Influence of lodgepole pine spacing intervals and herbicide treatment on soil characteristics
by Steven Eugene Hagler

A thesis submitted in partial fulfillment of the requirement for the degree of Master of Science in Soils
Montana State University

Abstract:
Soil and vegetation influence each other. In forested ecosystems individual trees and understory vegetation influence soil characteristics as the forest undergoes succession, beginning with the disturbance of logging and site preparation activities. The objective of this study was to compare levels of soil parameters (organic matter, pH, nitrate-nitrogen, phosphorus, and potassium) in various lodgepole pine spacing intervals. Changes in the soil were evaluated in each tree spacing interval as distance from the tree increased. Effects on soil parameters resulting from an herbicide treatment of the understory vegetation was evaluated. Comparisons were also made between various unsprayed and sprayed tree spacing interval stands, an unspaced naturally regenerated stand, and a mature stand. Existing 35-40 year old USDA Forest Service plots on the Lewis and Clark, and Targhee National Forests were used. Trees were spaced at intervals of 1.8m by 1.8m, 3.6m by 3.6m, and 5.4m by 5.4m. A transect at each tree was established and quadrat locations near the bole, at the dripline, and at the midpoint were selected along each transect. Soil samples were collected from the center of each quadrat at a depth of 5-10 cm. Soils were analyzed in the lab and were compared using analysis of variance. On the Lewis and Clark site tree harvest had the most widespread effect on potassium, with more limited effects on phosphorus and organic matter. Tree harvest reduced potassium and organic matter in the unsprayed 1.8m tree spacing intervals, and organic matter, phosphorus, and potassium in the sprayed 1.8m tree spacing intervals. Tree harvest also reduced phosphorus and potassium in the wide sprayed tree spacing intervals. The trend was for high nitrate-nitrogen, phosphorus, potassium, and organic matter in the wider unsprayed tree spacing intervals. In sprayed areas high potassium was found in both the 1.8m and 5.4m tree spacing intervals, and high nitrate-nitrogen occurred in the wide tree spacing interval. Distance from the tree affected the soil only in the wider tree spacing intervals. Potassium increased with increasing distance from the tree in the wider sprayed areas. Organic matter was negatively affected by distance from the tree in the wide sprayed spacing intervals. The herbicide treatment detrimentally affected organic matter, phosphorus and potassium in the wide tree spacing intervals. On the Targhee site tree harvest generally had a negative effect on both phosphorus and potassium, but nitrate-nitrogen showed a positive effect from tree harvest in the 1.8m tree spacing intervals. In the unsprayed areas pH was more acidic in the 1.8m tree spacing interval than in the wide tree spacing interval stands as a result of the tree spacing treatment. Phosphorus at the dripline was detrimentally affected by 1.8m tree spacing intervals in the unsprayed areas and organic matter benefited from intermediate tree spacing intervals in the sprayed areas. The trend was for higher nitrate-nitrogen in the 1.8m tree spacing intervals. Greater distances from the tree negatively affected phosphorus in the unsprayed 3.6m tree spacing interval, as well as in both the sprayed 3.6m and 5.4m tree spacing intervals. Levels of pH were generally more acidic in the sprayed areas than in the unsprayed areas. The herbicide treatment had a positive effect on nitrate-nitrogen at the midpoint and in the 1.8m tree spacing interval. Phosphorus was adversely effected by herbicides in the 3.6m tree spacing interval. The results of this study show that individual trees do exert an influence on soil characteristics, but the influence varies, depending on the soil parameter, tree spacing interval, and distance from the tree.

INFLUENCE OF LODGEPOLE PINE SPACING INTERVALS AND HERBICIDE TREATMENT ON SOIL CHARACTERISTICS

by

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APPROVAL

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ABSTRACT

Soil and vegetation influence each other. In forested ecosystems individual trees and understory vegetation influence soil characteristics as the forest undergoes succession, beginning with the disturbance of logging and site preparation activities. The objective of this study was to compare levels of soil parameters (organic matter, pH, nitrate-nitrogen, phosphorus, and potassium) in various lodgepole pine spacing intervals. Changes in the soil were evaluated in each tree spacing interval as distance from the tree increased. Effects on soil parameters resulting from an herbicide treatment of the understory vegetation was evaluated. Comparisons were also made between various unsprayed and sprayed tree spacing interval stands, an unspaced naturally regenerated stand, and a mature stand. Existing 35-40 year old USDA Forest Service plots on the Lewis and Clark, and Targhee National Forests were used. Trees were spaced at intervals of 1.8m by 1.8m, 3.6m by 3.6m, and 5.4m by 5.4m. A transect at each tree was established and quadrat locations near the bole, at the dripline, and at the midpoint were selected along each transect. Soil samples were collected from the center of each quadrat at a depth of 5-10 cm. Soils were analyzed in the lab and were compared using analysis of variance. On the Lewis and Clark site tree harvest had the most widespread effect on potassium, with more limited effects on phosphorus and organic matter. Tree harvest reduced potassium and organic matter in the unsprayed 1.8m tree spacing intervals, and organic matter, phosphorus, and potassium in the sprayed 1.8m tree spacing intervals. Tree harvest also reduced phosphorus and potassium in the wide sprayed tree spacing intervals. The trend was for high nitrate-nitrogen, phosphorus, potassium, and organic matter in the wider unsprayed tree spacing intervals. In sprayed areas high potassium was found in both the 1.8m and 5.4m tree spacing intervals, and high nitrate-nitrogen occurred in the wide tree spacing interval. Distance from the tree affected the soil only in the wider tree spacing intervals. Potassium increased with increasing distance from the tree in the wider sprayed areas. Organic matter was negatively affected by distance from the tree in the wide sprayed spacing intervals. The herbicide treatment detrimentally affected organic matter, phosphorus and potassium in the wide tree spacing intervals. On the Targhee site tree harvest generally had a negative effect on both phosphorus and potassium, but nitrate-nitrogen showed a positive effect from tree harvest in the 1.8m tree spacing intervals. In the unsprayed areas pH was more acidic in the 1.8m tree spacing interval than in the wide tree spacing interval stands as a result of the tree spacing treatment. Phosphorus at the dripline was detrimentally affected by 1.8m tree spacing intervals in the unsprayed areas and organic matter benefitted from intermediate tree spacing intervals in the sprayed areas. The trend was for higher nitrate-nitrogen in the 1.8m tree spacing intervals. Greater distances from the tree negatively affected phosphorus in the unsprayed 3.6m tree spacing interval, as well as in both the sprayed 3.6m and 5.4m tree spacing intervals. Levels of pH were generally more acidic in the sprayed areas than in the unsprayed areas. The herbicide treatment had a positive effect on nitrate-nitrogen at the midpoint and in the 1.8m tree spacing interval. Phosphorus was adversely effected by herbicides in the 3.6m tree spacing interval. The results of this study show that individual trees do exert an influence on soil characteristics, but the influence varies, depending on the soil parameter, tree spacing interval, and distance from the tree.

