.40	1.517
Aerial	1	1.00	
Total	6	2.17	1.472

Table 11. Levene's test of equality of error variances in mortality data.

F	df1	df2	Sig.
5.418	1	4	0.080

Table 12. Tests of between-subjects effects.

Source	Type III sum of squares	df	Mean square	F	Sig.
Corrected model	1.633[a]	1	1.633	0.710	0.447
Intercept	9.633	1	9.633	4.188	0.110
Aerial	1.633	1	1.633	0.710	0.447
Error	9.200	4	2.300		
Total	39.000	6			
Corrected total	10.833	5			

[a] R squared = .151 (adjusted R squared = -.062)

Table 13 is the descriptive statistics produced by one-way ANOVA of the height of competition species, which includes the count, mean, and standard deviation. The height of competition showed no statistically significant difference in the method of application as $p = 0.276$ (Table 14).

Table 13. Descriptive statistics of competition height (m) data.

Application method	Count	Mean	Standard deviation
Ground	10	0.282	0.056
Aerial	10	0.327	0.114
Total	20	0.305	0.090

Table 14. Tests of between-subjects effects.

Source	Type III sum of squares	df	Mean square	F	Sig.
Corrected model	.010[a]	1	0.010	1.262	0.276
Intercept	1.854	1	1.854	231.207	0.000
Treatment	0.010	1	0.010	1.262	0.276
Error	0.144	18	0.008		
Total	2.009	20			
Corrected total	0.154	19			

[a] R squared = .066 (adjusted R squared = .014)

DISCUSSION

The results of this experiment show that the methods of herbicide application do not produce any statistically significant difference. The results of the one-way ANOVA tests failed to reject the null hypothesis by proving that there was no statistically significant difference between the methods of application. The average height, the number of trees, the average current year's growth, the mortality, and the average height of competition were not significantly impacted by the method of herbicide application. The rejection of the hypothesis shows that the effectiveness of herbicides does not differ by method of application. There is no significant difference in the effectiveness of the two herbicide applications. Therefore, deciding which method of chemical site preparation is more effective is needless as both methods have similar effects.

Upon completion of this experiment, several deficiencies have come to light. Firstly, a prolonged period of observation would be beneficial to assess the study site. Assessing the study site the year before the herbicide application and at the time of planting would create a more comprehensive study. By assessing the same plots over consecutive years, further insight could be acquired, such as the cause of mortality in crop trees.

Secondly, a control group should be established to compare the growth and survival of crop trees that received herbicides with those that did not. Incorporating a control group in this study could prove whether an herbicide treatment is more effective than no herbicide treatment, and by how much. This could provide a further understanding of the effectiveness of chemical site preparation as Chen *et al.* (2006)

discovered that diameter at breast height, height, and volume growth of jack pine container trees increased with herbicide application.

Lastly, more factors and their potential impacts should be considered to understand other effects on the growth and survival of crop trees. These factors can include animal browse, soil type, planter technique, and the health of the seedlings. Each of these factors can affect the growth and survival of crop trees. Jack pine trees are susceptible to animal browse because they appear to be the most palatable conifer species (Parker 1986). If the crop trees were browsed, this could potentially skew the results of the average height comparison as defoliation has been noted to impact the growth rate of the tree (O'Neil 1962; Ericsson *et al.* 1980). Also, the seedlings were planted at 1.8 m, but in some circumstances, the spacing was either longer or shorter due to the soil type, unplantable spots, and the planter's discretion. In some instances, the soil was too shallow, and the planter decided not to plant a tree in that spot. The soil type was inconsistent throughout the study area, which could impact the average height and number of crop trees per plot. The variable health of the seedlings created another potential source of error. The seedlings were grown in a nursery and could have been subjected to different growing conditions. It is unknown whether the seedlings in the study were taller or healthier than others. In a more controlled environment, these factors could be taken into consideration to minimize their impact.

Although the results show that there is no significant difference in the effectiveness of herbicides by application method, it is still something to consider. The method of application differs depending on the characteristics of the target area. Due to these circumstances, one method of application may be better suited for chemical site preparation. It is recommended that further studies be conducted to fulfill this knowledge gap as a review by Chen *et al.* (2006) suggests that studies of the long-term effects of chemical site preparation on forest productivity do not exist.

CONCLUSION

The results generated by this study provide insight that the effectiveness of chemical site preparation is not significantly impacted by a different method of application. Aerial and ground application of herbicide has the same degree of effectiveness on similar sites. Herbicides are a heavily researched means of vegetation control, which have been used in forest management in northwestern Ontario for decades. At this time, the use of herbicides in northwestern Ontario is supported by a large industry with a history of adaptive management (OMNRF 2017). As the monitoring and evaluation of forest management practices continue, more knowledge of herbicides and their effects will be reported (OMNRF 2017).

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APPENDICES

APPENDIX I

AERIAL PLOTS DATA

Plot	Number of trees	Height (m)	Current growth (cm)	Mortality
1	8	0.7	0.15	
2	8	0.8	0.2	
3	7	0.7	0.2	
4	8	0.8	0.3	
5				
6	3	0.6	0.2	1
7	5	0.5	0.15	
8	8	0.7	0.2	
9	2	0.6	0.15	
10	4	0.5	0.2	

APPENDIX II

GROUND PLOTS DATA

Plot	Number of trees	Height (m)	Current growth (cm)	Mortality
1	4	1	0.2	
2	1	0.75	0.2	
3	7	0.8	0.25	
4	3	0.6	0.1	
5	12	0.65	0.25	
6	5	0.5	0.2	1
7	4	0.9	0.3	1
8	9	0.5	0.15	4
9	5	0.4	0.1	2
10	8	0.55	0.2	4