EFFECTS OF PRESCRIBED FIRE AND THINNING AS FUEL REDUCTION TREATMENTS ON THE SOILS OF THE CLEMSON EXPERIMENTAL FOREST

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ABSTRACT

Fire suppression on forested lands has been a standard practice for the last several decades resulting in increased fuel loads. Now more than ever, there is a need to reduce increasing fuels in our forest. This thesis is a component of the National Fire and Fire Surrogates Study (FFS). The Fire and Fire Surrogates Study takes place in thirteen sites (5 in the East and 8 in the West) across the United States as an integrated national network of long-term interdisciplinary research to facilitate broad applicability of fuel impacts. This part of the FFS study, in Clemson, S.C., looks at two ways of reducing fuel loads (prescribed burning and thinning). Each of these techniques seems to have a unique effect on forest soils. Soil variables studied were as follows: carbon (concentrations), nitrogen (concentratios), C:N for both the O and A/Bt horizons, bulk density, net mineralization, proportional mineralization, total exchangeable capacity, pH, and concentrations of sulfur, phosphorus, calcium, magnesium, potassium, sodium, boron, iron, manganese, copper, zinc and aluminum for the A/Bt horizon. Of these variables, prescribed burning caused a decrease in proportional mineralization, a decrease in carbon and nitrogen concentrations in the O horizon and a decrease in total exchange capacity and zinc concentration. Prescribed burning also increased pH in mineral soil. Thinning caused a decrease in iron concentration in the mineral portion and a decrease in carbon and nitrogen concentrations in the O-horizon. Unlike prescribed burning, thinning caused an increase in potassium, magnesium, and pH in the mineral soil. Thinning also increased bulk density. These changes were relatively small and may be only short term for both thinning and prescribed burning. The results seem minimal as

long as the prescribed burns are not intensive and the proper thinning techniques are used.

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TABLE OF CONTENTS

Table of Contents (Continued)

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

Introduction

Over the last several decades, fire suppression on forested lands has been a standard practice. As a result, there has been a tremendous increase in forest fuel loads resulting in many large-scale wildfires. These wildfires have greatly affected biomass levels and ecological productivity. In order to prevent these large-scale wildfires, fuel reduction must take place. There are several ways to reduce these fuel loads. The two studied herein are prescribed fire and thinning.

This thesis is a component (soils and forest floor) of the National Fire and Fire Surrogates Study (FFS). The Fire and Fire Surrogates Study takes place on thirteen sites in the United States:

1. Mission Creek, North-Central Washington, Wenatchee National Forest.
2. Hungry Bob, Blue Mountains of Northeast Oregon, Wallowa-Whitman National Forest.
3. Lubrecht Forest, University of Montana, Northern Rockies, Western Montana.
4. Southern Cascades, Northern California, Klamath National Forest.
5. Blodgett Forest Research Station, University of California-Berkeley, Central Sierra Nevada, California.
6. Sequoia National Park, Southern Sierra Nevada, California (satellite to Blodgett Forest Research Station Site).
7. Southwest Plateau, Coconino and Kaibab National Forests, Northern Arizona.
8. Jemez Mountains, Santa Fe National Forest, Northern New Mexico.

9. Ohio Hill Country, lands managed by the Ohio Division of Forestry and Mead Paper Corporation.

10. Southeastern Piedmont, Clemson Experimental Forest, Northwestern South Carolina.

11. Southern Coastal Plain, Myakka River State Park, Southwest Florida.

12. Gulf Coastal Plain, Solon Dixon, Andalusta, Alabama.

13. Southern Appalachian Mountains, Green River Game Management Area, Polk County, North Carolina.

The FFS uses four types of treatments in each site. These are an untreated control, prescribed fire only with periodic reburns, thinning, and a combination of thinning and then prescribed burning. Each of these treatment areas is replicated at least 3 times at each research site, using either a completely randomized or randomized block design as appropriate to the research site. In addition, each treatment area is 10-ha and has a buffer present. There are core response variables within the general groupings of vegetation, fuel and fire behavior, soils and forest floor (including relation to local hydrology), wildlife, entomology, pathology and treatment cost and utilization. The major objectives of the Fire and Fire Surrogate study are as follows (Executive Summary from the Final Proposal):

1. Quantify the initial effects (first five years) of fire and fire surrogate treatments on a number of specific core response variables (mentioned above).

2. Provide an overall research design that (a) establishes and maintains the study as an integrated national network of long-term interdisciplinary research sites utilizing a common "core" design to facilitate broad applicability of results; (b) allows each site to be independent for purposes of statistical analysis and modeling, as well as being a component of the national network; and (c) provides flexibility for investigators and other participants responsible for each research site to augment-without compromising-the core design as

desired to address locally-important issues and to exploit expertise and other resources available to local sites.

3. Within the first five years of the study, establish cooperative relationships, identify and establish network research sites, collect baseline data, implement initial treatments, document treatment costs and short-term responses to treatments, report results, and designate FFS research sites as demonstration areas for technology transfer to professionals and for the education of students and the public.

4. Develop and maintain an integrated and spatially-referenced database format to be used to archive data for all network sites, facilitate the development of interdisciplinary and multi-scale models, and integrate results across the network.

5. Identify and field test, in concert with resource managers and users, a suite of response variables or measures that are: (a) sensitive to the fire and fire surrogate treatments; and (b) both technically and logistically feasible for widespread use in management contexts. This suite of measures will form much of the basis for management monitoring of operational treatments designed to restore ecological integrity and reduce wildfire hazard.

6. Over the life of the study, quantify the ecological and economic consequences of fire and fire surrogate treatments in a number of forest types and conditions in the United States. Develop and validate models of ecosystem structure and function, and successively refine recommendations for ecosystem management.

This thesis is the soils component of the Southeastern Piedmont portion of the FFS study. This project's objective is to study the effects of these different treatments on soils and involves pre-and-post treatment sample analysis of the soils under the different treatments. Specific objectives are as follows:

1. To determine pre and post treatment mineralization/nitrification levels (net and proportional values).

2. To determine pre and post treatment carbon and nitrogen concentrations in the O and A horizons and macronutrient content in the A horizon (first 10 cm, sometimes containing the upper part of the Bt horizon).

3. To determine pre and post treatment bulk density levels of A/Bt horizons.

4. To map plot disturbance (bare ground and skid trails).

CHAPTER II

LITERATURE REVIEW

Thinning

Different silvicultural practices have shown negative, positive, and even no effect on soil properties. The type of harvesting practice (single tree selection, row thinning, clear cutting, etc.) may determine the degree of soil disturbance. For the most part, more soil disturbance has occurred as a result of clearcutting (Olsson 1996, Johnson 2001, Prescott 1997, Holmes 1999, Walley 1996, Weston 1996) . This was attributed to total site disturbance (removal of every tree) and soil scarification (extensive felling and skidding).

Negative Effects of Thinning

Canopy removal during harvesting influences both soil temperature and moisture regimes. The physical effects of ground-based skidding may include soil structural change, which influences water retention and flow, along with reductions in aeration and root penetration (Ballard 2000). This reduction of porosity results in a loss of saturated hydraulic conductivity, which limits soil infiltration capacity (impedes gases). Froehilich's (1978) studies found that the greatest changes in soil bulk density are associated with the first few trips over the ground, and even low ground pressures (e.g. 35-65 kPa) can result in substantial compaction. This implies that less intensive logging may cause these changes as well. Intensive logging can also expose mineral soil to erosive rainfall, which may cause significant localized nutrient removals (Ballard 2000).

This may negatively influence some soil biota also. Some of their food sources may be removed and substantial habitat changes may occur. Whole tree harvesting may result in increased bulk density along with decreases in content of organic matter, total nitrogen, sulfur, and exchangeable calcium in the upper layers (Merino 1998). Merino (1998) also found that these decreases in organic matter led to a higher potential for soil erosion. Negative changes in soil chemistry have also been noted. Soil pH has been shown to decrease with clearcutting (Johnson 1991). Acidification of the E and B horizons may have been a result of increased production of H through nitrification and mobilization of Al from the forest floor and mineral soil (Johnson 1991).

Positive Effects of Thinning

Some studies have shown positive effects of harvesting. A harvesting study in Wyoming found increases in soil N supply, increase in KCl extractable N, increased net N mineralization rates, and larger pine seedlings in bioassays following a clearcut (Giardiana 2001).

Single tree selection or other types of less intensive thinning do not seem to have any effects on soil properties (excluding some minor changes in bulk density mentioned above and acute variations in soil chemistry). Johnson (2001) found that on average, forest harvesting in North America, had little or no effect on soil C and N. Concentrations of C and N may have a slight decrease within the first year of harvesting but it is not substantial or prolonged (Knoepp 1997). Backing up this theory is the idea that some of the losses of nutrients and the forest floor are not actually lost. Mechanical mixing into underlying mineral soil may also account for the loss of the forest floor observed between the preharvest condition and the second growing season after whole-tree harvesting (Ryan 1992). This result may depend upon the intensity of the harvesting operation. Some operations harvesting 65% of the stand surface area resulted in the removal of 25% of the forest floor (Ryan 1992). Depending on terrain and harvesting procedures, percentages may be more or less than noted above. Some of these differences in results could be caused by the yearly climate differences between pre and post treatment sampling times. The variability in the mechanical thinning mentioned above also could have accounted for the inconsistency in the results of the studies.

Prescribed Burning

Prescribed burning, as a silvicultural management tool is very contradictory in the literature. Like thinning, this also has produced a variety of results on soil properties. The effects (where noted) are dependent upon the intensity and frequency of the management technique. In general, severe burns have a greater effect on the soil properties than do less intensive burns according to the studies where negative effects were noted (Ballard 2000, Johnson 1992, Vose 1999, Covington 1992, Bird 1999, Debano 1979, Knoepp 1993, Kovaic 1986). Phillips (2000) found that periodic burns in oak forests in middle Tennessee did not significantly alter organic matter or bulk density; however, annual burns showed an increase in bulk density and lower organic matter contents.

Negative Effects of Prescribed Burning

Prescribed fire results in substantial nutrient losses through volatilization (notably of N and S) and in some cases fly-ash losses (losses of particulate matter in the smoke column). Hydrolysis of oxides results in increased soil pH and both the magnitude and the duration of the pH changes are influenced by soil- buffering capacity (Ballard 2000). Severe losses of nitrogen are a result of fire (Grogen 1999). Monleon (1997) found that net N mineralization decreases significantly after prescribed burning. Most of the documented losses of N are only short term and return to pre treatment conditions within one year (Monlenon 1997, Knoepp 1997, DeLuca 2000). Since Mckay (1998) found that soil fertility is closely related to pH and cation exhange capacity and Thomas (1996) found that soil pH is the most informative measure that can be made to determine soil characteristics, it is very important to consider the effects of prescribed fire on these factors. Ballard (2000) found that hydrophobicity sometimes results from prescribed burning. The process of hydrophobicity of a soil is the result of a waxy substance that (derived from plant material) is burned and penetrates the soil as a gas then solidifies as it cools to form a waxy coating. Hydrophobicity is also sometimes caused by soil fungi that excrete substances that make the litter and surface layer repel water and reduces the amount of water infiltration into the soil.

Soil texture plays an important role in the effect that prescribed burning has on the soil. Ballard (2000) found that coarse-textured soils are especially susceptible to development of extreme hydrophobicity, because of their low specific surface. Some researchers postulate that frequent prescribed fires would eventually deplete exchangeable base stocks in a soil because of frequent liberation for leaching (Mckay 1998)

Positive Effects of Prescribed Burning

Some studies have found that burning increases the availability of most plant nutrients (Debano 1990). This provides the soil substrate needed for vigorous seedling growth, which is very important in timber management implications. The highest ammonium N is found immediately following a prescribed fire (Debano 1990). However, burns do not readily affect nitrate N concentrations. Knoepp (1993) notes that soil ammonium (NH4+) content increased significantly in three paired watersheds treated with a fell and burn prescription but there was no change in soil nitrate. These are generalizations but some variations are due to soil conditions at the time of the burn and the intensity of the burn. Covington (1986) showed increases of ammonium as much as twenty-fold and burning in some forest types may cause increase in soil pH. Jorgensen (1971) noted that in loblolly pine forests of the South Carolina Coastal Plain prescribed burning resulted in nitrogen increases of 23 kg/ha/year. Some soil properties are more susceptible to fire than others. Nutrients and properties (structure and wettability) have different threshold temperatures (Table. 1). Soil moisture directly affects the prescribed fires, since dry soil is a poor conductor of heat (Debano 1990). Prescribed fires should be conducted when the soil and litter have a lower moisture content. When soils and litter are dry at the time of burning, more total nitrogen is lost (Debano 1979).

With the exception of high intensity burns, most research indicates that prescribed burning does not affect soils (Ballard 2000, Johnson 1992, Vose 1999, Covington 1986, Bird 1999, Debano 1979, Knoepp 1993, Kovaic 1986). Vose's (1999) studies in southern Appalachian pine-hardwood ecosystems found that soil and stream chemistry showed no response to burning. Binkley (1992) found that on the Coastal Plain of South Carolina, burning in loblolly and longleaf pine forest soils showed only slight differences in nitrogen, sulfur, acidity and extractable cations. Slight changes in soil chemistry have

Table 1. "Threshold temperatures for insensitive, moderately sensitive, and sensitive soil properties." (Debano 1990).

Soil Property		Threshold Temperature[+]	
Relatively Insensitive		°C	°F
Potassium and Phosphorus		774	(1425)
Calcium		1484	(3150)
Manganese		1962	(3564)
Clay destruction		980	(1796)
Moderately Sensitive			
Organic Matter		100	(212)
Nitrogen		200	(392)
Sulfur		375	(707)
Soil structure		300	(572)
Soil wettability		250	(482)
Sensitive			
Bacteria	Wet	110	(230)
	Dry	210	(410)
Nitrosomas bacteria	Wet	75	(167)
	Dry	140	(284)
Fungi	Wet	100	(212)
	Dry	155	(311)
VAM (Vesicular-Arbuscular Mycorrhizas)		94	(201)
Glowing combustion		650	(1202)
Flame temperatures		1100	(3542)

[+]*Temperature at which detectable changes of a soil property begin in response to…* (Debano 1990).

been recorded but generally result in the same conclusions as above. Some variations in the differences noted may have been because of climate, burning conditions, and burning intensity. Measurements taken immediately after burning in red pine (*Pinus resinosa*), eastern hemlock (*Tsuga Canadensis*), and Douglas-fir (*Pseudotsuga menziesii*) forests showed total and available N losses from the O1 horizons but gains in total and available N in underlying layers (Mroz, 1980). Also, Johnson (1992) found that in Monterey pine (*Pinus radiata*) forests, low intensity prescribed fire usually resulted in little change in soil C, but intense prescribed fire or wildfire can result in a large loss of soil C.

Time of sampling may be the major factor of varying results found in various studies. This factor along with the effects studied should be dependent upon the management objectives, i.e., long-term vs. short-term. There could be significant effects on certain long-term properties. Johnson (2001) noted that in his studies of North American forests, fire resulted in no significant overall effects on either C or N (when categories were combined), but there was a significant effect of time since fire with an increase in both soil C and N after 10 years (compared to controls). Boerner (2000) found that one month after prescribed fires in Ohio, mixed-oak forest total inorganic nitrogen was not significantly different from prior levels in either burned or unburned watersheds.

In conclusion, when determining the effects of these forest management practices, all available factors should be taken into consideration (intensity, conditions, time of year, etc.). Management objectives will determine the time window of the effects of the study. The effects of thinning and prescribed fire are not consistent in the literature because of the variation in site composition, study times, intensity of treatments, etc.

Based on the body of literature, both thinning and prescribed fire treatments do not have significant effects on soil properties as long as they are not conducted intensively.

CHAPTER III

METHODS

The Study Area

The study was conducted on the Clemson Experimental Forest located near Clemson, South Carolina (Figure 1).

The Clemson Experimental Forest is located in the upper Piedmont of South Carolina. The types here mostly loblolly (*Pinus taeda*), shortleaf (*Pinus echinata*), virginia (*Pinus virginiana*) and eastern white pines (*Pinus strobus*) along with yellow-poplar (*Liriodendron tulipifera*) and a variety of oaks, including white (*Quercus alba*), southern red (*Quercus falcata*), water (*Quercus nigra*), and scarlet (*Quercus coccinea*). The site index in the Piedmont province for loblolly pine is usually between 70 and 80 ft tall at base age 50. Elevations are between 700 and 1,100 feet above mean sea level. The mean annual temperature is approximately 16°C with an average of 122 cm to 132 cm of rainfall per year with mild droughts from June through September (Myers 1986). The forest is 17,500 acres and is a result of the Clemson College Community Conservation Project (Sorrells 1984). This project started in the early 1930's. This reclamation process was a result of the high percentage of poorly farmed land in the early 1900's (as a result of the agricultural surge caused by World War I, Figures 2 and 3). This project originally consisted of 35,000 acres but after the construction of Lake Hartwell, approximately half of the original land was below water. Of the 17,500 total acres remaining, about 350-400 acres were used in this study. Stands selected were dominated

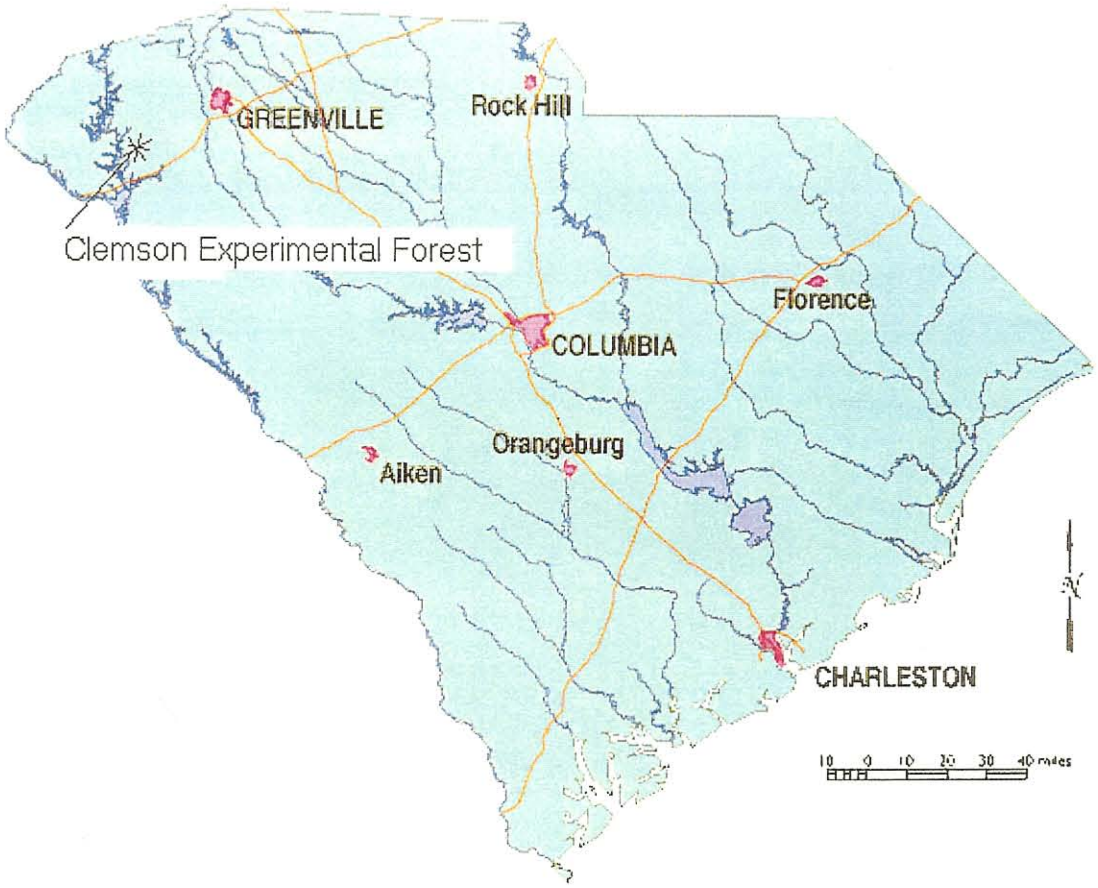


Figure 1. Study site location.