INTRODUCTION

Species occurrence, plant cover, vegetative biomass, and soil characteristics in any forest ecosystem are the result of a complex sequence of events, or a process, that includes interacting factors of climate, topography, and living organisms on geologic parent material over time (Jenny, 1941). As with any landscape on earth this process is occurring on the forest landscape in the Rocky Mountains of Montana and Idaho. USDA-Forest Service study sites established to evaluate effects of tree spacing intervals on lodgepole pine (*pinus contorta*) growth present an opportunity to observe soil characteristics resulting from both soil forming and successional processes. Succession on these plots has been managed specifically to maintain a lodgepole pine overstory while understory species composition has been allowed to develop without a specific seral goal. Of course it would seem reasonable that any treatment to maintain a specific seral overstory would also affect understory and soil characteristics.

Soil and vegetation influence each other. In a forest ecosystem, patterns of soil properties develop and vary spatially under the influence of individual trees (Zinke, 1962; Boettcher and Kalisz, 1990). An individual tree influences soil development by affecting microclimate, crown drip and stem flow, quantity and composition of litter, and the character of the root system (Alban, 1969). These four factors exert a direct influence on soil development, as well as an indirect influence on soil microorganisms and understory vegetation.

Although the literature contains a voluminous repertoire of reports regarding general effects of dominant overstory species on soil properties, it is relatively limited in studies dealing with spatial variation resulting from the direct influence of individual lodgepole pine trees. Muller (1887) described mull humus soils beneath oak trees indicating differences in soil characteristics under the trees compared to the adjacent podzolized heath land soils. Jamison (1942) studied soil properties under orange trees in Florida and described changes as distance from individual trees increased. Some studies undertaken in the middle of the century, showed that individual plants influence soil properties in a predictable manner (Fireman and Hayward, 1952; Harradine, 1954; Muller and Muller, 1956). Fireman and Hayward (1952) found that various desert shrub species influenced exchangeable sodium patterns differently. Harradine (1954) observed that soil nitrogen was less in the open than under the influence of *Pinus ponderosa*. Muller and Muller (1956) noted that in desert areas the occurrence of herbaceous ground vegetation was associated with the influence of individual shrubs on the soil.

A classic study showing the influence of a single tree on soil properties was reported by Zinke (1962). He showed that soil properties exhibited distinct patterns of radial symmetry around a 45-year-old shore pine (*Pinus contorta* Dougl. ex Loud). Nitrogen levels decreased as distance from the tree increased. Divalent cations (Ca and Mg) decreased from the bole to the dripline, then increased as distance from the crown increased. Monovalent cations (K and Na) decreased from the bole to beyond the dripline as distance from the tree increased. Barth (1980) hypothesized that elemental concentrations in the soil under the canopy would increase with tree age. Many studies have been done to show that soil nutrient levels exhibit radial symmetry around older trees (Dickson and Crocker, 1954; Zinke, 1962; Lodhi, 1977; Barth, 1980; Everett et al., 1986; Perez, 1995). Most of the trees in these studies were much older than 35 years of age.

Very little work has been reported regarding the radial spatial distribution patterns of soil characteristics in 35-40 year old lodgepole pine stands. Primary objectives of this study were to 1) determine and evaluate soil characteristics as influenced by individual trees and the associated understory vegetation in various tree spacing intervals, 2) determine and evaluate differences in soil characteristics resulting from prior herbicide treatments in various tree spacing intervals, 3) determine the existence of spatial variation resulting in radial pattern, and 4) determine the changes in soil characteristics caused by timber harvest and site preparation. Since the lodgepole pine stands used in this study are young, and disturbance of the topsoil from logging and site preparation activities is relatively recent, understory succession and especially soil development of the surface horizon are in their early stages.

STUDY SITES

The two sites selected for this study were part of a USDA Forest Service research project initiated in 1964 (FS-INT-1251-520) to monitor the growth of lodgepole pine subjected to various tree spacing intervals. Experimental plots are located on the Lewis and Clark, and Targhee National Forests.

Targhee Site

The Targhee study site is located in the SW 1/4 of Section 10, Township 13 North, Range 43 East, which is approximately 5 km north of Island Park, Idaho. Slopes on the study site are 0-5% with north and east aspects and the elevation is 1951 meters above sea level. Geologically, the site is on the northwest edge of the Island Park caldera (Alt and Hyndman, 1989). The parent material is rhyolite, has a low bulk density, and is almost pumiceous. Soil derived from this parent material is classified as a Typic Cryopsamment (Stermitz et al., 1974).

Climate information from nearby Island Park Dam (U.S. Weather Bureau, 1970-81) shows the annual mean temperature is 7° C and the annual precipitation averages 78 cm.

Understory vegetation on the study site is dominated by grouse whortleberry (*Vaccinium scoparium*), pinegrass (*Calamagrostis rubescens*), elk sedge (*Carex geyeri*), and silky lupine (*Lupinus sericeus*). The overstory is lodgepole pine (*Pinus contorta*). Habitat type is classified as Douglas fir/pinegrass (*Pseudotsuga menziesii/Calamagrostis rubescens*) (Pfister et al., 1977).