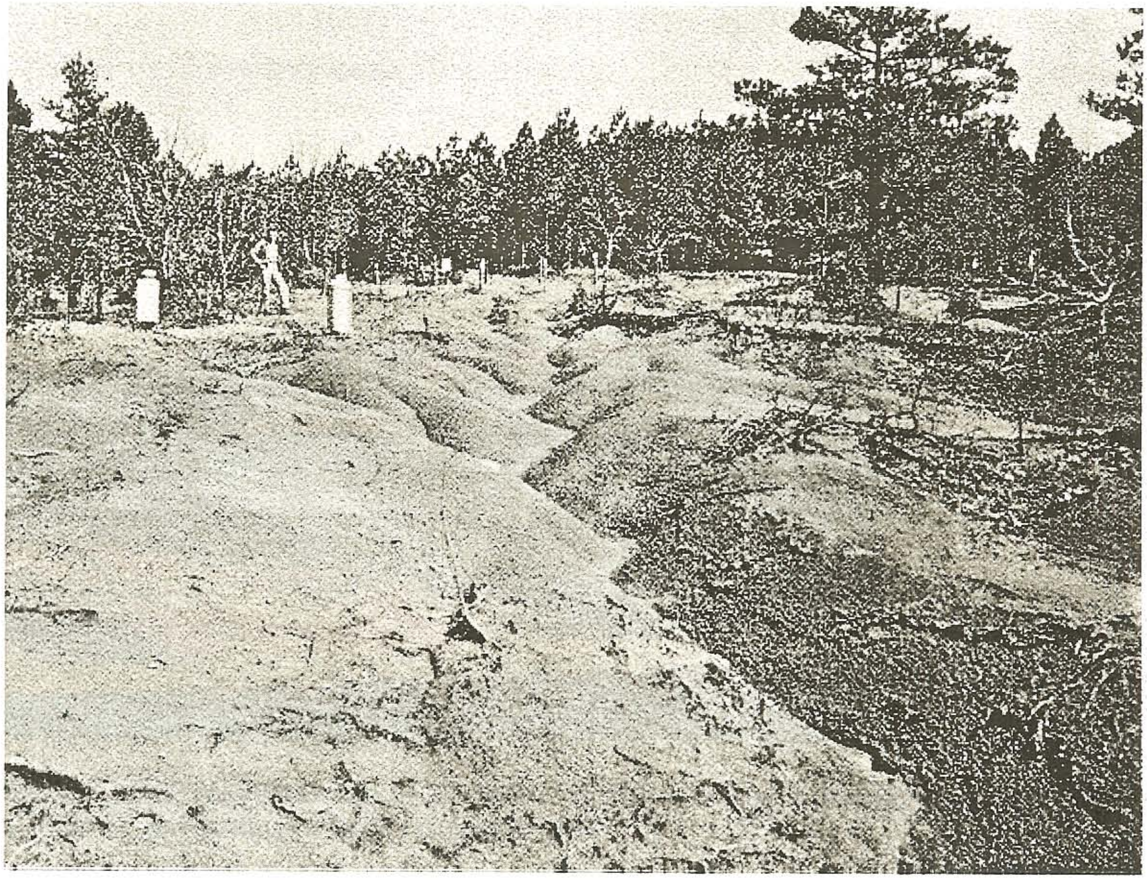


Figure 2. In the pre-reclamation era of Clemson Experimental Forest erosion was a major problem (Sorrells 1984).

Figure 3. The reclamation era of Clemson Experimental Forest erosion control often resulted in the planting of kudzu (Sorrells 1984).

by loblolly pine or shortleaf pine mixed with other hardwoods in the under and mid-story. These stands range in tree size classes from predominately pulpwood to predominately sawtimber sized tree classes (Table 2).

Table 2. Tree size class and diameter by block.

Block/Rep	Tree Size Class	Tree Size dbh (cm)
1	Pulpwood	15-25
2	Mixed Pulpwood and Sawtimber	15-25, >25
3	Sawtimber	>25

The parent material of the soil consists of phyllites, granites, gneisses and various schists formed in the late Precambrian to early Paleozoic age (Sorrels 1984). The soils are mostly Ultisols with moderate to extreme erosion (Sorrels 1984). The soils studied here are mostly Typic Hapludults and Typic Kanhapludults. The soils series found on these sites are of Pacolet (fine, kaolinitic, thermic Typic Kanhapludults), Madison (fine, kaolinitic, thermic, Typic Kanhapludults), Cecil (fine, kaolinitic, thermic Typic Kanhapludults), and Tallapoosa (loamy, mixed, semiactive, thermic, shallow Typic Hapludults) (Table 3).

Table 3. Stand Soil Series Description (National Cooperative Soil Survey 1958,1966).

Rep	Treatment	Soil Series (texture).
1	Control	Madison (sandy loam).
1	Thin	Pacolet (clay loam), Cecil (sandy loam, clay loam).
1	Burn	Pacolet (sandy loam), Madison (sandy loam).
2	Control	Pacolet (sandy loam), Madison (sandy loam).
2	Thin	Cecil (sandy loam), Pacolet (sandy loam).
2	Burn	Madison (sandy loam, clay loam), Tallapoosa (loam), Pacolet (fine sandy loam).
3	Control	Cecil (sandy loam).
3	Thin	Madison (sandy loam).
3	Burn	Madison (sandy loam), Pacolet (fine sandy loam).

Field Methods and Data Analysis

Nine stands were selected within the Clemson Experimental Forest based on preset parameters (there are two treatments, a control and three replications of each). The two main criteria for these stands were that stand composition should be predominately pine and that there was no cutting in the past 10 years and no fire in the last 5 years. These 30-40 acre stands are predominately pine/hardwood of various age and tree diameter classes (Table 2).

Plot Installation

Grid points with spacing of 50 x 50 meters were generated using ArcView and overlaid on National Aerial Photography Program Color Infrared (NAPP CIR) 1:40,000 aerial photos of the treatment areas. Distinct objects were located on each map and used as reference points for laying out the grid points. USDA Forest Service crews installed grid points along a middle line run in the direction of the long axis of the treatment area. Tapes and compasses were used to measure the distance to and from each grid point in

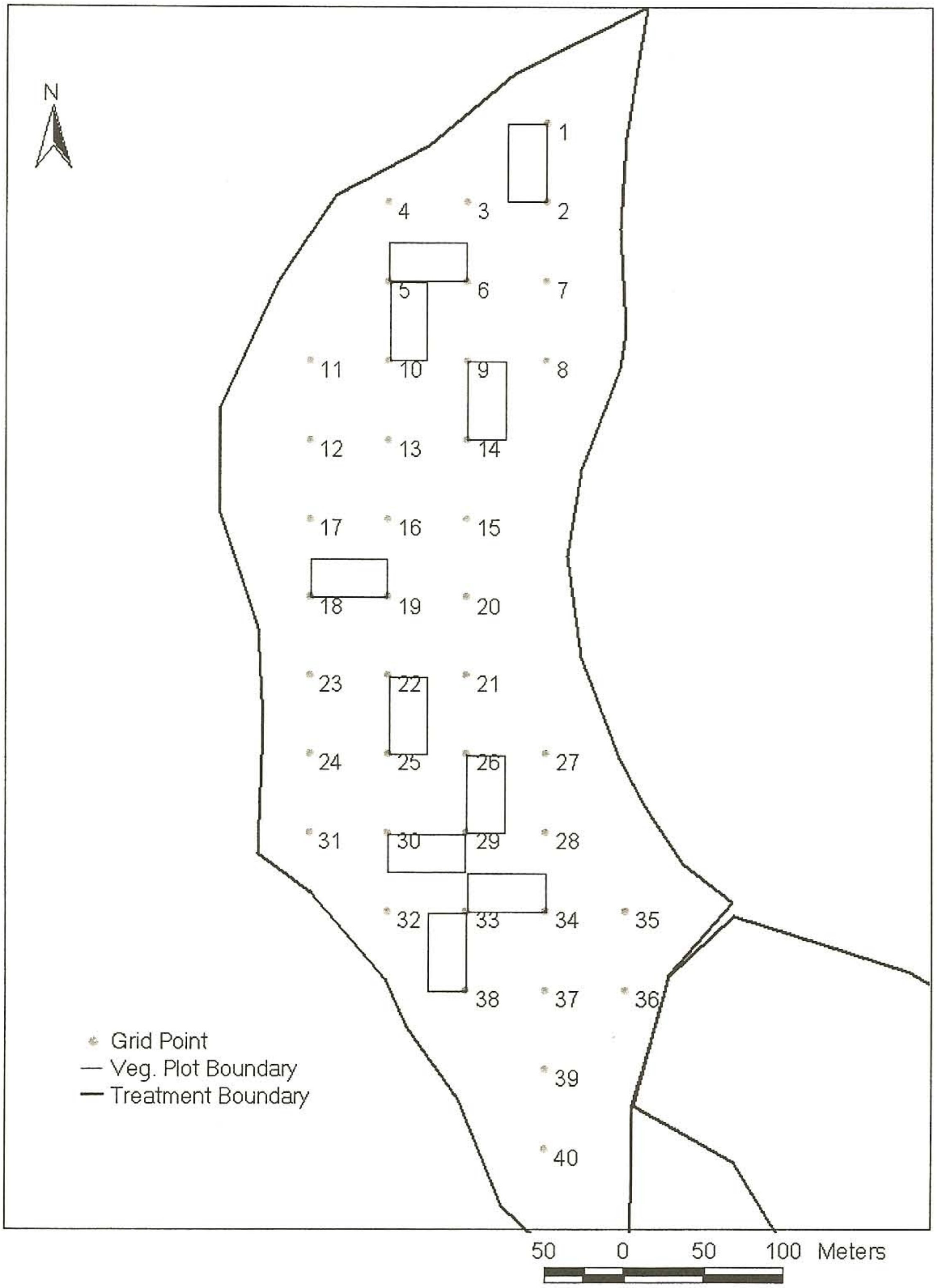


Figure 4. Typical stand map showing grid points, vegetation plot boundaries and treatment boundaries.

Soil Sampling

Within each of the nine stands, there are ten 20 x 50 meter plots in which the soil sampling took place. From each plot, 20 soil samples were taken (the O horizon and the first 10 cm of mineral soil). Twelve samples (6 from the O horizon and 6 from the A and/or upper Bt horizon) were taken for carbon, nitrogen and macronutrient analysis (Figure 5). These samples were taken 1.5-2 m towards the center of the plot along each transect (Figure 5). Four more samples from the A horizon were used to determine mineralization/nitrification rates (Figure 6). The other four (A horizon) samples of the twenty were placed back in the ground for a 20-30 day in-situ period. After this period, these samples were tested for mineralization and nitrification and contrasted to the prior samples.

The carbon, nitrogen and macronutrient concentrations (C, N, C:N, TEC, pH, Soluble Sulfur, P, Ca, Mg, K, Na, H, B, Fe, Mn, Cu, Zn, and Al for the A horizon and C, N, for the O horizon) levels were obtained by compositing the soil samples (O and A, on a per plot basis) and then contracting the lab analysis work (Brookside Laboratories, Inc). The C and N concentrations, and C:N ratios were tested by using a Carlo Erba 1500NA Carbon/Nitrogen analyzer. The pH was tested by performing a 1:1 soil to water pH. All of the cations and anions are Mechlich III extractable and determined on a Jarrel Ash 61EIP. The organic matter was tested by using a 360° ash method (loss on ignition). The F, E, B, and A subplot samples were taken 2m from each corner pin transecting toward the inside of the plot at 45° angles (Figure 6). The D and C subplot samples were taken at the mid points between each subplot and transecting 2 m toward the middle of the plot (Figure 5).

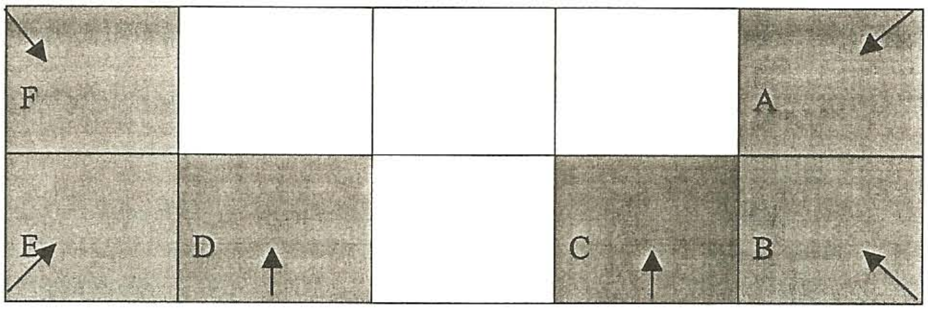


Figure 5. Carbon, nitrogen and macronutrient sampling locations.
[1]Gray shaded regions = subplot location.
[2]Carbon/Nitrogen/Macronutrient is taken on all lettered subplots.
[3]Lines correspond to sample location transect.

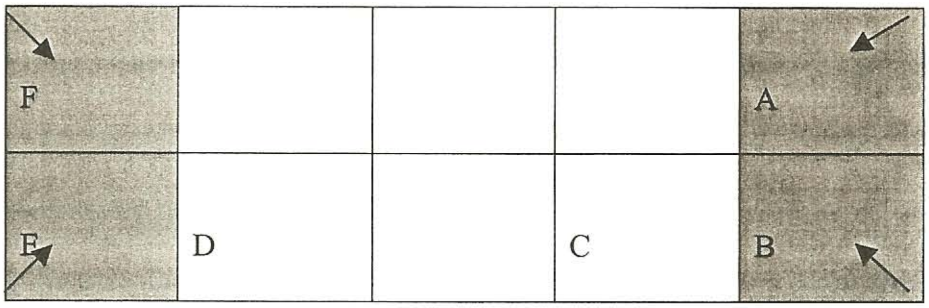


Figure 6. Mineralization and nitrification sampling locations
[1]Gray shaded regions = nitrification sample subplot location.
[2]Mineralization and nitrification is taken on F,E,B,A,
[3]Lines correspond to sample location transect.

The sample locations for mineralization/nitrification were taken on the F,E,B, and A subplot samples 1.5m from each corner pin transecting toward the inside of the plot at 45° angles (Figure 5).

These mineralization/nitrification samples were analyzed by KCl extraction. Net and proportional mineralization were calculated as follows:

Net = (After NH_4 + After NO_3) – (Before NH_4 + Before NO_3).

Proportional = (After NO_3 – Before NO_3) / (Before NH_4 + Net).

Where "Before" refers to samples taken at initial retrieval and "After" refers to samples collected after a 20-30 day *insitu* period.

There were 10 bulk density samples taken per plot (5 on each 50 meter side). These bulk density samples were taken by using a soil sampler (slide hammer) and a series of rings. The locations of these samples were on the long side of each plot. The samples were taken starting 5 meters from the bottom corner of the plot and then every 10 meters until the fifth sample was taken. Samples were taken along the adjacent side at the same distance along the long axis of the plot (Figure 7). Each of these sample points were offset 2-5 meters outside the plot to compensate for boundary soil compaction (due to extensive research activity).

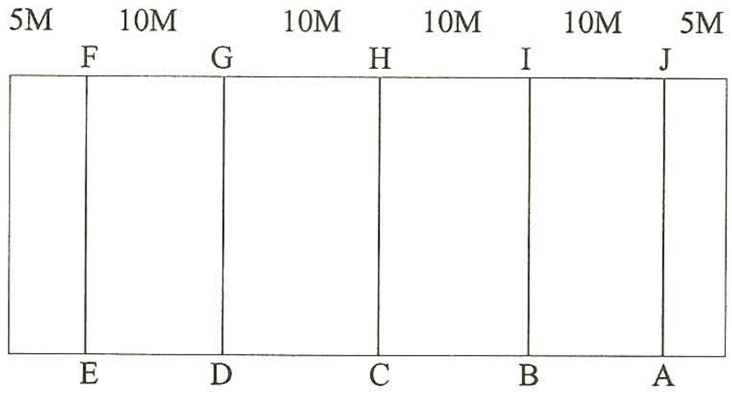


Figure 7. Bulk Density and Penetrometer Sample Location.

After collection, these samples were oven dried at 104°C for 16-24 hours. The samples were then weighed and used to calculate the bulk density (gms/cm^3) for each single unit. These measurements were then averaged by plot to determine mean bulk density (pre/post treatment).

Ten penetrometer measurements (to a 7.5cm depth) were taken at the same points as bulk density. These penetrometer measurements were likewise averaged on a per plot basis (pre-treatment) and used to show the difference (if any) among the treatments. Pre-treatment readings were collected, however, we did not collect post treatment readings due to extreme variability in the readings.