In 1956 a 67-year-old stand of lodgepole pine was harvested and the slash was broadcast burned the next year. Stocking density in 1966 was 16,556 trees per hectare when the site was thinned to establish the original lodgepole pine spacing study.

Lewis and Clark Site

The Lewis and Clark site is located in the SE 1/4 of Section 16, Township 11 North, Range 10 East, approximately 35 km west of Utica, Montana. The study site has slopes of 2-5% with a southeast aspect and is at an elevation of 1946 m. Climatic information is taken from MAPS Atlas (Caprio et al., 1994) which shows a mean annual temperature of 5° C and a mean annual precipitation of 42 cm in the general area of the study plot. The average date of first freeze is between August 28 and September 2 and the average date of the last freeze is between June 19 and 29 with the mean length of the freeze free season 50-70 days. Annual snowfall is between 508 cm and 762 cm.

Parent material on the site is granite and the soil is a moderate to deep well drained sandy loam. The soil is classified as a Typic Cryoboralf (USDA Soil Conservation Service, 1978). The overstory near the site is dominated by lodgepole pine with some subalpine fir (*Abies lasiocarpa*), whitebark pine (*Pinus albicaulis*) on the high ridges, and Engelmann spruce (*Picea engelmannii*) in the wetter draws. Lodgepole pine is the only overstory species on the study site. Understory vegetation is dominated by grouse whortleberry, elk sedge, silky lupine, and showy aster (*Aster conspicuus*). The habitat type is classified as subalpine fir/grouse whortleberry (*Abies lasiocarpa/Vaccinium scoparium*) (Pfister et al., 1977).

In 1954 the 150-year-old timber stand was harvested and the slash was dozer piled and burned that same year. The pine spacing study was started on this site in 1965 when the regenerated lodgepole pine stand was thinned to the experimental treatment spacing intervals. At the time the regenerated stand was thinned the stocking density was 36,793 trees per hectare.

METHODS AND PROCEDURES

This study was conducted on two previously established sites (Lewis and Clark, 1965, and Targhee, 1966, National Forests) by the USDA Forest and Range Experiment Station (FS-INT-1251-520) to evaluate effects of various tree spacing intervals on the growth of lodgepole pine. Each site represents different geographical locations, environmental conditions, elevation, precipitation, climate, and habitat type.

Both of the study sites consisted of five different tree spacing intervals in a randomized complete-block design of two replications. Only the 1.8 meter by 1.8 meter, 3.6m by 3.6m, and 5.4m by 5.4m spacing interval plots were used in this study. The trees were thinned to the approximate spacing interval at the time the plots were established by either mechanical or chemical means. One half of each tree spacing interval plot was thinned mechanically, while the other half of the plot was thinned using chemical herbicides. Dalpon, 2-4-5-T, and 2-4-D were applied to kill all vegetation except for selected trees which were to be used in the pine spacing study. The 1.8m by 1.8m tree spacing interval plots were thinned to ten rows of thirteen trees on each half plot (Fig. 1). This study utilized the six center trees in the center two rows (twelve trees). The 3.6m by 3.6m tree spacing interval plots were thinned to six rows of nine trees on each half plot (Fig. 1). The six center trees in the center two rows were utilized (twelve trees). On the half plots of 5.4m by 5.4m tree spacing intervals, the trees were thinned to seven trees in each of seven rows (Fig. 1). The center four trees in the center three rows were utilized (twelve trees). In each tree spacing interval plot, the trees surrounding the utilized trees acted as a buffer zone from the influence of trees outside the study plots.

```
                     Unsprayed                   Sprayed
               |b b b b b b b b b b b b b|b b b b b b b b b b b b b|
               |b b b b b b b b b b b b b|b b b b b b b b b b b b b|
               |b b b b b b b b b b b b b|b b b b b b b b b b b b b|
               |b b b b b b b b b b b b b|b b b b b b b b b b b b b|
1.8 m x 1.8 m  |b b b b x x x x x x b b b|b b b x x x x x x b b b b|
               |b b b b x x x x x x b b b|b b b x x x x x x b b b b|
               |b b b b b b b b b b b b b|b b b b b b b b b b b b b|
               |b b b b b b b b b b b b b|b b b b b b b b b b b b b|
               |b b b b b b b b b b b b b|b b b b b b b b b b b b b|
               |b b b b b b b b b b b b b|b b b b b b b b b b b b b|

               |b b b b b b b b b|b b b b b b b b b|
               |b b b b b b b b b|b b b b b b b b b|
3.6 m x 3.6 m  |b b x x x x x x b|b x x x x x x b b|
               |b b x x x x x x b|b x x x x x x b b|
               |b b b b b b b b b|b b b b b b b b b|
               |b b b b b b b b b|b b b b b b b b b|

               |b b b b b b b|b b b b b b b|
               |b b b b b b b|b b b b b b b|
               |b b x x x x b|b x x x x b b|
5.4m x 5.4m    |b b x x x x b|b x x x x b b|
               |b b x x x x b|b x x x x b b|
               |b b b b b b b|b b b b b b b|
               |b b b b b b b|b b b b b b b|

               b=buffer trees     x=possible utilized trees
```

Figure 1. Study plot layout showing the location of trees utilized for each of the three tree spacing intervals.

Nine of the center twelve trees were randomly selected to run a transect diagonally between two tree-pairs. Diagonal transects were selected to allow sampling along the maximum growing space available to the trees. The direction of the transect was randomly selected from one of four possible directions. All nine transects on a half plot were run in the same direction from the selected trees. Three 20 cm x 50 cm quadrats were selected along each transect. The first quadrat location was 45 cm from the trunk (bole) of the tree (near the bole), the second at the crown edge (dripline), and the third at the greatest distance between two tree crowns (midpoint). Distances between the three quadrats along each transect were recorded.