Bare ground and skid trail disturbance were mapped in the field by hand using a 50-meter tape (this disturbance was classified as greater than one meter in diameter), and digitally reproduced/mapped.

Analytical Procedures

Analysis of Variance

To describe the effect of treatment, we used Analysis of Variance and Covariate Analysis (SAS 1991). Each treatment type was grouped by variable and then compared and contrasted to each different treatment type. The variables tested were mean bulk density, net mineralization, proportional mineralization, carbon, nitrogen, C and N ratios for both the O and A/Bt horizons and total exchange capacity, pH, phosphorous, calcium, magnesium, potassium, hydrogen, boron, iron, manganese, copper , zinc and aluminum in the A/Bt only. Analysis of covariance is a procedure for comparing treatment means that incorporates information on a quantitative variable "x" (Ott 1993). In this study the pre-treatment data collected were used as the covariate. Doing this would take into account pre-treatment differences that were already present. Box and Whisker outlier analysis along with scatter plots were done on the original pre-treatment data to determine extreme outliers. There was no need to do further outlier analysis since the large sample size and compositing of some samples would diminish the effect of any extreme outliers.

Burn Treatment

The following burning information was provided by Ross Phillips, USDA Forest Service, Southern Research Station, Clemson, S.C. (personal communication). Each treatment area was burned as a separate burn unit in April 2001. Replication 1 was burned on April 10. Fire lines were almost unnecessary as the treatment area is bounded by Lake Hartwell on the west and an existing logging road on the east. Hand lines were established on small portions of the north and south sides. A backing fire was set by hand at 1230 hrs along the northeast side to burn into a southwesterly wind. Strip headfires were set in parallel lines approximately 3 to 5 meters apart. Relative humidity was 51% at the time the fire started and dropped to a low of 42% at 1520 hrs. Temperatures ranged from 22°C at 1230 hrs to 30°C at 1520 hrs. Eye-level wind speeds ranged from 5 to 8 km/hr and were mainly from the southwest. Forest floor samples were collected at 1030 hrs; moisture content was found to be 91% for the duff and 17% for the litter layer (Table 4). Moisture content of 10-hr timelag fuels was 13% at 1030 hrs.

Table 4. Percent moisture content of various fuel components collected one hour prior to ignition in each burn-only treatment area (data provided by the fuels crew of the National Fire and Fire Surrogate Study).

	Replication 1	Replication 2	Replication 3	All Replications (Avg.)
Litter	16.55	16.76	12.91	15.45
Duff	91.47	58.77	70.30	73.58
1-hr fuels	12.40	14.29	12.76	13.12
10-hr fuels	12.85	14.83	12.05	13.20
100-hr fuels	27.92	26.73	27.41	27.37
Forbs	197.83	188.55	447.22	307.20
Grasses	59.46	88.07	76.93	69.67
Shrubs	153.79	141.68	105.47	135.32
Vines	94.47	119.71	97.13	100.83

Fire intensity was generally low with flame heights below 1 m. Heat-sensitive paints placed on tiles 1 m above ground showed temperatures generally below 150°C throughout the burn unit. Occasional hot spots occurred in areas where southern pine beetle attacks created unusually high fuel loads. In these areas, flames reached into the crowns of dead trees and temperatures reached as high as 350 to 400°C. Flames covered the entire burn unit and all burning was completed by 1700 hrs.

Replication 3 was burned on April 11, 2001. Existing logging roads were used as fire lines on the east and south sides and the majority of the west side. Hand lines were established along the north side. A backing fire was set by hand at 1230 hrs along the north side to burn into a southerly wind. Flanking fires were set perpendicular to the backing fire; each was approximately 10 m long. Spot fires were used throughout the burn unit to burn areas not covered by the flanking fires.

Relative humidity was 46% at the time the fire started and remained at that level much of the afternoon. Temperatures ranged from 24°C at 1230 hrs to 29°C at 1515 hrs. Eye-level wind speeds ranged from 4 to 9 km/hr and were mainly from the south. Forest floor samples were collected at 1030 hrs; moisture content was found to be 59% for the duff and 17% for the litter layer. Moisture content of 10-hr timelag fuels was 15% at 1030 hrs.

Fire intensity was moderate with flame heights generally between 1 and 2 m. Heat-sensitive paints showed temperatures ranging from 100 to 200°C throughout the burn unit. Occasional hot spots occurred in areas where southern pine beetle attacks created unusually high fuel loads. In these areas, temperatures reached 300°C. Flames covered the entire burn unit and all burning was completed by 1900 hrs.

Replication 2 was burned on April 12, 2001. An existing road was used as a fire line on the east side but plowed lines were necessary on all other sides. A backing fire was set by hand at 1100 hrs along the northern side to burn into a southerly wind. Strip headfires were set in parallel lines approximately 3 to 5 meters apart.

Relative humidity was 56% at the time the fire started and dropped to a low of 45% at 1600 hrs. Temperatures ranged from 23°C at 1230 hrs to 29°C at 1545 hrs. Eye-level wind speeds ranged from 5 to 10 km/hr and were mainly from the south. Forest floor samples were collected at 1000 hrs; moisture content was found to be 70% for the duff and 13% for the litter layer. Moisture content of 10-hr timelag fuels was 12% at 1000 hrs.

Fire intensity was generally low with flame heights below 1 m. Heat-sensitive paints showed temperatures generally below 150°C throughout the burn unit. An area of high intensity occurred where erosion gullies created a chimney effect, allowing flames to carry into the crowns of a few trees. In these areas, temperatures 1 m above ground reached as high as 300°C. Flames covered the entire burn unit and all burning was completed by 1600 hrs.

Thinning Operations

The pre-treatment stocking of the thinned stands was 86.4 m^2 ba/ha (replication 1), 71.6 m^2 ba/ha (Replication 2), and 109.8 m^2 ba/acre (Replication 3) (Table 5). The thinning prescription was a 5^{th} row thin with operator selection between rows. After this prescription, the residual basal area was 58.9 m^2 ba/ha, 55.8 m^2 ba/ha, and 92.1 m^2 ba/ha respectively for each replication (Table 6).

Table 5. Pre-treatment basal area (m^2/ha) for burn, control and thin stands (data provided by the USFS crew of the National Fire and Fire Surrogate Study, Clemson, S.C.).

Pre-treatment Basal Area

Trt	Replication 1	Replication 2	Replication 3	Total
Control	99.7	109.0	95.4	101.4
Thin	86.4	71.6	109.8	88.9
Burn	66.1	88.4	85.1	79.9

Table 6. Post-treatment basal area (m^2/ha) for burn, control and thin stands (data provided by the USFS crew of the National Fire and Fire Surrogate Study, Clemson, S.C.).

Post-treatment Basal Area

Trt	Replication 1	Replication 2	Replication 3	Total
Control	84.1	108.7	95.7	96.1
Thin	58.9	22.6	92.1	68.5
Burn	53.1	71.8	56.0	60.2

Table 7. Thinning Dates (data provided by the USFS crew of the National Fire and Fire Surrogate Study, Clemson, S.C.).

Block	Date of Thinning Operations
Replication 1 Thin	3/07/01 - 04/04/01
Replication 2 Thin	12/18/00 – 01/18/01
Replication 3 Thin	02/05/01 – 02/21/01

CHAPTER IV

RESULTS

Bulk Density

There was a significant difference in bulk density samples after treatments. The thin treatment was significantly different from the control treatment but was not significantly different from the burn. The post treatment means ranged from 0.801 grams/cm^3 to 0.875 grams/cm^3. The Control treatment had the lowest average and the thin treatment had the highest average (Table 8). Covariate analysis did result in a significant difference among treatments. The increased bulk density associated with thinning may have been caused by compaction due to the use of feller bunchers and skidders. Also, the variation in these results may have been caused by sampling techniques or the soil's natural variation.

Table 8. Bulk Density in grams/cm^3. Means in each column with different letter indicate significant difference at $\alpha = 0.05$. Mean values represented as ± SE (standard error).

Treatment	Bulk Density (Actual means)
Control	0.801a ± 0.015
Thin	0.875b ±0.016
Burn	0.818ab ±0.022

Net and Proportional Mineralization

There were no significant differences among treatments for net minerailization when using covariate analysis. These averages varied from -0.031 (control) to 0.512 (thin) (Table 9).

Table 9. Net and Proportional Mineralization levels. Means in each column with different letter indicate significant difference at $\alpha = 0.05$. Mean values represented as ± SE (standard error).

Treatment	Net	Proportional
Control	-.031a ± 0.067	0.153a ± 0.063
Thin	0.512a ± 0.221	0.061a ± 0.022
Burn	0.437a ± 0.113	-0.021b ± 0.016

In addition to net mineralization, proportional mineralization was also calculated. There was a significant difference between some treatments for proportional mineralization. The control and thin treatments were not significantly different from each other but they were significantly greater than the burn treatment. These averages ranged from -0.021 (burn) to 0.153 (control) (Table 9).

Carbon and Nitrogen Concentrations, and C:N Ratios (O Horizon)

When evaluating the O horizon for carbon, nitrogen, and carbon nitrogen ratios; the following differences occurred among treatments. The thin treatment and the burn treatment were not significantly different from each other but both were significantly less than the control treatment for carbon content. These averages varied from 19.49 ppm (burn) to 25.49 ppm (control) (Table 10).

Table 10. Carbon, Nitrogen, and C:N for the O horizon (% excluding ratios). Means in each column with different letter indicate significant difference at $\alpha = 0.05$. Mean values represented as ± SE (standard error).

Treatment	Carbon	Nitrogen	C:N
Control	25.49a ± 1.03	1.03a ± 0.05	25.04ab ± 0.53
Thin	20.17b ± 1.08	0.81b ± 0.05	25.8a ± 0.60
Burn	19.49b ± 1.06	0.82b ± 0.05	23.81b ± 0.61

Nitrogen levels followed the same pattern as carbon levels. The thin treatment and the burn treatment were not significantly different from each other but both were significantly lower than the control treatment. These averages varied from 0.81 ppm (thin) to 1.03 ppm (control) (Table 10).

The carbon nitrogen ratios however did not follow the pattern mentioned above. The control treatment was not significantly different from the burn or the thin treatments. However, the burn was significantly lower than the thin treatment. These averages ranged from 23.8 ppm (burn) to 25.8 ppm (thin) (Table 10).

Carbon, Nitrogen Concentrations and C:N Ratios (A/Bt Horizon)

There were no significant differences in the A/Bt horizon among treatments for carbon, nitrogen, or carbon nitrogen ratios (Table 11).

Table 11. Carbon, Nitrogen, and C:N for the A horizon (% excluding ratios). Means in each column with different letters indicate significant difference at $\alpha = 0.05$. Mean values represented as ± SE (standard error).

Treatment	Carbon	Nitrogen	C:N
Control	2.567a ± 0.110	0.111a ± 0.011	17.162a ± 1.683
Thin	1.925a ± 0.082	0.083a ± 0.011	12.219a ± 1.653
Burn	2.493a ± 0.176	0.073a ± 0.012	14.103a ± 2.338

Macronutrients

Macronutrient analysis was conducted on the A/Bt horizons (Table 12). There were no significant differences among the treatments for concentrations of sodium, manganese, copper, sulfur, phosphorus or aluminum.

Total exchangeable capacity varied significantly among some of the treatments (Table 12). The thin treatment was not significantly different from the burn or the control treatments. However, the burn treatment was significantly less than the control. The pH was significantly different among all treatments and these values ranged from 5.0 (control) to 5.2 (thin). Calcium concentration was significantly greater (353.27 ppm) in the thin treatment than the burn (247.97 ppm) but the control treatment (307.03 ppm) was not significantly different from either of the other treatments. Magnesium concentration also had significant differences among treatment regimes. The control and burns were not significantly different from each other but both were significantly different from the thin treatment. These averages varied from 39.7 ppm (burn) to 74.7 ppm (thin) (Table 12). Potassium concentration had significant differences among treatment regimes. Burn and control regimes were not significantly different, but they were both significantly less the thin. These averages varied from 51.15 ppm (burn) to 76.22 ppm (thin) (Table 12). Hydrogen (exchangeable acidity) values were significantly different among all treatments

Table 12. TEC, pH, cation, anion, other, and hydrogen analysis for the A/Bt horizon (in ppm, excluding TEC- $cmol_3/kg$, pH, other-base saturation %, and H-exchangeable acidity %). Means in each row with different letter indicate significant difference at $\alpha = 0.05$. Mean values represented as ± SE (standard error).

Treatment	Control	Thin	Burn
TEC	4.34b ± 0.33	4.53ab ± 0.30	3.38a ± 0.27
pH	5.0a ± 0.03	5.268c ± 0.05	5.076b ± 0.02
Ca	307.03ab ± 30.12	353.27b ± 33.86	247.97a ± 27.91
Mg	47.3a ± 2.57	74.683b ± 6.53	39.77a ± 3.08
K	51.28a ± 1.79	76.22b ± 4.90	51.15a ± 2.59
Na	7.516a ± 0.35	7.283a ± 0.22	6.716a ± 0.30
Fe	130.8b ± 3.61	124.65a ± 3.76	107.592a ± 4.92
Mn	31.933a ± 2.42	40.767a ± 5.45	26.5a ± 2.17
Cu	0.632a ± 0.04	0.437a ± 0.02	0.741a ± 0.04
Zn	1.462b ± 0.174	1.16ab ± 0.053	1.249a ± 0.054
Soluble Sulfur	33.083a ± 1.67	28.033a ± 1.25	32.1a ± 1.17
P	12.866a ± 0.72	11.7a ± 0.79	11.816a ± 0.39
Other_pct	7.4c ± 0.07	6.868a ± 0.10	7.246b ± 0.04
Hpct	44.067c ± 0.87	36.73a ± 1.56	42.3b ± 0.67
B	0.326ab ± 0.01	0.348b ± 0.009	0.318a ± 0.007
Al	1071.52a ± 15.96	990.75a ± 16.65	1066.4a ± 23.07

and varied consistently with the pH values. These values ranged from 36.73%(thin) to 44.06% (control) (Table 12). Boron levels had significant differences among treatments. Although the control treatment was not significantly different from the burn or thin treatments, the burn was significantly less than the thin. These averages ranged from 0.318 ppm (burn) to 0.348 ppm (thin) (Table 12). Iron also had significant differences among treatments. The thin and burn treatments were not significantly different from each other but, both were different from the control. These averages ranged from 107.59 ppm (burn) to 130.8 ppm (control) (Table 12). Finally, zinc had significant differences among treatments. The thin treatment was not significantly different from the control or the burn treatments. However, the control and burn treatments were significantly different from each other. These averages varied from 1.16 ppm (thin) to 1.46 ppm (control) (Table 12).

Skid Trail and Plot Disturbance Mapping

Each plot was examined for pre-treatment and post-treatment bare ground spots (there were no pre-treatment bare ground spots). Post-treatment skid trail disturbance was also mapped and noted where the actual sample location was disturbed. This was used for background information for particular soil samples that may be extreme outliners in any given variable (see Appendix A and B). However, there was no need for further outlier analysis because the large sample size and compositing of some samples would diminish the effect of any extreme outliers.

CHAPTER V

DISCUSSION

Bulk Density

In this study, bulk density did not change with burning but did change with thinning. These results agreed with Phillips (2000) that prescribed burning did not affect bulk density. The observed non-significant differences may have been due to variation in sampling technique or in variation across the landscape. The variation by sampling technique may have been caused by different size collection rings. A longer ring may have collected more of the Bt horizon than a shorter ring, thus causing an increase in measurable bulk density since the B-horizon has a higher percentage of clay and a lower level of porosity. For the pre-treatment year more than one size ring was used. These rings had a sampling depth of 5cm to 10cm. The post-treatment year used the same ring size for all samples. This ring had a sampling depth of 5cm. This may have caused the bulk density averages to be lower for the post-treatment year than the pre-treatment year. The smaller ring would be sampling less of the Bt horizon than the larger ring making the bulk density to appear lower.

Ballard (2000) found that thinning led to a reduction in aeration and root penetration. Our study concurs with Ballard (2000). This may have been caused by intensive sampling only in skid trails rather than across the landscape as a whole. In addition, some results may be related to topography. Skidding on steep, slick surfaces may account for the higher bulk densities than on flat ground. Skidding on flat surfaces may have less impact because of more efficient logging with less heavily used skid trails that do not have to be designed to account for topography. Skid trails have to be longer on steeper topography, causing more surface area disturbance. Froehilich's (1978) study found most changes in bulk density are associated with the first few trips over the ground even with low pressures.

Variable fire may account for some of the heterogeneity in studies that have been conducted. With the exception of high intensity burns, most research indicates that prescribed burning does not affect soils (Ballard 2000, Johnson 1992, Vose 1999, Covington 1986, Bird 1999, Debano 1979, Knoepp 1993, Kovaic 1986).

Net and Proportional Mineralization

Nitrification and mineralization is very important in soil dynamics. Nitrogen is essential for plant growth and is influenced by soil moisture, aeration, temperature, pH and microbial breakdown of soil organic matter. Nitrogen availability is increased through bacterial fixation of gaseous nitrogen (N_2) to ammonium (NH_4) compounds and nitrates (NO_3) which can be absorbed by plants. Within this process of nitrogen mineralization, ammonification and nitrification take place. Ammonification is the conversion of organic nitrogen into ammonium (NH_4). Organic nitrogen in the soil solution is comprised of 30-40% amino acid N, 5-10% amino sugar N, 1-2% purine and pyrimidine N and 40-60% unidentified N. This process of ammonification is conducted with the aid of *Arthrobacter* and *Aspergillis* bacteria.

Nitrification is the conversion of ammonium (NH_4) to nitrite (NO_2) and then into nitrate (NO_3). This process is conducted with the aid of *Nitrosomonas* and *Nitobacter* bacteria. The rate of nitrification is greatly affected by the temperature and pH of the soil but usually takes between two and four weeks. Warmer soils (temp above 50°F) with a pH between 5.5 and 6.5 are ideal for this process. There are three ways that nitrogen is lost from soil: ammonia volatilization, leaching, and denitrification. Ammonia volatilization occurs when soils have a high pH (>6.5), warm temperatures (>50°F), and the nitrogen is in dry soil or is very near the surface. Leaching accounts for approximately 20% of nitrogen lost. This process is usually restricted to nitrates. Denitrification is the biochemical bacterial conversion of nitrate to nitrite to nitric oxide, nitrous oxide or nitrogen gas that is lost in the atmosphere.

In this study, net mineralization did not change with any of the treatments. This measurement is important to this study because it is the measure of total nitrogen being produced in both the form of NO_3 and NH_4. However, proportional mineralization did change as a result of prescribed burning. This is important because it gives us the proportion of NO_3 to total nitrogen production. Again, other studies have varied depending upon fire and thinning intensity (Ballard 2000, Johnson 1992, Vose 1999, Covington 1992, Bird 1999, Debano 1979, Knoepp 1993, Kovaic 1986). Prescribed burning significantly reduced proportional mineralization in this study. Monleon (1997) also found decreases in mineralization due to prescribed burning. However, Monleon (1997) found that this loss is short and return to pre-treatment levels occurs within one year. This may be a result of the volatilization and fly ash losses of N as seen in Ballard (2000).

Carbon, Nitrogen, and C:N (O Horizon)

Carbon and nitrogen decreased in both the burn and the thin treatments. The decrease for the burning treatment may have been caused by volatilization of N and fly ash losses which also affect the proportional mineralization mentioned above. The decrease for the thinning treatment may have been a result of mechanical mixing of the existing pre-treatment O horizon into the A/Bt horizons. The mechanical surface disturbance caused by the feller bunchers and skidders may have caused mixing of horizons (Ryan 1992), causing a relocation of C and N rather than a loss on site. The degree of mixing depends upon total site disturbance. In both the burn and thin stands, these decreases may only be short term and could return to pre-treatment levels within a short time period.

Carbon, Nitrogen, and C:N (A/Bt Horizon)

Carbon, Nitrogen and C:N ratios did not differ significantly among the treatments for the A/Bt horizon, which concurs with Johnson (2001). The time lag between treatments and sampling may be a factor upon the determination of results for prescribed fire and thinning.

Macronutrients

This study found that both prescribed burning and mechanical thinning affect macronutrient levels, concuring with McKay, Ballard (1999), Giardina (2001), Johnson (1991), Merino (1998). These changes may have been due to localized conditions (time of thinning/burning, temperatures of fires, different soil moisture content), sampling techniques, or even sampling time lag. In this study, soluble sulfur, phosphorous, sodium, manganese, copper and aluminum did not change as a response to thinning or prescribed burning. However, total exchange capacity was significantly greater in the thin and the control stands than in the burns. This may have been caused by the volatilization of some cations (Ca, Fe, Zn), or particulate matter loss through smoke that is sometimes associated with fire. Soil pH was raised in the thin treatment as compared to the control and the burn treatments. This differs with Johnson's (1991) findings that soil pH decreases with clearcutting as a result of acidification of the E and B horizons. This is a result of increased production of hydrogen through nitrification and mobilization of aluminum from the forest floor and mineral soil.

The increase in pH in the thin treatment may have been caused by the increases seen in calcium, manganese, and potassium and the decrease in hydrogen. Prescribed burning also showed an increase in soil pH, as noted by the significant decrease in soil hydrogen. Ballard (2000) found that hydrolysis of oxides associated with prescribed burning resulted in the increase in soil pH but the magnitude and duration of these changes are greatly influenced by the soils buffering capacity. Soil biota, microclimate, or mechanical churning of the soil changes may also be associated with these changes in pH.

Calcium, which is required for plant defense mechanisms and is present in protective tissues (cell walls and middle lamella), is available in the soil solution as Ca^{+2}. The thin treatment had significantly higher levels of calcium than the burn treatment but neither was significantly different from the control. The difference between the thin and the prescribed burned stands may have been caused by the loss of calcium as particulate matter in smoke. Calcium was probably not volatilized because of its very high volatilization temperature (1484°C, Debano 1990).

Magnesium and potassium levels increased in response to thinning when compared to burning and the control stands. Magnesium is needed for the synthesis of chlorophyll and transformation of energy and is available in the soil solution as Mg^{+2}. Likewise, potassium facilitates nutrient translocation, controls sap pH, osmotic pressure and is available in the soil solution as K^{+}. The opening of the overstory and surface soil disturbance may have caused these changes. These openings allowed more sunlight to reach the forest floor and the coarse woody debris left from thinning. The increased radiation and the soil surface disruption in conjunction with the coarse woody debris may have increased decomposition and leaching of the nutrients into the A/Bt horizons. However, since there was not much time lag between thinning and sampling, it is questionable that this was the cause.

Boron, which is essential for cell division and is usually available in the soil solution as H_3BO_3 and H_2BO_3, increased significantly with thinning when compared to the burning and the control. However, these values were minute with respect to change (.02 ppm). The thinning effects mentioned above on magnesium and potassium may have caused these changes. Iron, which participates in oxidation-reduction reactions and is usually available in the soil solution as Fe^{2}, $Fe(OH)_2$, $Fe(OH)^{2}$, and Fe^{3}, decreased in response to burning and thinning when compared to the control. The decrease in iron with response to burning corresponds to Ohr and Bragg (1985). The reduction of iron associated with burning may have been due to volatilization or particulate loss in the smoke column. Thinning may have shown an overall reduction in iron levels due to the mechanical mixing of the nutrient rich A and Bt horizons. This would cause post treatment sampling to measure more of the overturned Bt horizon rather than the A horizon.

Zinc, which promotes seed maturation and production is usually available in soil solution as Zn^2 and $ZnOH_2$, differed for the control and the burn stands, but neither the controls or the burns differed from the thin stands. Thinning and burning treatments lowered the overall zinc levels when compared to the control. The thinned stands may have shown lower zinc levels again as a result of mechanical mixing of nutrient rich A horizons into lower portions of the soil profile. However, in this study, the levels of zinc were not significantly different between the thin treatment and the control. Some of the losses of zinc associated with prescribed fire may be caused by particulate matter loss in smoke. It is not likely that zinc was volatilized in these burns due to its high relatively high volatilization temperature.

CHAPTER VI

CONCLUSIONS

A total of 8,700 soil samples were taken during the two-year period that this study was conducted (1,500 O horizons, 1,500 A horizons, 2,000 mineralization, 1,200 penetromenter readings, 2,500 bulk density). Sampling was conducted from mid to late spring until late summer for pre and post treatment years. In this study, prescribed burning and thinning affected some soil properties (Table 13).

Prescribed fire was the only treatment to affect proportional mineralization. Likewise, prescribed fire had more of an influence on soil properties than thinning. In addition, it affected carbon and nitrogen in the O horizon, total exchange capacity, pH, iron and zinc. Since these variables are important to sustaining site productivity one should use caution when prescribing fire as a fuel reduction method (however, this decreases short term site productivity). On small tracts or larger tracts with smaller tree classes that do not create enough revenue to cover the operational cost of thinning, prescribed burning could be a sound fuel reduction treatment.

Thinning had an effect on carbon and nitrogen in the O horizon, pH, magnesium, potassium and iron. Unlike prescribed fire, thinning caused an increase in many nutrients (especially cations). This may make this type of fuel reduction more favorable. However, this type of management technique is more labor intensive. In some cases, this may even generate revenue for the landowner if there is a market for the product.

Table 13. Variables with significant differences (X) as affected by mechanical thinning and prescribed burns.

Treatment	Thin	Burn
Bulk Density		
Net Mineralization		
Proportional Mineralization		X
C-O Horizon	X	X
N-O Horizon	X	X
C:N-O Horizon		
C-A Horizon		
N-A Horizon		
C:N-A Horizon		
TEC		X
pH	X	X
S		
P		
Ca		
Mg	X	
K	X	
Na		
B	X	
Fe	X	X
Mn		
Cu		
Zn		X
Al		

In some ecosystems, thinning is not size restrictive and should be used. For instance, areas where the restoration of woodpeckers and birds of prey are an important management objective, thinning would prove very beneficial. Leaving snags could create a food source for woodpeckers and observation points for birds of prey. Likewise, the coarse woody debris left behind on site would create a favorable environment for insects and rodents.

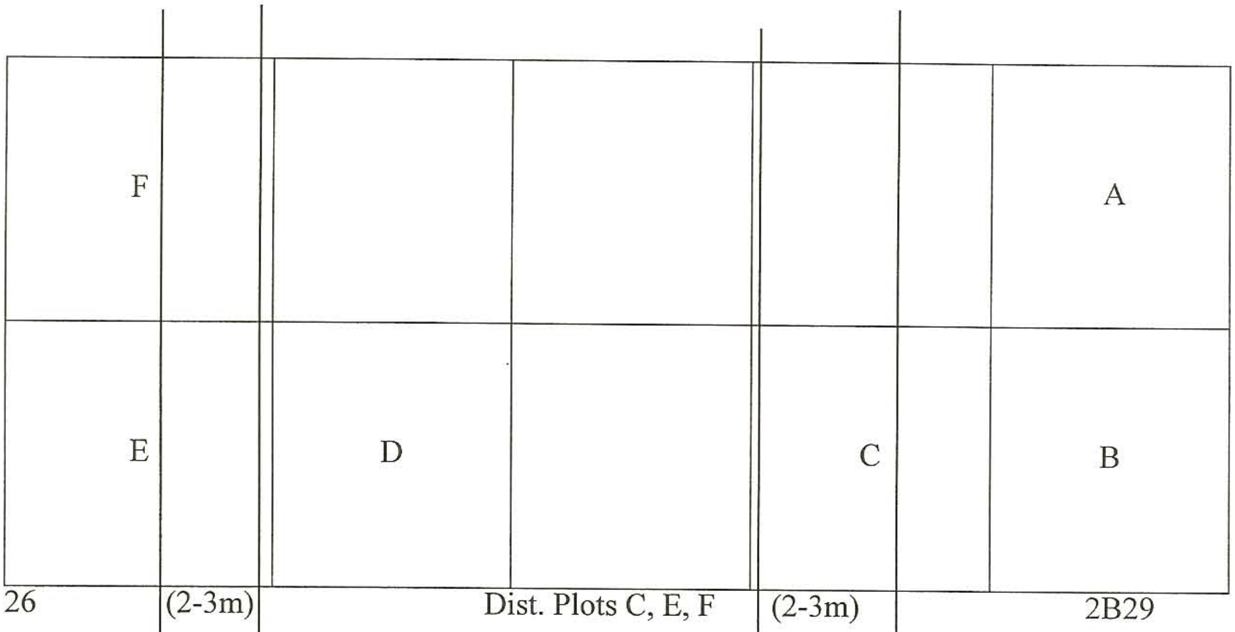
The resetting of sucessional stages and creation of edge that is associated with thinning would favor more earlier successional and edge species of wildlife like white-tailed deer, turkey, and rabbits.

Thinning may also need to be used as a fuel reduction method in areas where fuel loads are dangerously high and fire may be hard to control. It may also be used in areas where fire may be restricted like metropolitan areas where smoke may pose a problem. In conclusion, these changes were relatively small and may only be short term for both thinning and the prescribed burning. These results seem minimal as long as the prescribed burning is not too intensively conducted (ex: using a fire that gets too hot) and the proper thinning techniques are used (ex: following Best Management Practices).

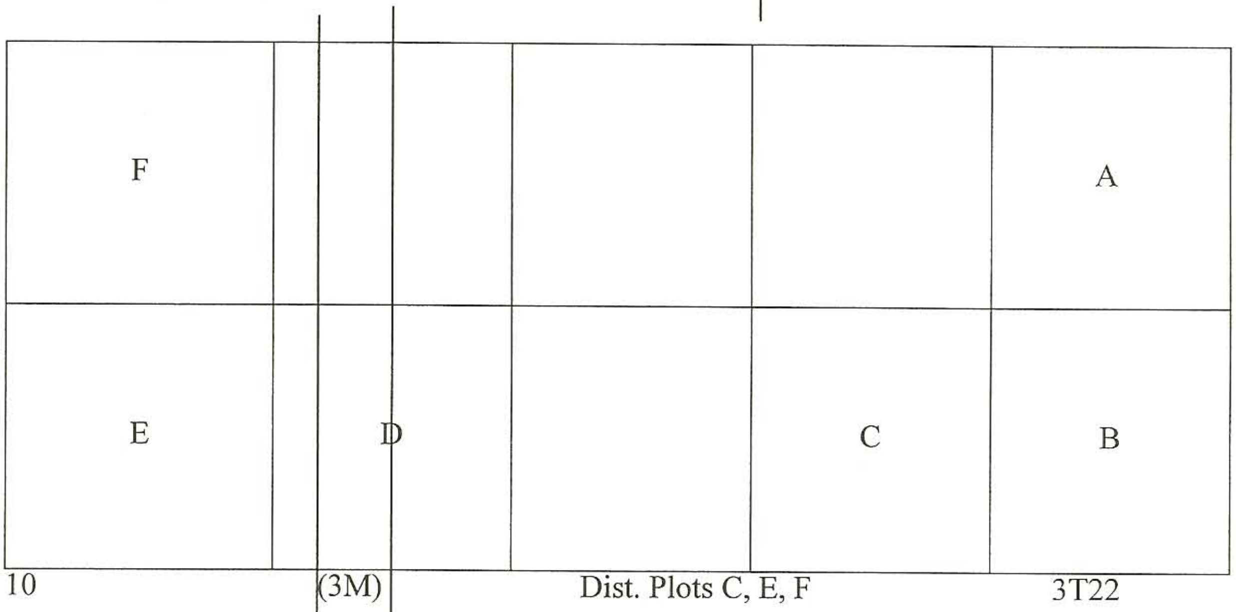
APPENDICES

Appendix A

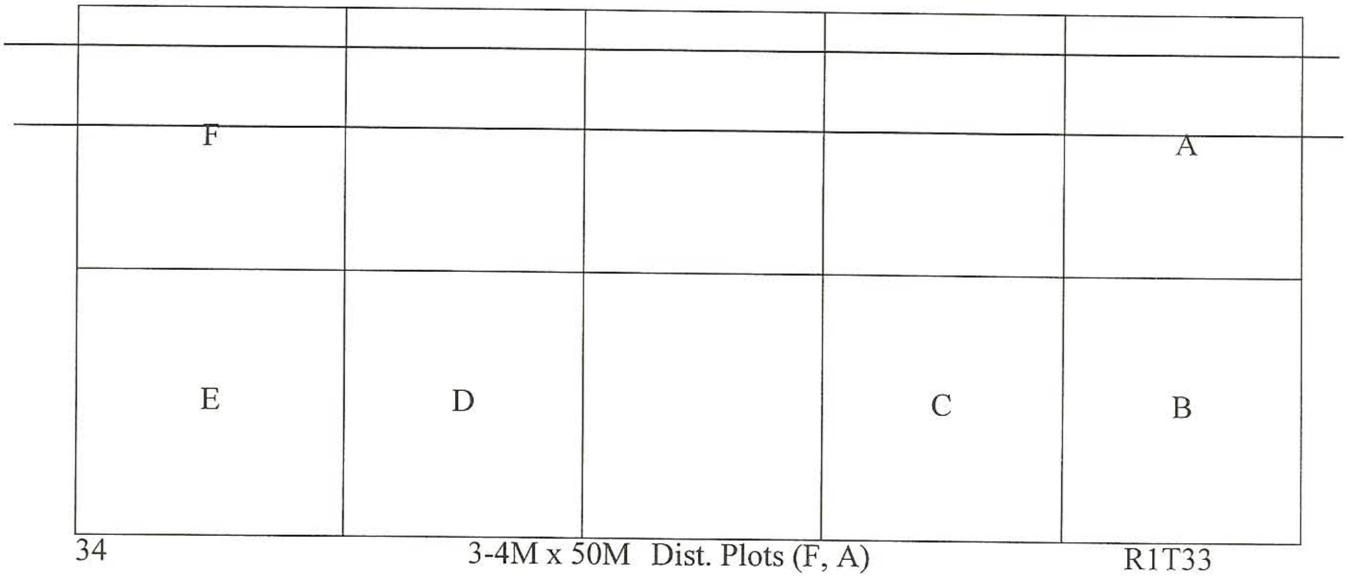
Bare Ground/Exposed Mineral Soil (Post Treatment, Lines Indicate Exposed Soil).



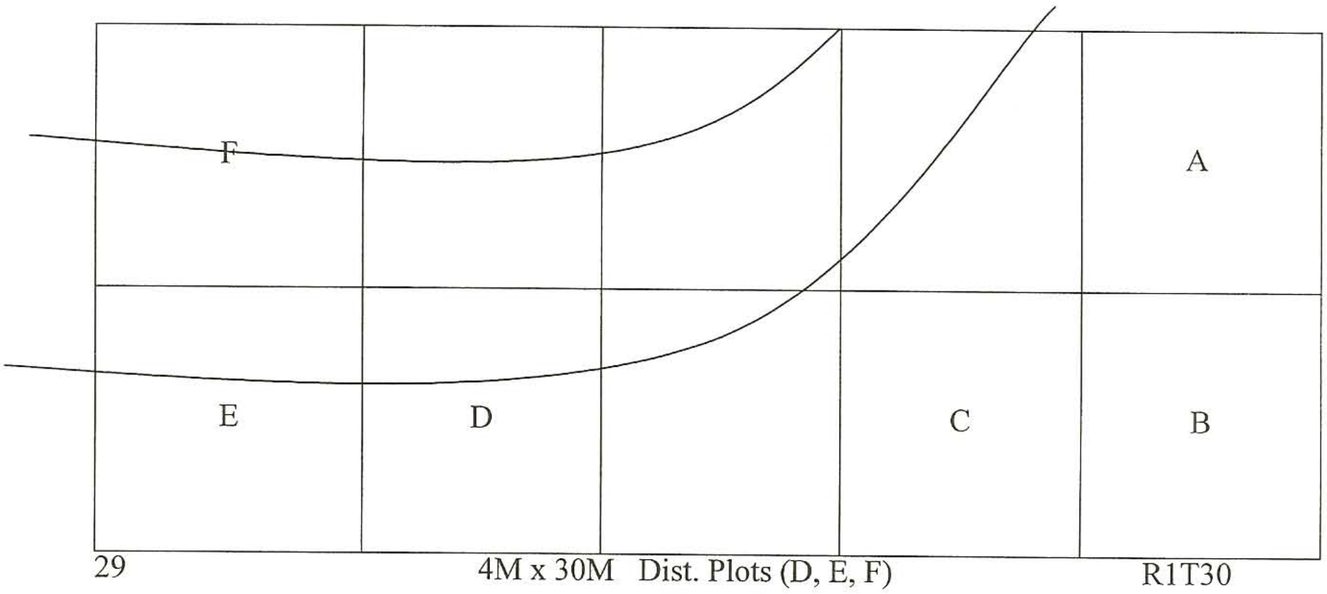
Replication 2 burn plot 29 map.