Soil sampling on the Lewis and Clark site was done during the second week of August, and the Targhee site during the first week of September. Soil samples were taken at a depth of 5-10 cm in the center of each quadrat on every third transect. The first transect selected on each half plot was randomly selected from transect numbers 1, 2, and 3. The soil samples were oven-dried and analyzed for pH, percent organic matter, nitrate nitrogen, phosphorous, and potassium. Measurements from all quadrats within sprayed or unsprayed half plots, regardless of quadrat location or tree spacing interval, were used to derive a plot-wide average measurement.

Soil samples were also collected in an unspaced naturally regenerated clearcut and in an uncut mature stand of timber. Both stands were contiguous to the study plots. Soil samples within the unspaced naturally regenerated clearcut were taken from four randomly selected transects, with 20 cm by 50 cm quadrats placed at 45 cm from the bole of the tree, at the dripline of the crown, and at the midpoint between the crowns of two diagonally adjacent trees. Soil samples were taken at a depth of 5-10 cm in the center of all quadrats on four randomly selected transects. Samples within the uncut mature stand were taken from the center of six randomly selected quadrats. Their location relative to the bole and dripline of the nearest tree were recorded, as well as tree diameter. Soil samples were taken at a depth of 5-10 cm in the center of the six randomly selected quadrats.

Within 24 hours of collection, the soil samples were placed in an oven at 105° C for drying. After drying the samples were taken to the Montana State University Soil Testing Laboratory where they were ground and analyzed for percent organic matter, pH, nitrate-nitrogen, phosphorus, and potassium. The methods the soil testing laboratory used to analyze all five soil characteristics are described in detail by Page et al. (1982). In addition, procedures where colorimetric analysis was needed (i.e. nitrate-nitrogen analysis), are described by Clesceri et al. (1989).

Statistical analysis was done using SAS (SAS, 1987). Analysis of variance was used to compare five soil characteristics (percent organic matter, pH, nitrate-nitrogen, phosphorous, and potassium) in the three tree spacing intervals (both herbicide treated and untreated), the unspaced naturally regenerated stand, and the mature stand. This analysis was used to show effects of spacing interval, distance from the bole of the tree, the past herbicide treatment, and timber harvest.

From the analysis of distance from the bole of the tree, radial pattern can be characterized. In this study radial pattern is classified as either sequential or nonsequential. Sequential radial pattern occurs when values progressively increase or decrease along the bole to midpoint transect. The presence or absence of statistically significant differences will determine if evidence for radial pattern is strong strong. In this study the term "significant" means P < or = .05.

RESULTS AND DISCUSSION

Lewis and Clark Site

Plot-wide Overview

Effect of Herbicide Treatment on Soil Characteristics. Some differences between unsprayed and sprayed areas would be expected if soil parameters were directly affected by herbicides or indirectly affected by herbicide residuals, or by vegetation in which succession was altered as a result of herbicide effects. The level of all soil parameters, except pH, was higher in the unsprayed areas than in the sprayed areas of the study site (Table 1), but the differences were small. Since differences in the level of all soil characteristics between unsprayed and sprayed areas were not significant, it appears that herbicide treatment has had no direct deleterious effects, nor are indirect detrimental effects on soil characteristics evident.

Table 1. Measurements of soil parameters in the unsprayed and sprayed areas on the Lewis and Clark study site.

Soil	Regenerated Stands	
Parameter	Unsprayed	Sprayed
POM(%)	1.50	1.27
pH	4.7	4.7
N(mg/kg)	0.6	0.4
P(mg/kg)	37.0	34.0
K(mg/kg)	125	122

POM=percent organic matter; N=nitrate-nitrogen; P=phosphorus; K=potassium

Effect of Tree Harvest on Soil Characteristics. It is expected that soil development in the top ten centimeters on the study plot would have progressed little in the short time since logging disturbance (37 years ago). Mixed results occurred when comparing soil parameters in the unspaced naturally regenerated stand and the mature stand (Table 2). Nitrate-nitrogen and pH were slightly higher in the unspaced naturally regenerated stand than in the mature stand. Percent organic matter, phosphorus, and potassium levels were higher in the mature stand than in the unspaced naturally regenerated stand. Percent organic matter may be significantly higher in the mature stand because the forest floor has not been disturbed, the litter layer is larger, and over time, organic matter has accumulated; whereas, in the unspaced naturally regenerated stand, logging activities have disturbed the litter layer and the upper part of the mineral soil. Sufficient time has not passed to allow extensive accumulation of organic matter at the five to ten centimeter depth (sampling depth) in the unspaced naturally regenerated stand.

Table 2. Measurements of soil parameters in the unspaced naturally regenerated stand and the mature stand on the Lewis and Clark study site.

Soil Parameter	Unspaced Regeneration	Mature
POM(%)	1.20b	1.75b
pH	4.8	4.7
N(mg/kg)	0.7	0.2
P(mg/kg)	39.1	41.5
K(mg/kg)	118	148

b-significant difference between Unspaced & Mature
POM=percent organic matter; N=nitrate-nitrogen; P=phosphorus; K=potassium

Effects of Tree Harvest on Percent Organic Matter

Unsprayed Versus Mature. The percent organic matter was higher in the mature stand than in the unsprayed areas of the 1.8m and 3.6m tree spacing interval stand (Table 3). It was expected that the percent organic matter would be higher in the mature stand than in all three tree spacing interval stands, since litter in the mature stand has had more time to decompose. Because differences in the percent organic matter levels between the unsprayed 1.8m tree spacing interval stand and the mature stand were statistically significant, the hypothesis is supported. The differences in percent organic matter between the mature stand and the unsprayed 3.6m tree spacing interval stands were not statistically significant, therefore, the hypothesis is not supported. In the 5.4m tree spacing interval stand the percent organic matter was higher in the unsprayed areas of the study plot than in the mature stand, which also does not support the hypothesis. Timber harvest has only affected percent organic matter in the narrow tree spacing interval stands.

Table 3. Percent organic matter comparing spaced unsprayed areas with a mature stand on the Lewis and Clark study site.