Replication 3 thin plot 22 map.



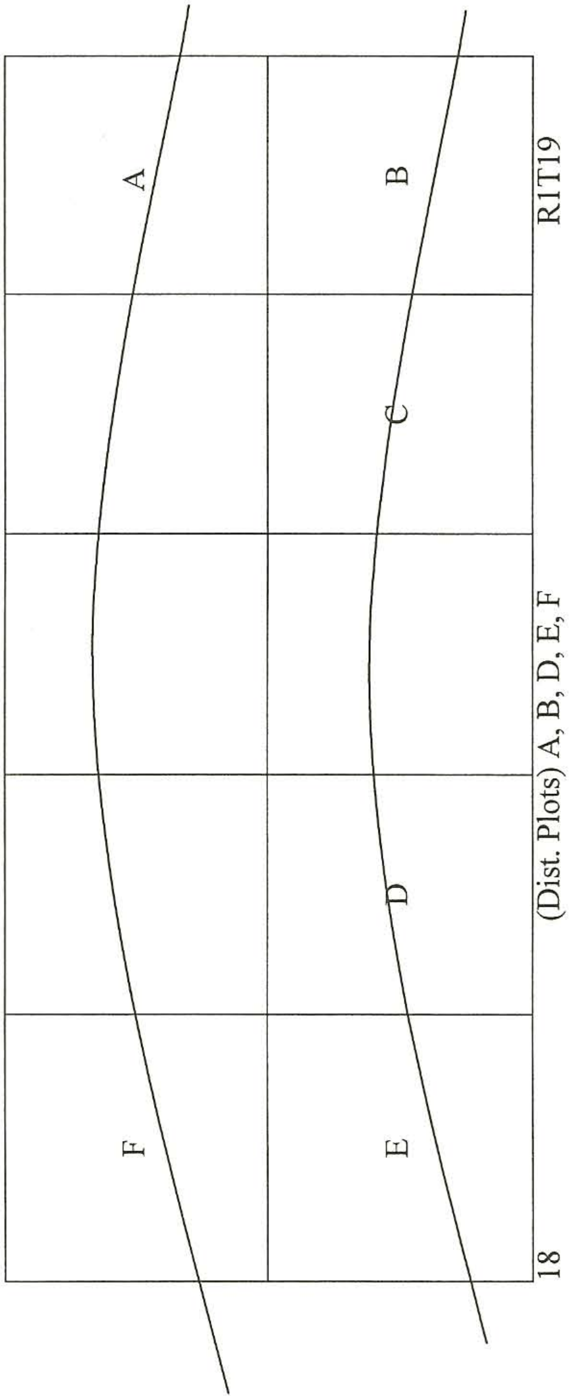
Replication 1 burn plot 33 map.



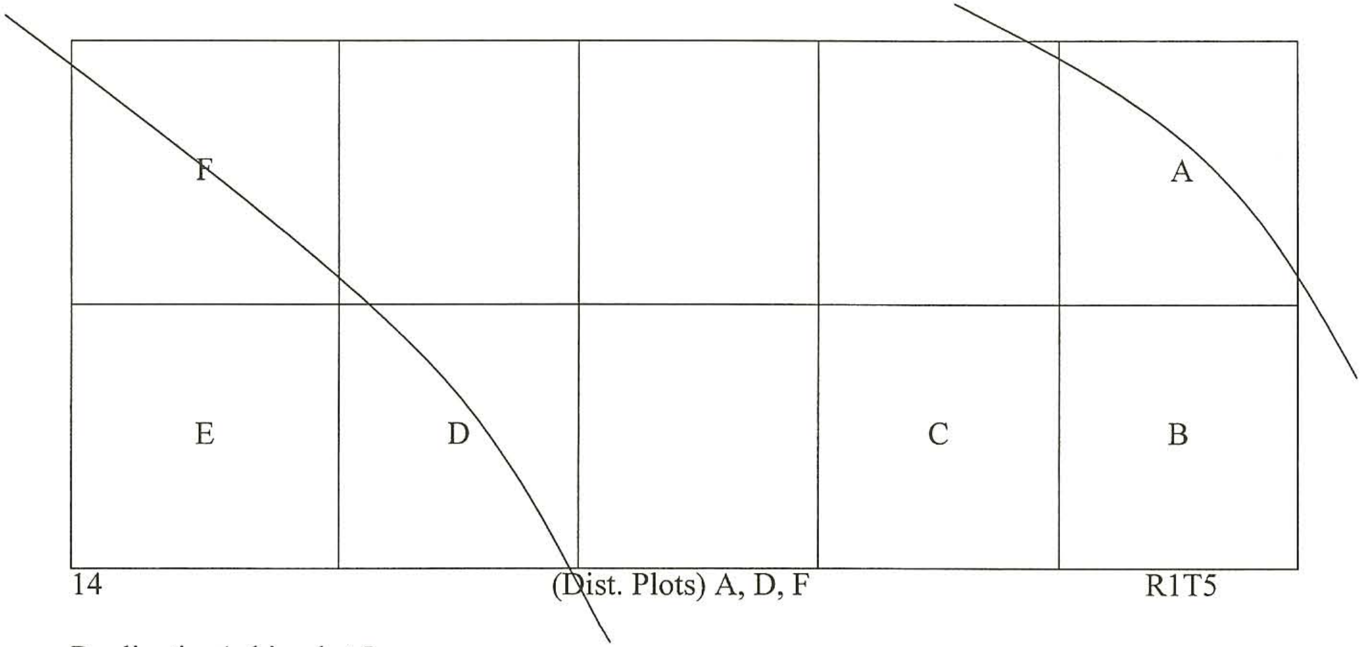
Replication 1 thin plot 30 map.

Appendix B

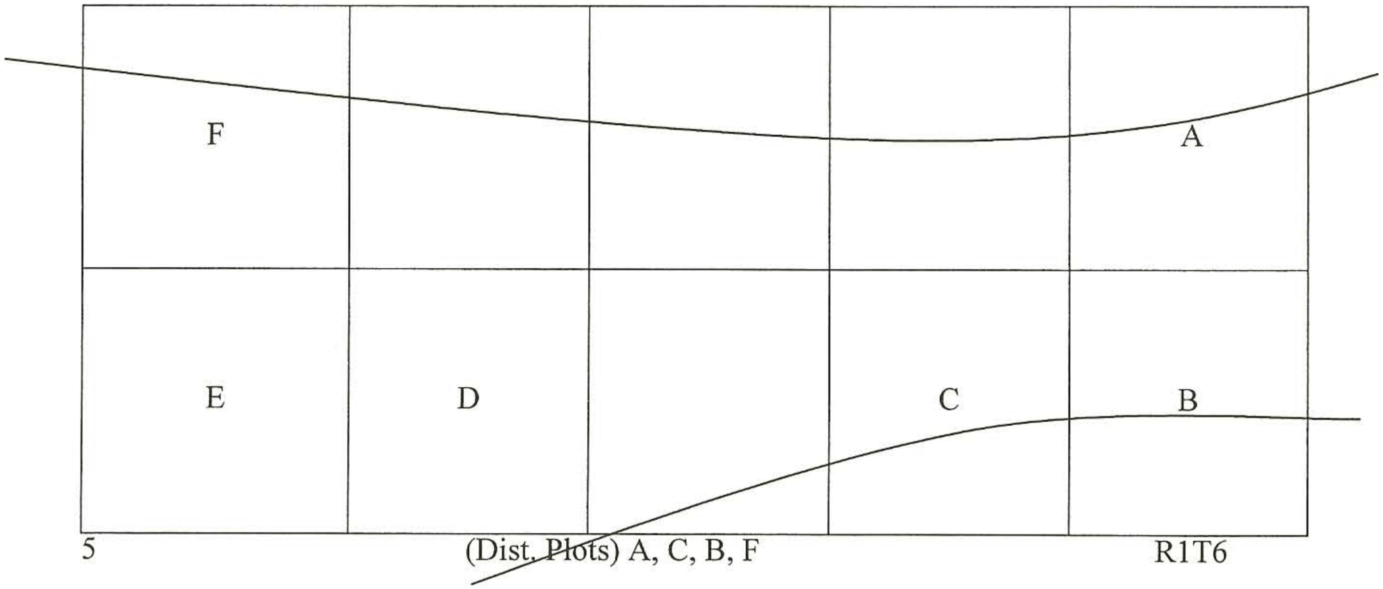
Skid Trail and Site Disturbance Maps (Post Treatment, Lines Indicate Disturbance).



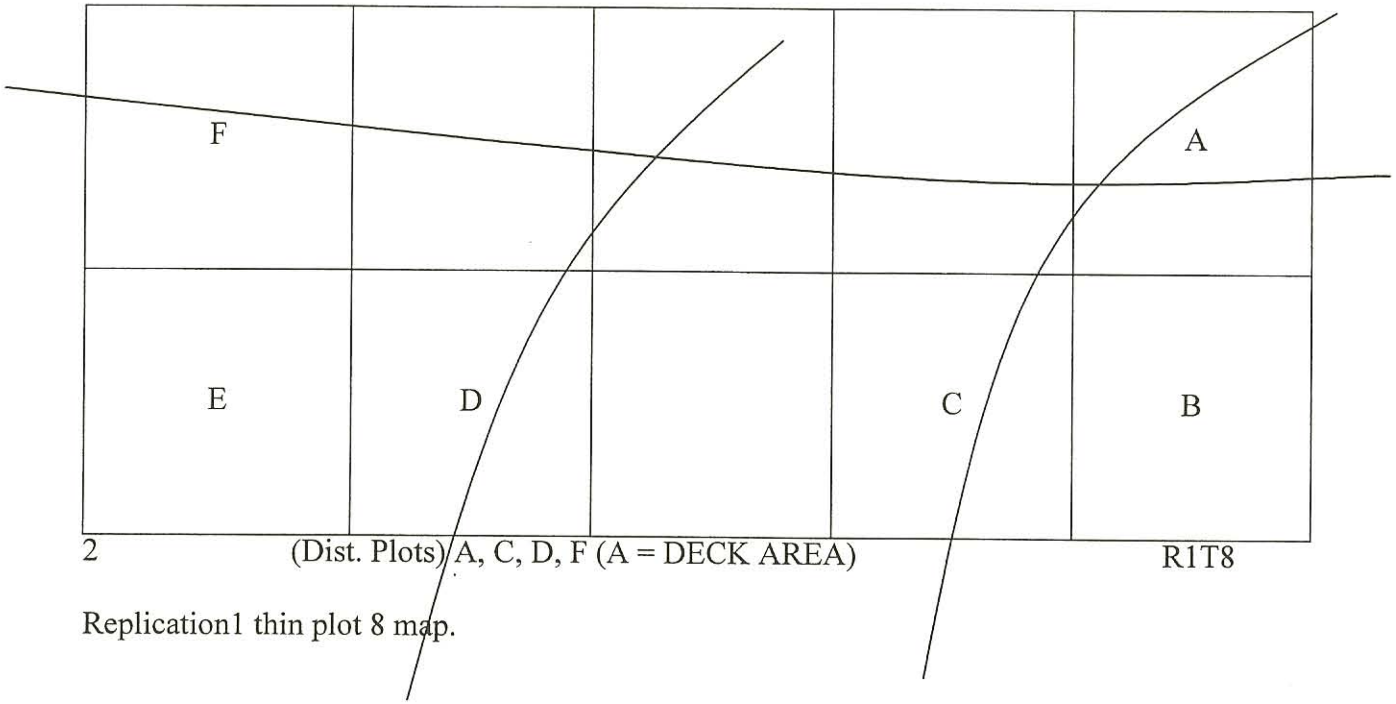
Replication1 thin plot 19 map.



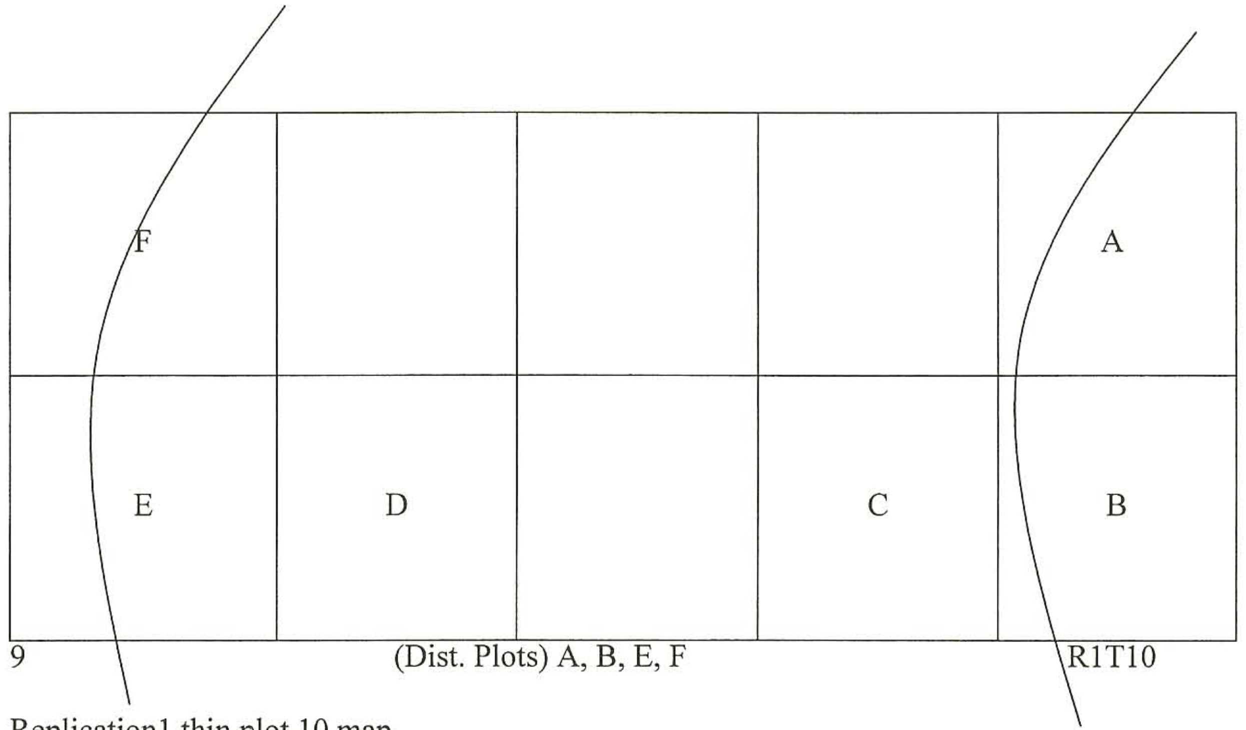
Replication1 thin plot 5 map.



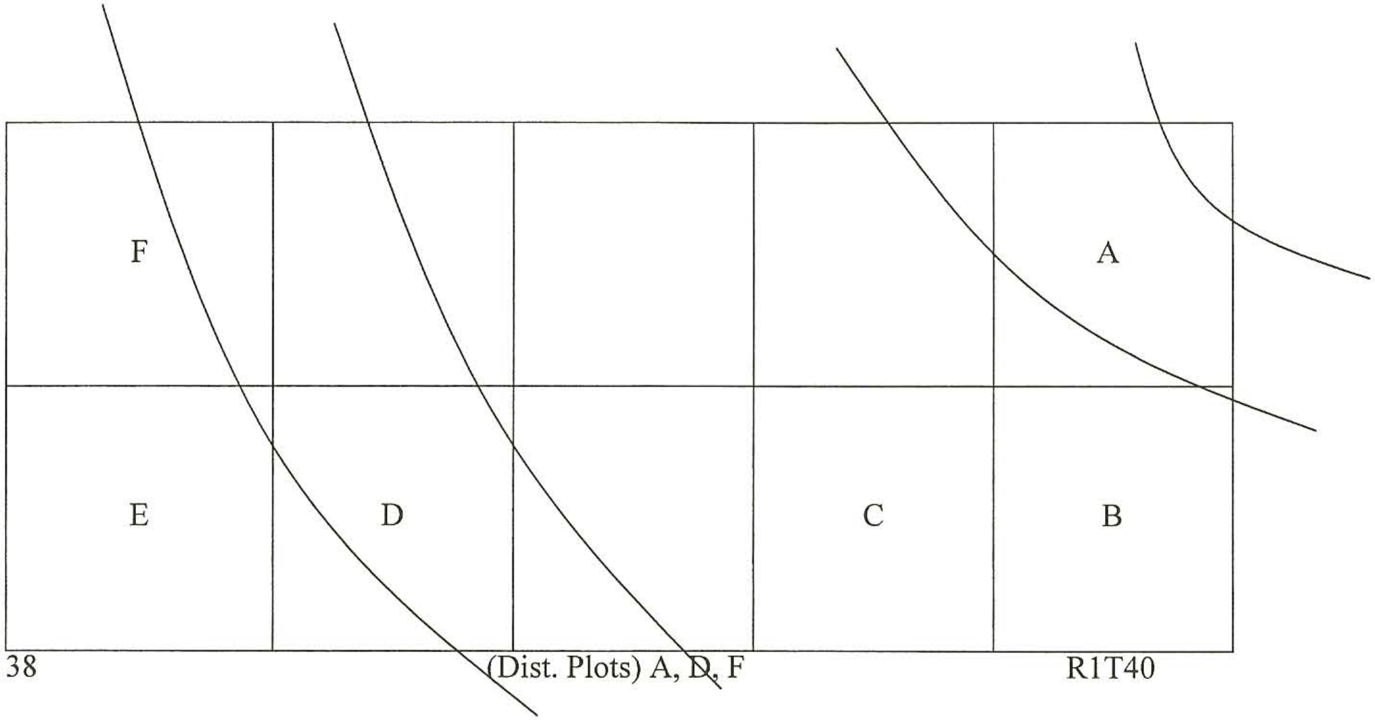
Replication1 thin plot 6 map.



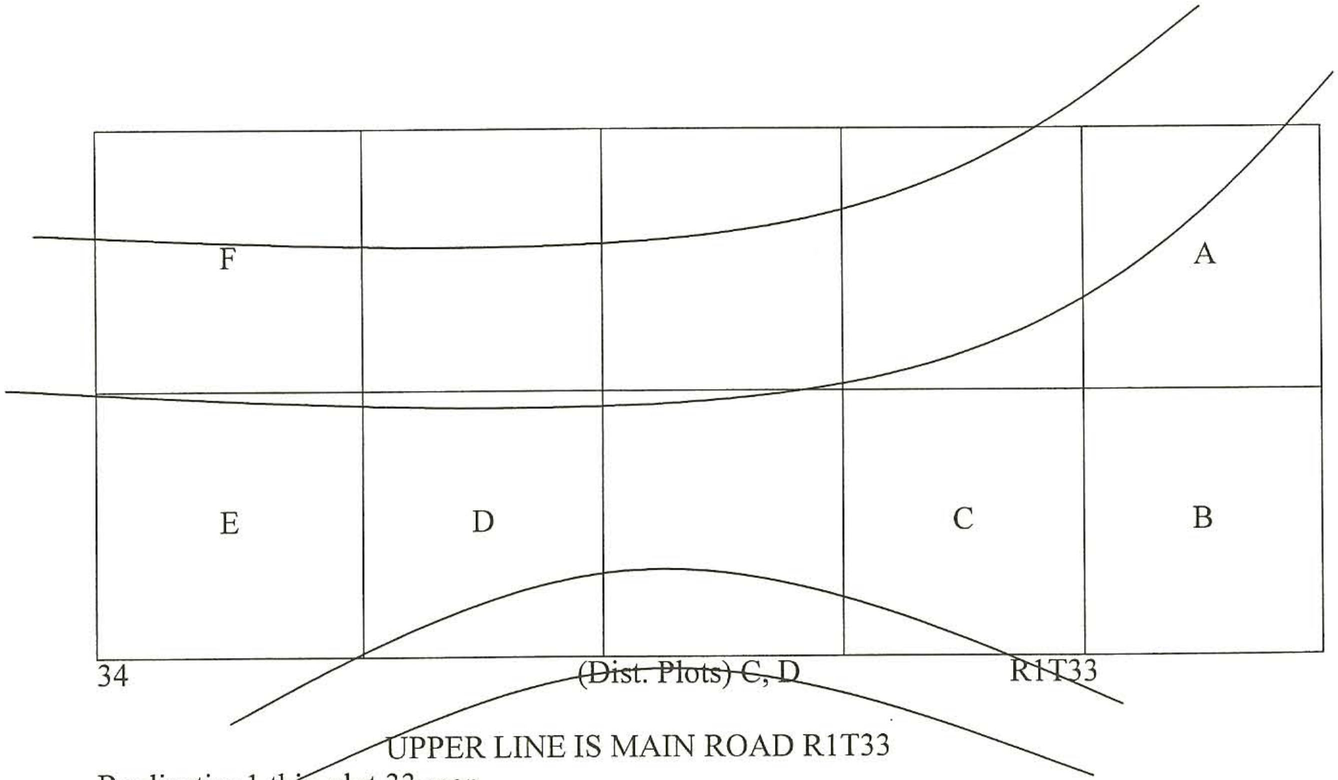
Replication1 thin plot 8 map.



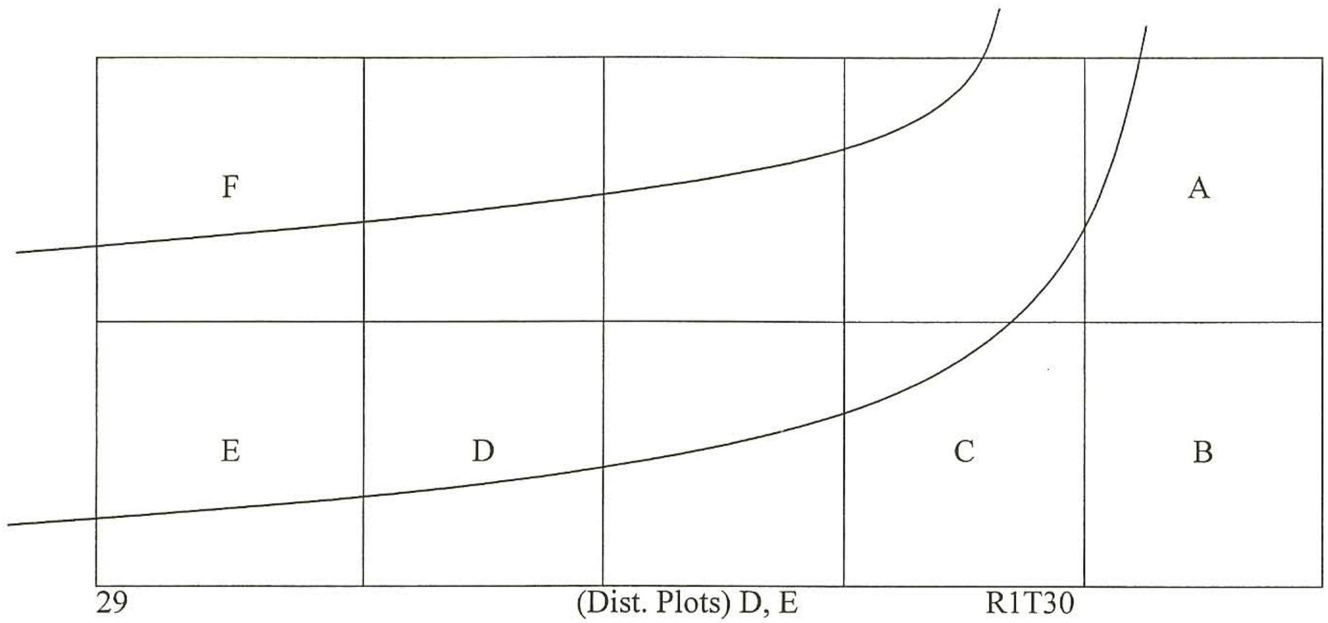
Replication1 thin plot 10 map.



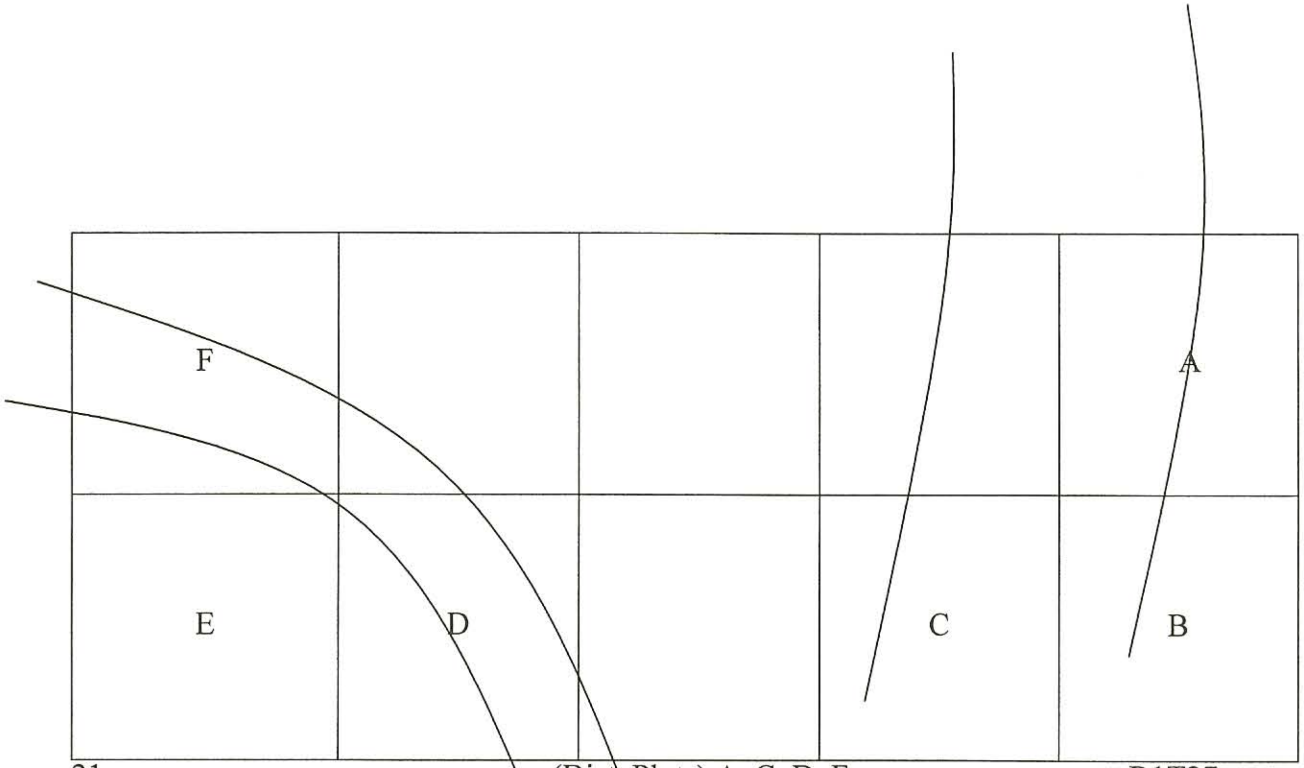
Replication1 thin plot 40 map.



Replication1 thin plot 33 map.



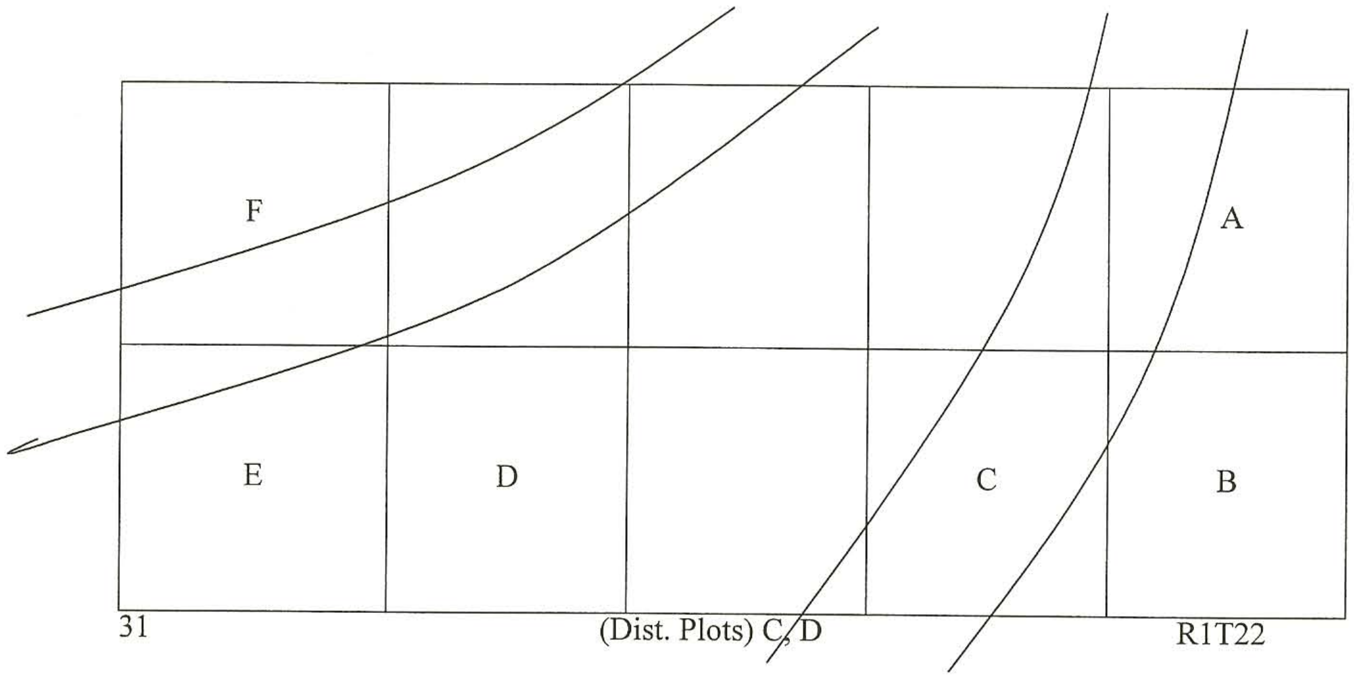
Replication1 thin plot 30 map.



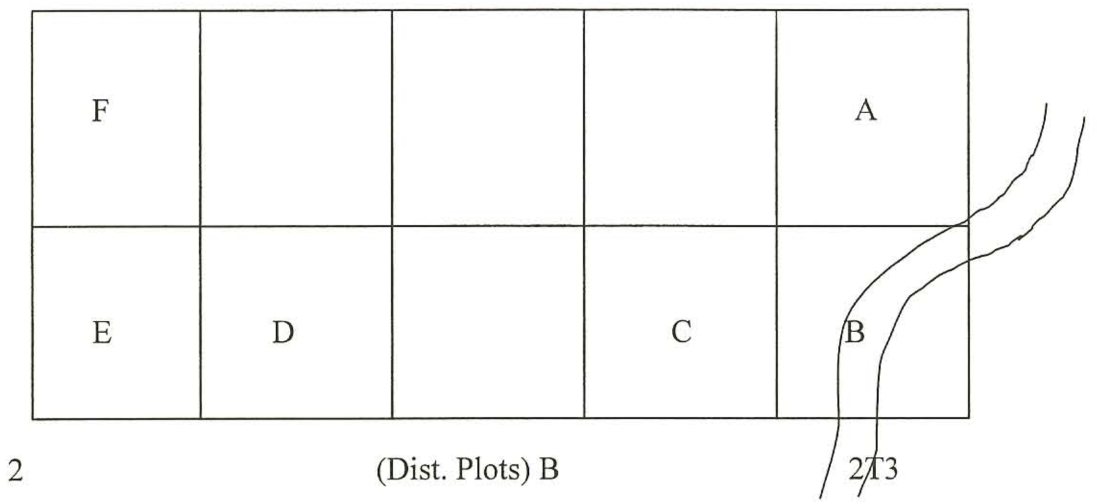
21 (Dist. Plots) A, C, D, F R1T27

(RIGHT SKID TRAIL HAS HEAVY SLASH)

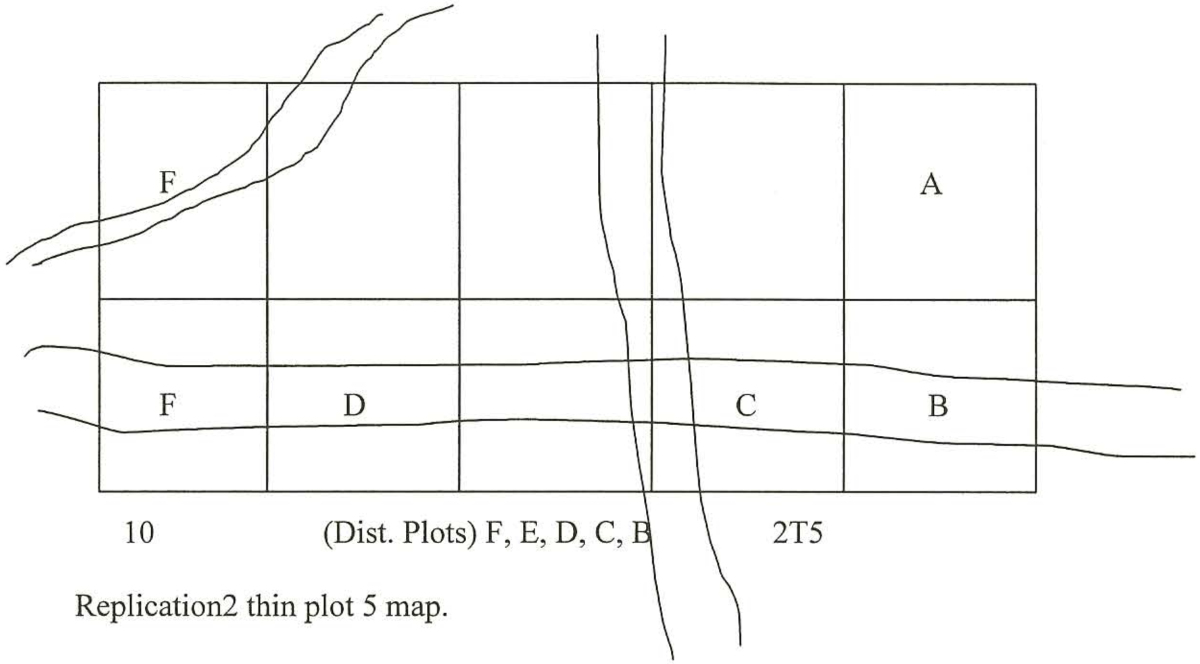
Replication1 thin plot 27 map.



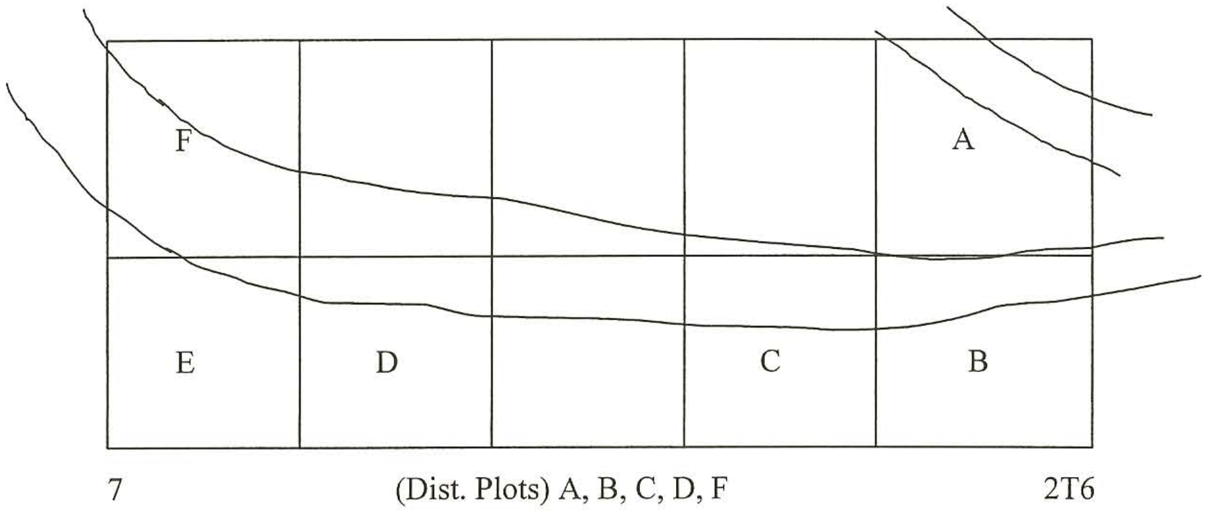
Replication1 thin plot 22 map.