Spacing Interval	Spaced Unsprayed	Mature
1.8m	1.09c	1.87c
3.6m	1.36	1.72
5.4m	1.98	1.68

c-significant difference between Unsprayed & Mature

Sprayed Versus Mature. The percent organic matter was appreciably higher in the mature stand than percent organic matter in the sprayed areas in the 1.8m tree spacing interval stand (Table 4). Percent organic matter was also higher in the mature stand than in the sprayed areas of both the 3.6m and 5.4m tree spacing interval stands.

It was expected that the percent organic matter would be higher in the mature stand than in all three tree spacing interval stands, since litter has had more time to decompose. Because differences in the percent organic matter levels between the sprayed 1.8m tree spacing interval stands and the mature stand were statistically significant, the hypothesis is supported. Since the differences in percent organic matter between the mature stand and both the sprayed 3.6m and 5.4m tree spacing interval stands were not statistically significant, the hypothesis is not supported. In the sprayed areas, as in the unsprayed areas, tree harvest has only affected percent organic matter in the narrow tree spacing interval stands.

Table 4. Percent organic matter comparing spaced sprayed areas with a mature stand on the Lewis and Clark study site.

Spacing Interval	Spaced Sprayed	Mature
1.8m	1.13d	1.87d
3.6m	1.40	1.72
5.4m	1.31	1.68

d-significant difference between Sprayed & Mature

Effects of Spacing Treatment on Percent Organic Matter

Unsprayed Areas. In the unsprayed areas of the Lewis and Clark study site, the highest percent organic matter measurements occurred in the 5.4m tree spacing interval stand at all three quadrat locations (Table 5). At quadrat locations near the bole and at the midpoint, percent organic matter increased with increasing tree spacing intervals, and at the midpoint the differences in percent organic matter between the 1.8m and 5.4m tree spacing interval stands were statistically significant. At the dripline, percent organic matter was highest in the 5.4m tree spacing interval stand, intermediate in the 1.8m tree spacing interval stand, and lowest in the 3.6m tree spacing interval stand. Although this pattern is different than at the other two quadrat locations, the statistically significant differences in the data, here, as well as at the midpoint, suggest that spacing interval does affect percent organic matter in the less dense lodgepole pine stands.

Table 5. Percent organic matter in each tree spacing interval, by quadrat location, for unsprayed areas on the Lewis and Clark study site.

Quadrat Location	Unsprayed Spacing Interval 1.8m	3.6m	5.4m
Bole	1.23	1.77	1.84
Dripline	1.24f	1.06e	2.11ef
Midpoint	0.97f	1.29	2.00f

e-significant difference between 3.6m & 5.4m   f-significant difference between 1.8m & 5.4m

Sprayed Areas. Percent organic matter near the bole increased as tree spacing interval increased in the sprayed areas of the Lewis and Clark study site (Table 6). At the dripline and at the midpoint the spatial distribution patterns were different. While the high level of organic matter at both of these quadrat locations occurred in the 3.6m tree spacing interval stand, the low organic matter level occurred at the dripline in the 5.4m tree spacing interval stand and at the midpoint in the 1.8m tree spacing interval stand. Since none of the differences were statistically significant the data indicate that lodgepole pine spacing interval has no effect on percent organic matter in the sprayed areas of the study plot.

Table 6. Percent organic matter in each tree spacing interval, by quadrat location, for sprayed areas on the Lewis and Clark study site.

Quadrat Location	Sprayed Spacing Interval 1.8m	3.6m	5.4m
Bole	1.22	1.37	1.78
Dripline	1.22	1.24	1.10
Midpoint	0.90	1.55	1.02

Unsprayed Versus Unspaced Regeneration. Percent organic matter was higher in the unspaced naturally regenerated stand than in the unsprayed areas in the 1.8m tree spacing interval stand (Table 7). The percent organic matter in the 3.6m and 5.4m tree spacing interval stands was higher in the unsprayed areas than in the unspaced naturally regenerated stand.

Table 7. Percent organic matter comparing spaced unsprayed areas with an unspaced naturally regenerated stand on the Lewis and Clark study site.

Spacing Interval	Spaced Unsprayed	Unspaced Regenerated
1.8m	1.11	1.25
3.6m	1.37	1.20
5.4m	2.00b	1.15b

b-significant difference between Unsprayed & Unspaced Regenerated

It was expected that percent organic matter in the unspaced naturally regenerated stand and in the narrower tree spacing interval stand would be similar, since in both stands the trees are spaced close together. This hypothesis is supported by the data because the differences in percent organic matter between the unspaced naturally regenerated stand and the unsprayed 1.8m and 3.6m tree spacing interval stands were not statistically significant. Further evidence is found in the dissimilarity of percent organic matter levels between the unsprayed 5.4m tree spacing interval stand and the unspaced naturally regenerated stand, as the difference was statistically significant. These data suggest that wide tree spacing interval stands may be beneficial for higher percent organic matter.

Effects of Distance from the Tree on
Percent Organic Matter

Unsprayed Areas. In the unsprayed areas of the Lewis and Clark study site, the spatial distribution patterns of percent organic matter in each tree spacing interval stand were different, but all three indicate possible nonsequential radial pattern (Table 8). Since no statistically significant differences were found for percent organic matter measurements between quadrats in any of the three tree spacing interval stands, evidence for radial pattern is considered weak. These data also suggest that distance from the trunk of the tree has no significant effect on percent organic matter.

Table 8. Percent organic matter in each tree spacing interval along the bole to midpoint transect for unsprayed areas on the Lewis and Clark study site.

Quadrat	Unsprayed Spacing Interval		
Location	1.8m	3.6m	5.4m
Bole	1.23	1.77	1.84
Dripline	1.24	1.06	2.11
Midpoint	0.97	1.29	2.00

Sprayed Areas. In the 1.8m and 5.4m tree spacing interval stands, percent organic matter decreased along the bole to midpoint transect, indicating the presence of sequential radial pattern (Table 9). Evidence for radial pattern is considered weak in the 1.8m tree spacing interval stand because the differences in percent organic matter along the bole to midpoint transect were not statistically significant. Strong evidence for radial pattern does exist in the 5.4m tree spacing interval stand, since there is a significant difference between percent organic matter near the bole and percent organic matter at the midpoint. The spatial distribution pattern of organic matter was different in the 3.6m tree spacing interval stand where the highest level was found at the midpoint and the lowest level at the dripline, indicating nonsequential radial pattern. Without statistically significant differences in percent organic matter between quadrat locations, the evidence must be considered weak. This significant difference also suggests that distance from the trunk of the tree adversely affects percent organic matter in wide tree spacing interval stands.