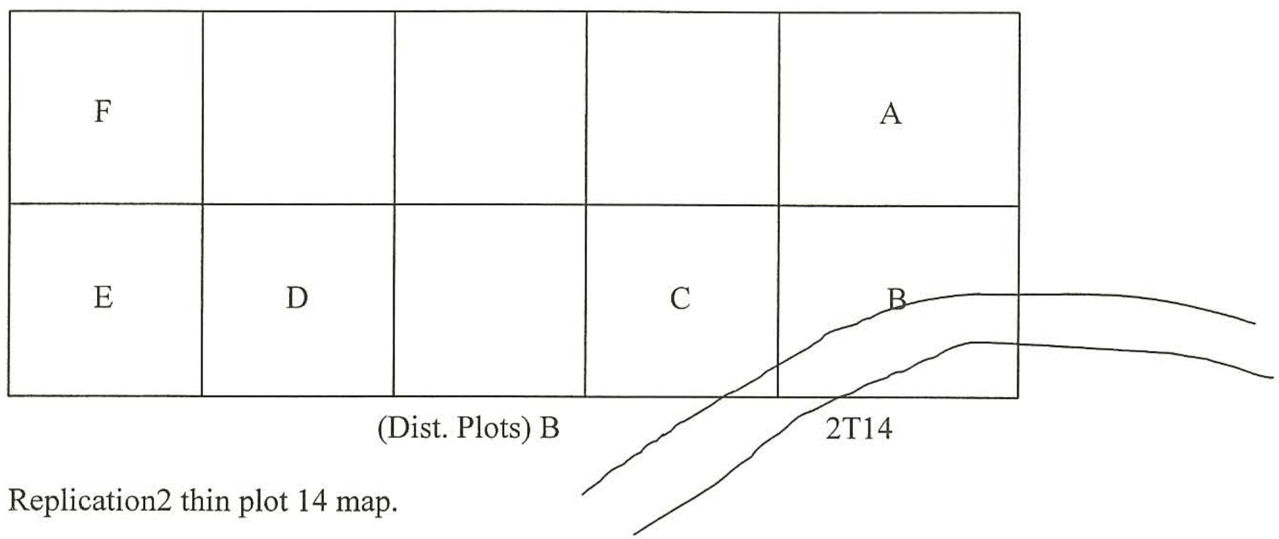
Replication2 thin plot 3 map.



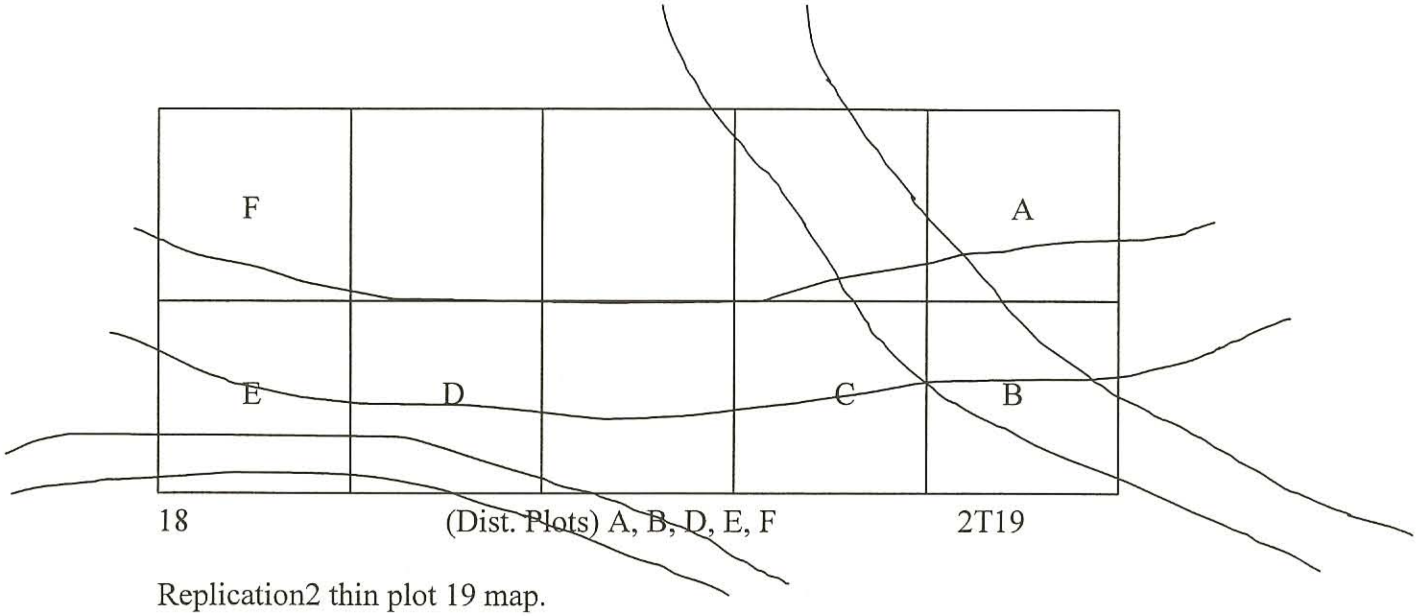
Replication2 thin plot 5 map.



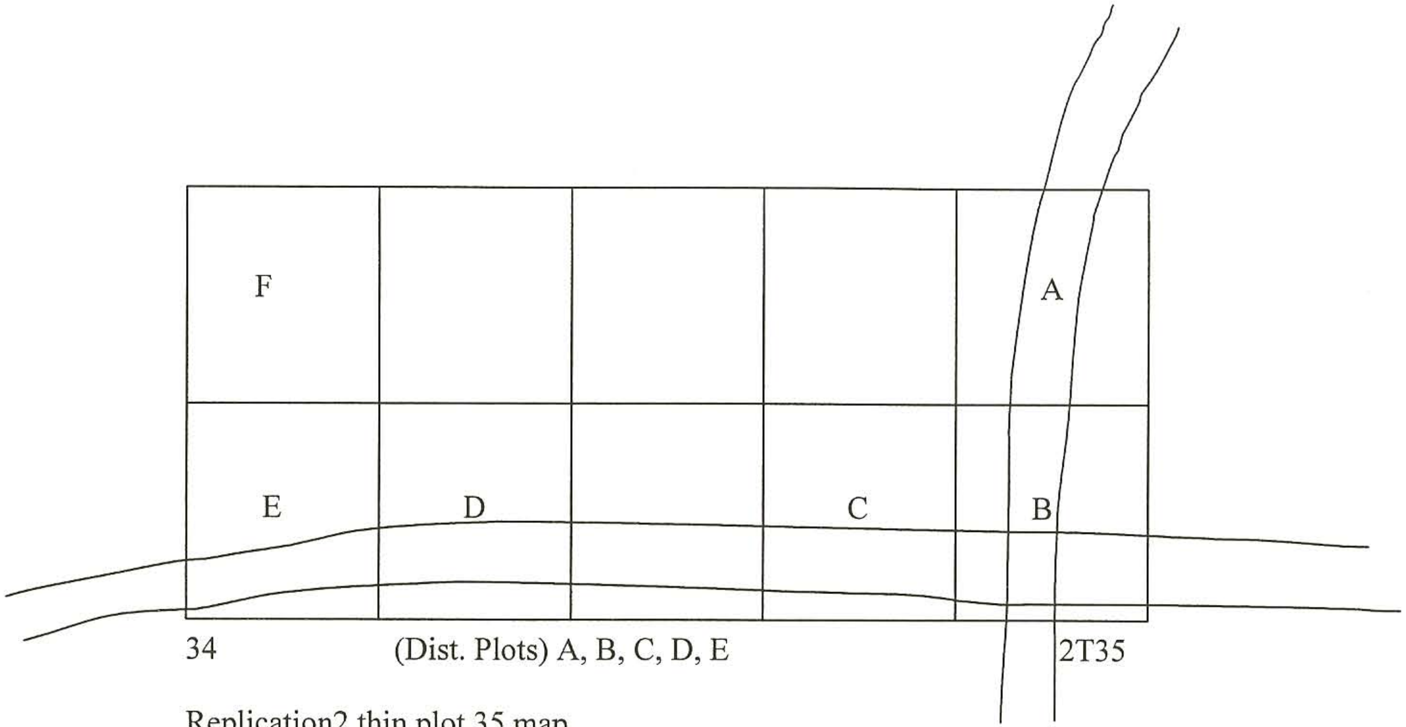
Replication2 thin plot 6 map.



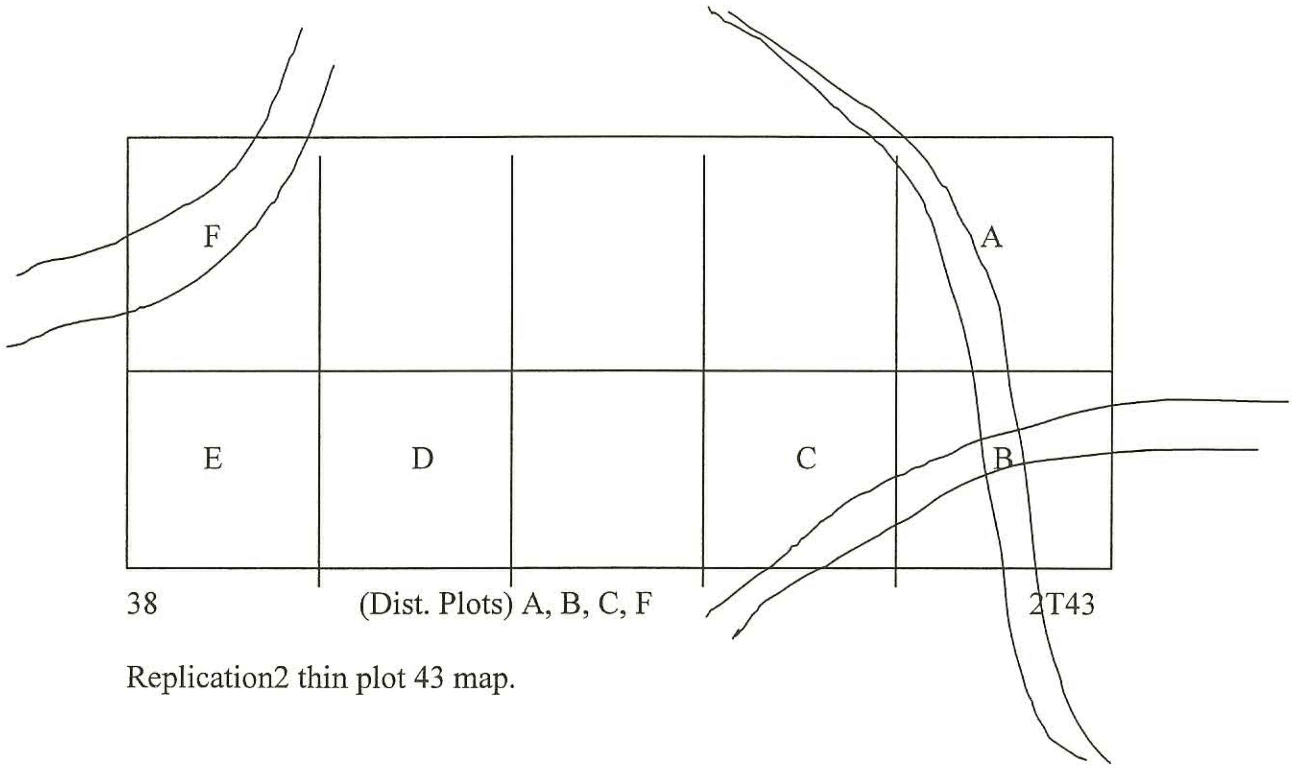
Replication2 thin plot 14 map.



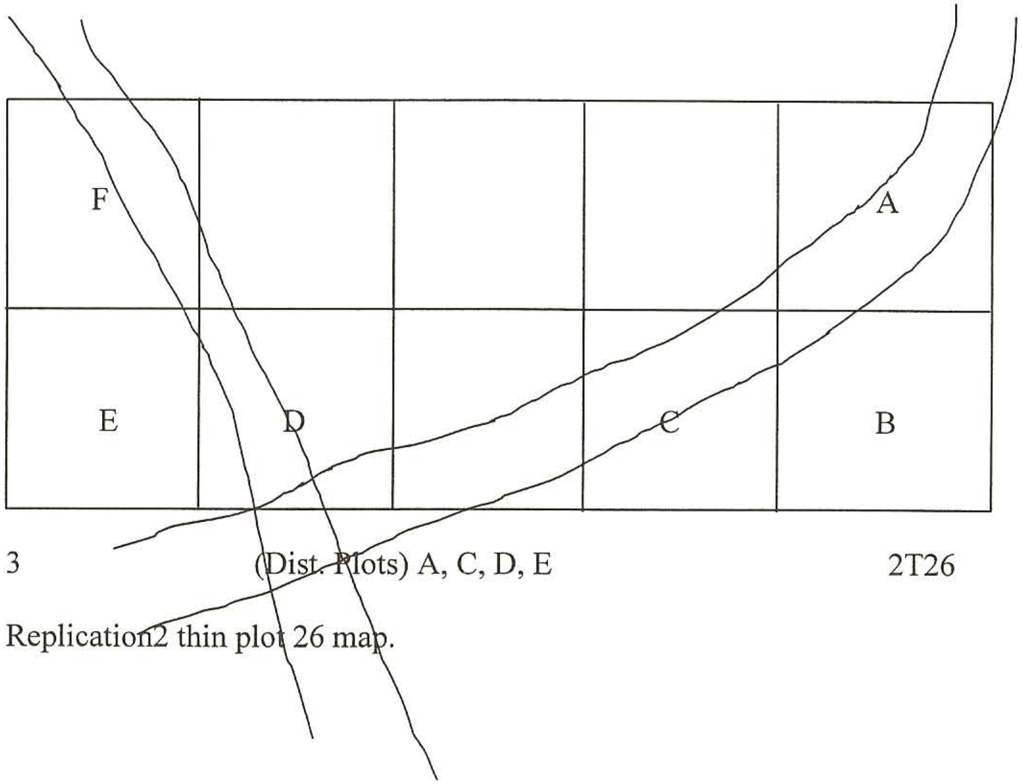
Replication2 thin plot 19 map.



Replication2 thin plot 35 map.

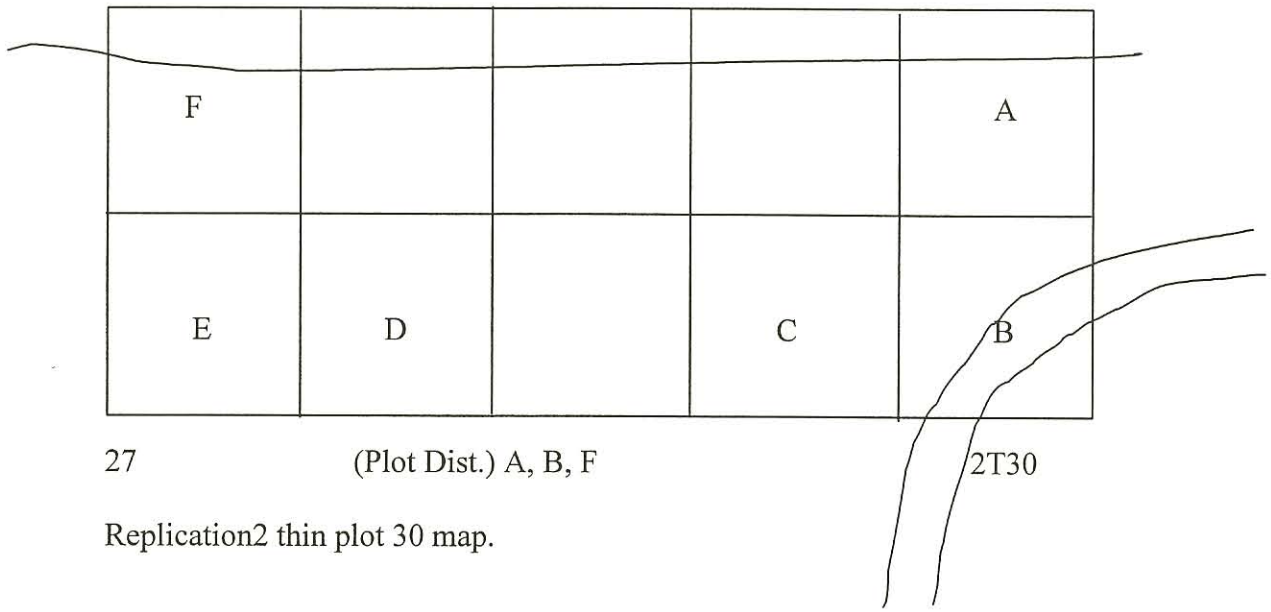


Replication2 thin plot 43 map.

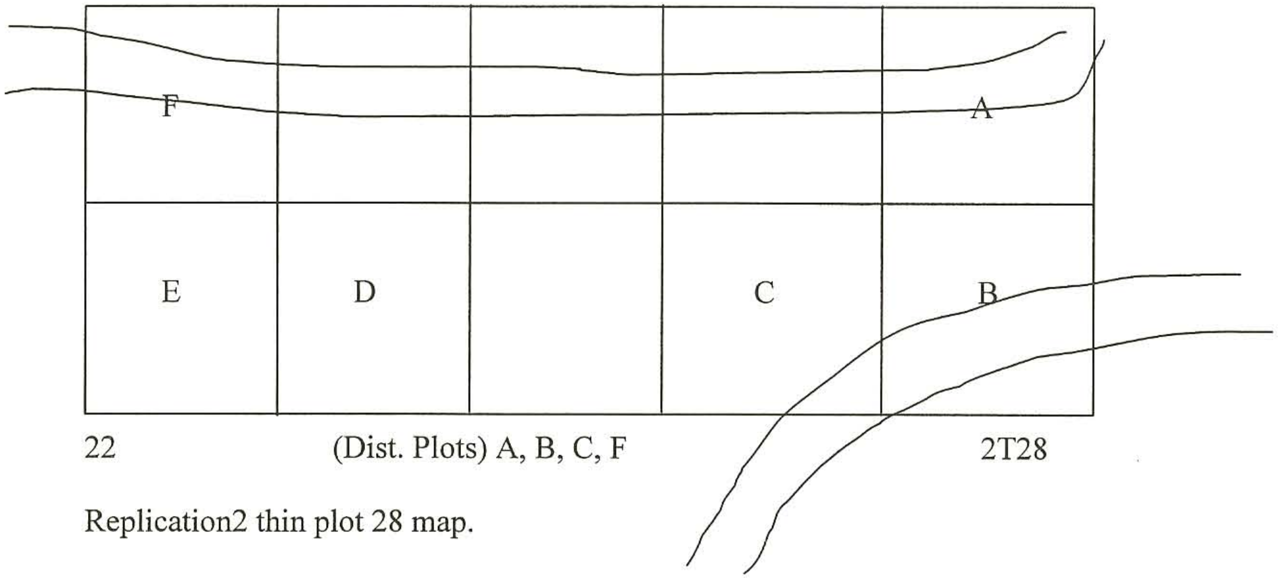


3 (Dist. Plots) A, C, D, E 2T26

Replication2 thin plot 26 map.