Table 9. Percent organic matter in each tree spacing interval along the bole to midpoint transect for sprayed areas on the Lewis and Clark study site.

Quadrat	Sprayed Spacing Interval		
Location	1.8m	3.6m	5.4m
Bole	1.22	1.37	1.78c
Dripline	1.22	1.24	1.10
Midpoint	0.90	1.55	1.02c

c-significant difference between Bole & Midpoint

Unsprayed Versus Unspaced Regeneration. The percent organic matter at all three quadrat locations was higher in the unsprayed areas than in the unspaced naturally regenerated stand (Table 10). Although percent organic matter differences between the two stands are not statistically significant, the higher levels in the unsprayed area is a result of the influence of higher percent organic matter in the wider tree spacing interval stands. In the unsprayed areas percent organic matter decreased along the bole to midpoint transect, indicating sequential radial pattern. Since the differences in percent organic matter between quadrats were not statistically significant the evidence is considered weak.

The spatial distribution pattern of percent organic matter in the unspaced naturally regenerated stand indicates nonsequential radial pattern. The evidence for radial pattern, however, is considered weak since the differences in percent organic matter between quadrats are not statistically significant. This is probably due to overlapping tree influence, since the trees are spaced randomly and are generally closer together in the unspaced naturally regenerated stand than trees in the various tree spacing interval stands. Distance from the trunk of the tree has no effect on percent organic matter in either the unsprayed areas or in the unspaced naturally regenerated stand.

Table 10. Percent organic matter comparing spaced unsprayed areas, by quadrat location, with an unspaced naturally regenerated stand on the Lewis and Clark study site.

Quadrat Location	Spaced Unsprayed	Unspaced Regenerated
Bole	1.61	1.25
Dripline	1.47	1.13
Midpoint	1.45	1.27

Effects of Herbicide Treatment on Percent Organic Matter

Unsprayed Versus Sprayed by Quadrat Location. Percent organic matter was higher in the unsprayed areas of the study plot than in the sprayed areas (Table 11) at each of the

Table 11. Percent organic matter comparing spaced unsprayed and sprayed areas, by quadrat location, on the Lewis and Clark study site.

Quadrat	Spaced	
Location	Unsprayed	Sprayed
Bole	1.61	1.46
Dripline	1.47	1.19
Midpoint	1.45	1.16

three quadrat locations. No statistically significant differences occur between the unsprayed and sprayed areas, indicating that the herbicide treatment has had no effect on percent organic matter.

Sprayed Versus Unspaced Regeneration by Quadrat Location. Percent organic matter was higher in the sprayed areas than in the unspaced naturally regenerated stand near the bole and at the dripline (Table 12). At the midpoint, however, percent organic matter was higher in the unspaced naturally regenerated stand than in the sprayed areas of the study plot. Since the differences in percent organic matter between the two stands are not statistically significant, they must be considered similar. Their similarity is another indication that the herbicide treatment has had no lasting effect on percent organic.

Table 12. Percent organic matter comparing spaced sprayed areas, by quadrat location, with an unspaced naturally regenerated stand on the Lewis and Clark study site.

Quadrat Location	Spaced Sprayed	Unspaced Regenerated
Bole	1.46	1.25
Dripline	1.19	1.13
Midpoint	1.16	1.27

Unsprayed Versus Sprayed by Spacing Interval. Percent organic matter was slightly higher in the sprayed areas than in the unsprayed areas in the 1.8m and 3.6m tree spacing interval stands (Table 13). In the 5.4m tree spacing interval stand, percent organic matter was significantly higher in the unsprayed areas than in the sprayed areas of the study plot, suggesting that the herbicide treatment has had an effect on percent organic matter in the wide tree spacing interval stands.

Table 13. Percent organic matter comparing spaced unsprayed and sprayed areas, by tree spacing interval, on the Lewis and Clark study site.

Spacing Interval	Spaced	
	Unsprayed	Sprayed
1.8m	1.11	1.14
3.6m	1.37	1.40
5.4m	2.00a	1.32a

a-significant difference between Unsprayed & Sprayed

Sprayed Versus Unspaced Regeneration. In comparing the sprayed areas with the unspaced naturally regenerated stand, percent organic matter at all three quadrat locations is pooled in each of the three tree spacing interval stands and in the unspaced naturally regenerated stand. Percent organic matter was higher in the unspaced naturally regenerated stand than in the sprayed areas in the 1.8m tree spacing interval stand (Table 14). The percent organic matter in the 3.6m and 5.4m tree spacing interval stands was higher in the sprayed areas than in the unspaced naturally regenerated stand. Since the differences between the two stands were not statistically significant, it appears that the herbicide treatment has had no effect on percent organic matter.

Table 14. Percent organic matter comparing spaced sprayed areas with an unspaced naturally regenerated stand on the Lewis and Clark study site.

Spacing Interval	Spaced Sprayed	Unspaced Regenerated
1.8m	1.14	1.25
3.6m	1.40	1.20
5.4m	1.32	1.15

Effects of Tree Harvest on pH

Unsprayed Versus Mature. It was expected that pH levels in the mature stand would be lower than pH levels in the various tree spacing interval stands, because needle and bark litter in older stands has had time to decompose, creating a more acidic mineral soil. This was the general trend on the Lewis and Clark study site (Table 15), although the differences were expected to be larger. Since none of the differences were statistically significant, the hypothesis is rejected.

Table 15. Measurements of pH comparing spaced unsprayed areas with a mature stand on the Lewis and Clark site.

Spacing Interval	Spaced Unsprayed	Mature
1.8m	4.7	4.7
3.6m	4.8	4.6
5.4m	4.7	4.6

Sprayed Versus Mature. It was expected that pH levels in the mature stand would be lower than pH levels in the various tree spacing interval stands, because needle and bark litter in older stands has had the time to decompose, creating a more acidic mineral soil. This was the general trend on the Lewis and Clark study site (Table 16), although the differences

Table 16. Measurements of pH comparing spaced sprayed areas with a mature stand on the Lewis and Clark site.

Spacing Interval	Spaced Sprayed	Mature
1.8m	4.7	4.7
3.6m	4.7	4.6
5.4m	4.7	4.6

were expected to be larger. Since none of the differences were statistically significant, the hypothesis is rejected.

Effects of Spacing Treatment on pH

Unsprayed Areas. The spatial distribution patterns of pH values differed at each quadrat location across tree spacing intervals. The high pH measurement near the bole occurred in the 3.6m tree spacing interval stand, while the low pH measurement occurred in both the 1.8m and 5.4m tree spacing interval stand (Table 17). At the dripline pH was highest in both the 1.8m and 3.6m tree spacing interval stand. At the midpoint pH levels did not vary across tree spacing interval stands. It was expected that pH would increase with increasing tree spacing intervals. Since this was not the case and since the differences in pH across tree spacing intervals were not statistically significant, pH was not affected by the density of lodgepole pine stands.

Table 17. Measurements of pH in each tree spacing interval, by quadrat location, for unsprayed areas on the Lewis and Clark study site.

Quadrat	Unsprayed Spacing Interval		
Location	1.8m	3.6m	5.4m
Bole	4.7	4.8	4.7
Dripline	4.7	4.7	4.6
Midpoint	4.8	4.8	4.8

Sprayed Areas. It was expected that the lowest pH measurements would occur near the bole in all three tree spacing interval stands. Higher pH measurements were expected in wide tree spacing intervals, with the highest pH measurements occurring at the midpoint in the 5.4m tree spacing interval stand. The results showed that the pH was highest at the midpoint in the 5.4m tree spacing interval stand (Table 18), but generally pH levels varied little in the sprayed areas. The most variation occurred at the midpoint, with the high pH level in the 5.4m tree spacing interval, the low pH level in the 3.6m tree spacing interval stand, and the intermediate level in the 1.8m tree spacing interval stand. Even this variation was not substantial enough to be significantly different. Without statistically significant differences, it appears that spacing interval has had no effect on pH.

Table 18. Measurements of pH in each tree spacing interval, by quadrat location, for sprayed areas on the Lewis and Clark study site.

Quadrat	Sprayed Spacing Interval		
Location	1.8m	3.6m	5.4m
Bole	4.7	4.7	4.7
Dripline	4.7	4.7	4.7
Midpoint	4.7	4.6	4.8

Unsprayed Versus Unspaced Regeneration. Measurements of pH in the unspaced naturally regenerated stand were higher than pH measurements in the unsprayed areas in the 1.8m and 3.6m tree spacing interval stands (Table 19). The pH level in the unsprayed areas of the 5.4m tree spacing interval stand and the pH levels in the unspaced naturally regenerated stand were the same.

It was expected that the pH in the unspaced naturally regenerated stand would be more similar to the narrow tree spacing interval stands than to the wider tree spacing interval stands, because trees in the 1.8m tree spacing interval stand and trees in the unspaced naturally regenerated stand are spaced close together. Since the differences in pH levels between the unspaced naturally regenerated stand and the unsprayed 3.6m and 5.4m tree spacing interval stands were not statistically significant, the hypothesis was not supported.

In fact, statistical analysis showed a significant difference between pH in the unspaced naturally regenerated stand and pH in the unsprayed 1.8m tree spacing interval stand, which also does not support the expected hypothesis. However, the data indicate that spacing interval does affect pH.

Table 19. Measurements of pH comparing spaced unsprayed areas with an unspaced naturally regenerated stand on the Lewis and Clark site.

Spacing Interval	Spaced Unsprayed	Unspaced Regenerated
1.8m	4.7b	4.8b
3.6m	4.7	4.8
5.4m	4.8	4.8

b-significant difference between Unsprayed & Unspaced Regenerated

Effects of Distance from the Tree on pH

Unsprayed Areas. The spatial distribution patterns of pH values differed along the bole to midpoint transect in each of the three tree spacing interval stands (Table 20). In the 1.8m tree spacing interval stand the high pH measurement occurred at the midpoint and the low pH measurements occurred near the bole and at the dripline, indicating that radial pattern may be present. In the 3.6m and 5.4m tree spacing interval stands, pH levels were highest near the bole and at the midpoint and lowest at the dripline, indicating nonsequential radial pattern. Since the differences in pH values between quadrats in all three tree spacing interval stands were not statistically significant, the evidence for radial pattern is considered weak. Also, this lack of significant differences indicates that distance from the trunk of the tree has no effect on pH.

Table 20. Measurements of pH in each tree spacing interval along the bole to midpoint transect for unsprayed areas on the Lewis and Clark study site.

Quadrat Location	Unsprayed Spacing Interval 1.8m	3.6m	5.4m
Bole	4.7	4.8	4.7
Dripline	4.7	4.7	4.6
Midpoint	4.8	4.8	4.8

Sprayed Areas. It was expected that the lowest pH measurements would occur near the bole in all three tree spacing interval stands. Higher pH measurements were expected farther from the bole of the tree, with the highest pH measurements occurring at the midpoint in the 5.4m tree spacing interval stand. The results showed that the pH was highest at the midpoint in the 5.4m tree spacing interval stand (Table 21), but generally pH levels varied little in the sprayed areas. Neither sequential or nonsequential radial pattern is indicated in the 1.8m tree spacing interval stand, since all pH values were 4.7. In the 3.6m and 5.4m tree spacing interval stands, the distribution pattern may indicate radial pattern, but without statistically significant differences in pH values between quadrats, the evidence must be considered weak at best. In the sprayed areas of the Targhee study site, pH levels varied little within each tree spacing interval stand, indicating that distance from the trunk of the tree has no effect on pH.

Table 21. Measurements of pH in each tree spacing interval by quadrat location along the bole to midpoint transect for sprayed areas on the Lewis and Clark study site.

Quadrat Location	Sprayed Spacing Interval 1.8m	3.6m	5.4m
Bole	4.7	4.7	4.7
Dripline	4.7	4.7	4.7
Midpoint	4.7	4.6	4.8

Unsprayed Versus Unspaced Regeneration. Measurements of pH in the unspaced naturally regenerated stand were higher than pH values in the unsprayed areas at the dripline (Table 22). At the midpoint levels of pH in the unsprayed stand were the same as pH values in the unspaced naturally regenerated stand. The measurements of pH in the unspaced naturally regenerated stand were higher at the midpoint and dripline than pH levels near the bole, indicating possible radial pattern. Since the differences in pH values between quadrats were not statistically significant, evidence for radial pattern in the unspaced naturally regenerated stand is considered weak. The lack of evidence and the pattern of spatial distribution could be caused by overlapping tree influence, because trees are spaced randomly and are closer together in the unspaced naturally regenerated stand. Since the differences are not statistically significant, the data indicates that distance from the bole of the tree does not effect pH.

Table 22. Measurements of pH comparing spaced unsprayed areas, by quadrat location, with an unspaced naturally regenerated stand on the Lewis and Clark study site.

Quadrat Location	Spaced Unsprayed	Unspaced Regenerated
Bole	4.7	4.7
Dripline	4.7	4.8
Midpoint	4.8	4.8

Effects of Herbicide Treatment on pH

Unsprayed Versus Sprayed by Quadrat Location. Levels of pH were higher in the unsprayed areas than in the sprayed areas at the midpoint on the Lewis and Clark study site (Table 23). No differences occurred in pH value between the unsprayed and sprayed areas at the dripline and near the bole. Since the differences in pH levels between the unsprayed and sprayed areas were not statistically significant, the herbicide treatment has had no effect on pH.

Table 23. Measurements of pH comparing spaced unsprayed and sprayed areas, by quadrat location, on the Lewis and Clark study site.

Quadrat Location	Spaced Unsprayed	Spaced Sprayed
Bole	4.7	4.7
Dripline	4.7	4.7
Midpoint	4.8	4.7

Sprayed Versus Unspaced Regeneration by Quadrat Location. Measurements of pH in the unspaced naturally regenerated stand were higher than pH values in the sprayed areas at the dripline (Table 24). The levels of pH in the unspaced naturally regenerated stand were slightly higher than pH levels in the sprayed areas of the study plot. Since the differences in pH levels between the unspaced naturally regenerated stand and the sprayed areas were not statistically significant, the herbicide treatment has had no lasting effect on pH.

Table 24. Measurements of pH comparing spaced sprayed areas, by quadrat location, with an unspaced naturally regenerated stand on the Lewis and Clark study site.

Quadrat Location	Spaced Sprayed	Unspaced Regenerated
Bole	4.7	4.7
Dripline	4.7	4.8
Midpoint	4.7	4.8

Unsprayed Versus Sprayed by Spacing Interval. Levels of pH were higher in the unsprayed areas than in the sprayed areas of the 5.4m tree spacing interval stand (Table 25). The pH levels were the same in the unsprayed and sprayed areas in both the 1.8m and 3.6m tree spacing interval stands. Since the differences in pH levels between the unsprayed and sprayed areas were not statistically significant, the herbicide treatment has had no effect on pH.

Table 25. Measurements of pH comparing spaced unsprayed and sprayed areas, by tree spacing interval, on the Lewis and Clark site.

Spacing Interval	Spaced Unsprayed	Spaced Sprayed
1.8m	4.7	4.7
3.6m	4.7	4.7
5.4m	4.8	4.7

Sprayed Versus Unspaced Regeneration. Measurements of pH in the unspaced naturally regenerated stand were higher than pH measurements in sprayed tree spacing interval stands (Table 26). Since the differences in pH levels between the unspaced naturally regenerated stand and the sprayed areas were not statistically significant, the herbicide treatment has had no lasting effect on pH.

Table 26. Measurements of pH comparing spaced sprayed areas with an unspaced naturally regenerated stand on the Lewis and Clark site.

Spacing Interval	Spaced Sprayed	Unspaced Regenerated
1.8m	4.7	4.8
3.6m	4.7	4.8
5.4m	4.7	4.8

Effects of Tree Harvest on Nitrate-nitrogen

Unsprayed Versus Mature. Nitrate-nitrogen levels in the unsprayed areas of the 3.6m and 5.4m tree spacing interval stand were higher than the nitrate-nitrogen level in the mature stand (Table 27). Nitrate-nitrogen levels in the mature stand were higher than the nitrate-nitrogen levels in the unsprayed areas of the 1.8m tree spacing interval stand. Since the differences in nitrate-nitrogen between the unsprayed areas and the mature stand were not statistically significant, the data indicates that the age of the lodgepole pine stand has no effect on nitrate-nitrogen.

Table 27. Nitrate-nitrogen levels (mg/kg) comparing spaced unsprayed areas with a mature stand on the Lewis and Clark study site.

Spacing Interval	Spaced Unsprayed	Mature
1.8m	0.2	0.3
3.6m	0.8	0.3
5.4m	0.7	0.3

Sprayed Versus Mature. Nitrate-nitrogen levels in the sprayed areas of the 3.6m and 5.4m tree spacing interval stand were higher than the nitrate-nitrogen level in the mature stand (Table 28). The nitrate-nitrogen level in the mature stand was higher than the nitrate-nitrogen level in the sprayed areas of the 3.6m tree spacing interval stand. Since the differences in nitrate-nitrogen between the sprayed areas and the mature stand were not statistically significant, the data indicates that the tree harvest pine stand has no effect on nitrate-nitrogen.

Table 28. Nitrate-nitrogen levels (mg/kg) comparing spaced sprayed areas with a mature stand on the Lewis and Clark study site.

Spacing Interval	Spaced Sprayed	Mature
1.8m	0.4	0.3
3.6m	0.2	0.3
5.4m	0.5	0.3