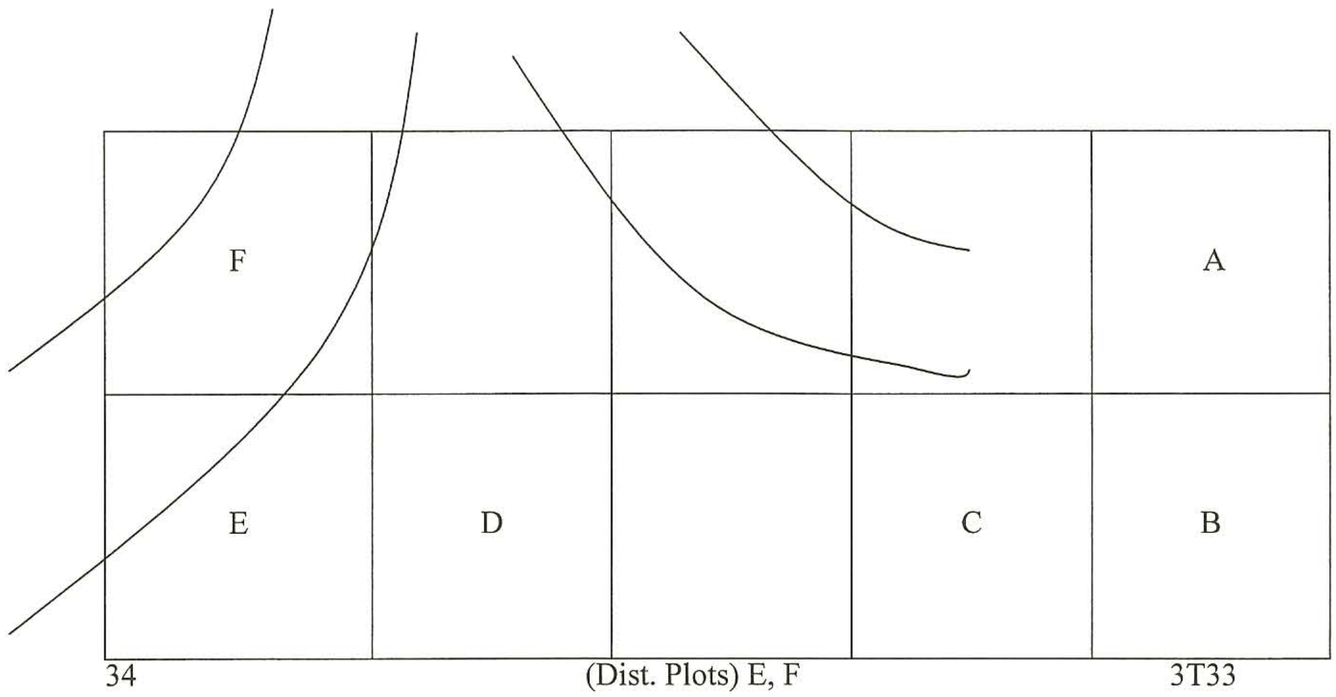


Replication2 thin plot 30 map.

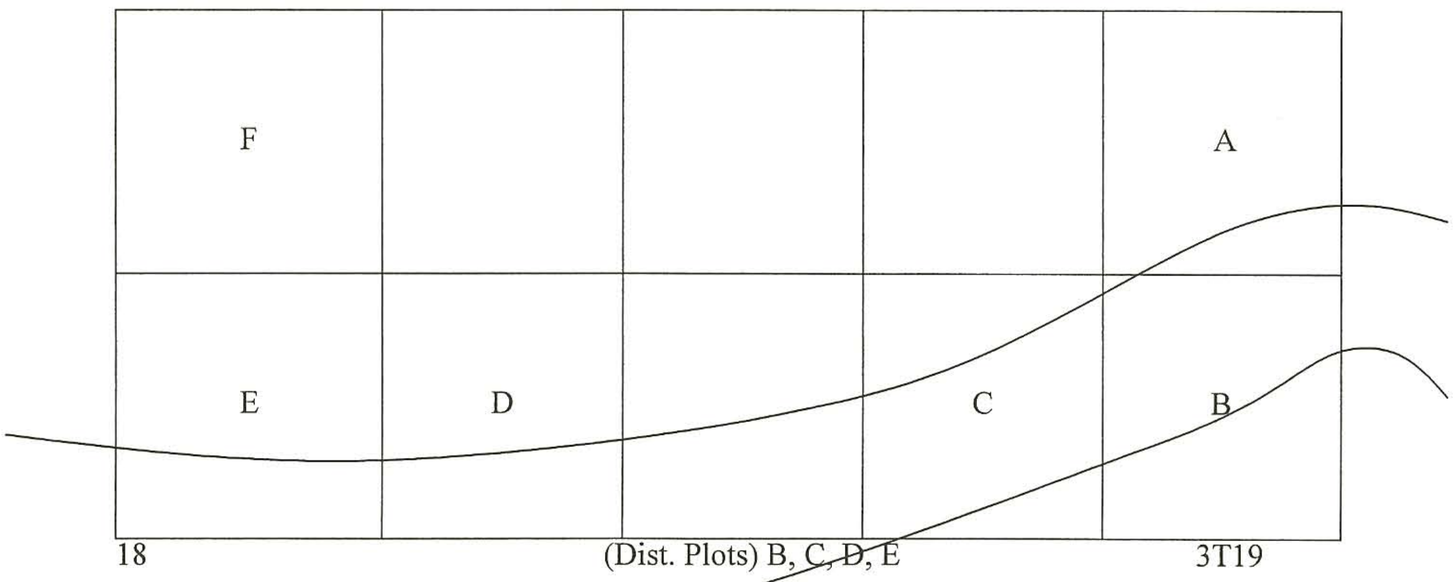


22 (Dist. Plots) A, B, C, F 2T28

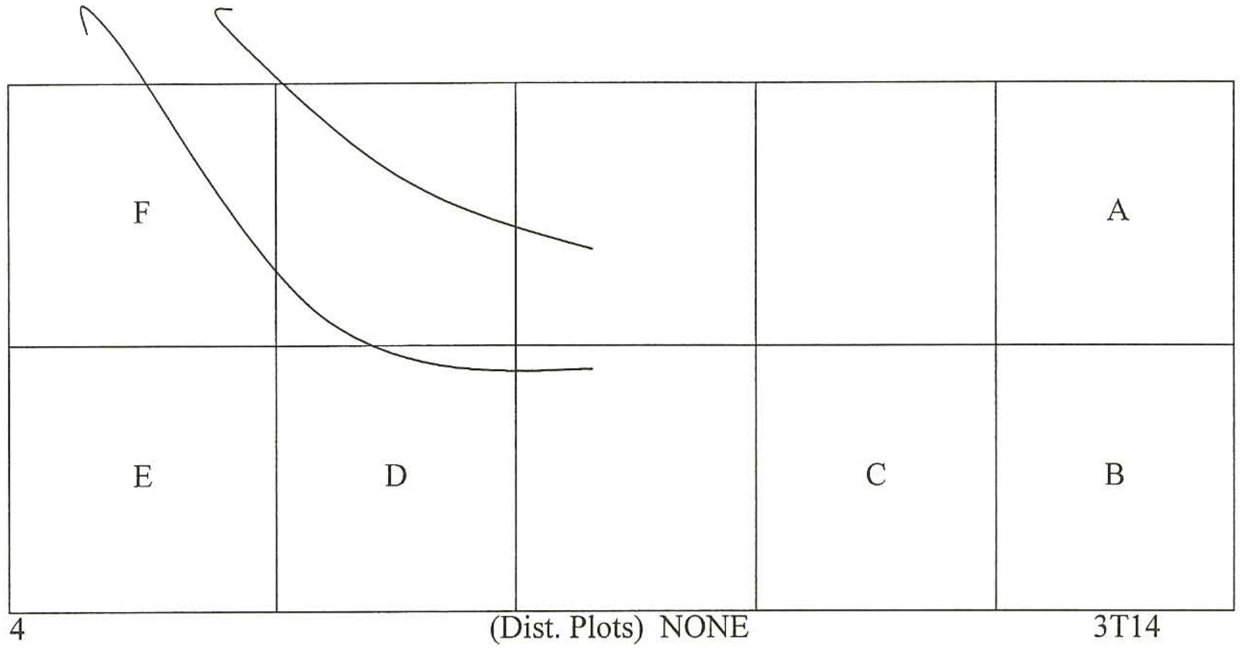
Replication2 thin plot 28 map.



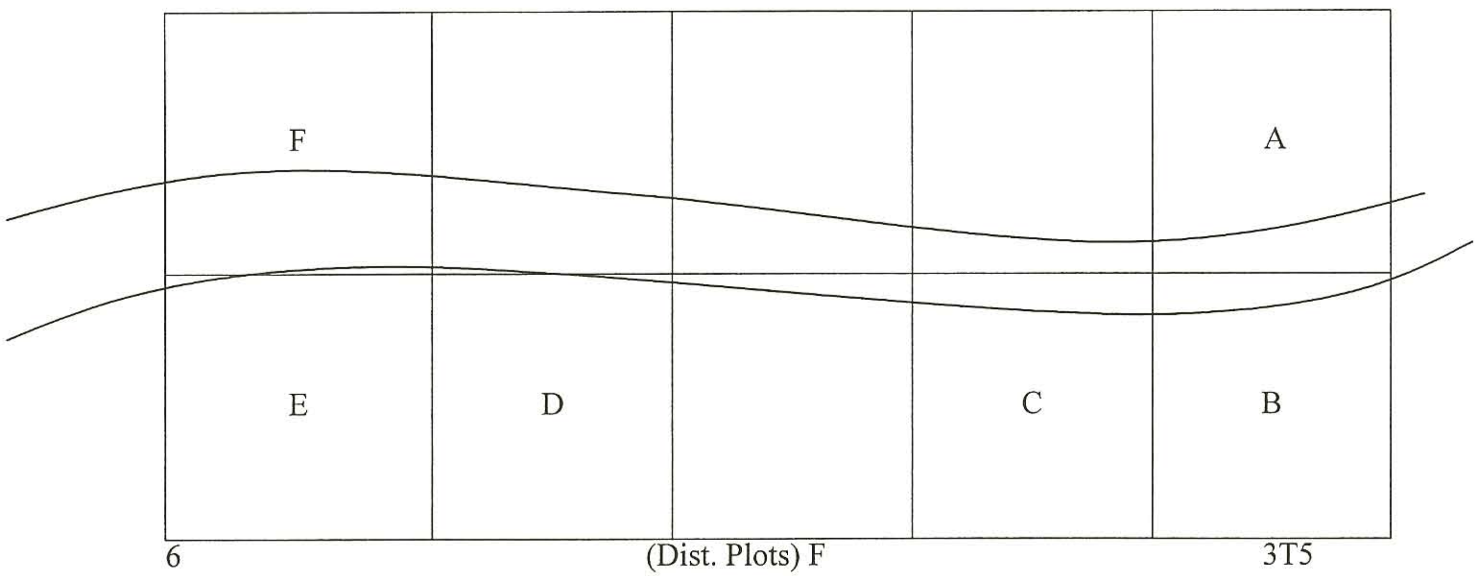
Replication3 thin plot 33 map.



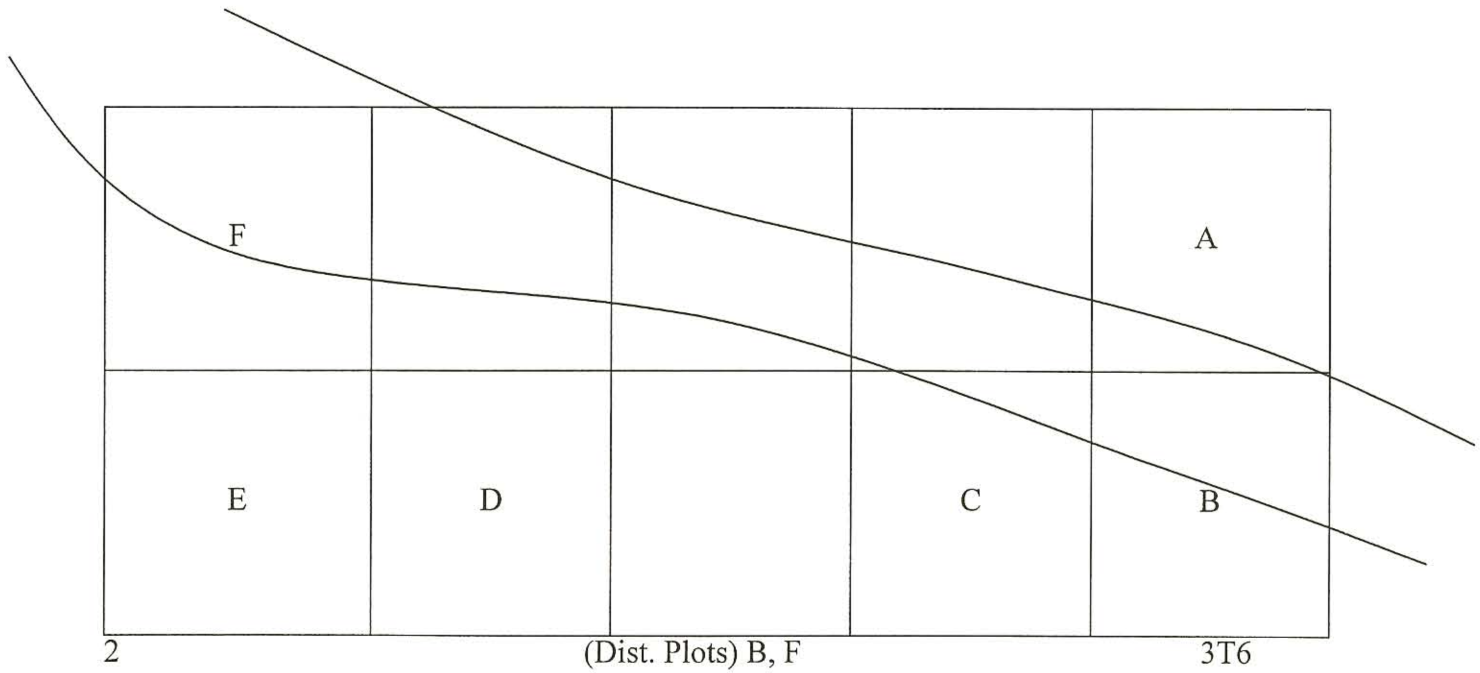
Replication 3 thin plot 19 map.



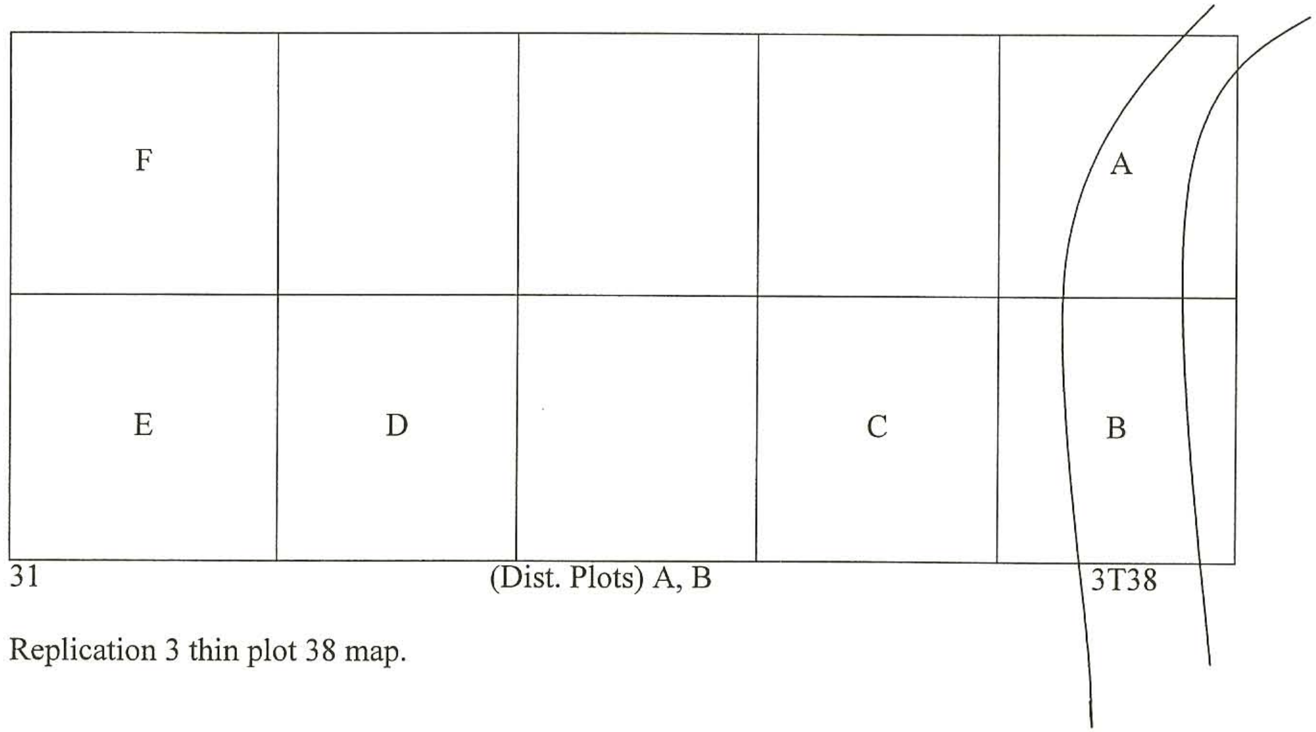
Replication 3 thin plot 14 map.



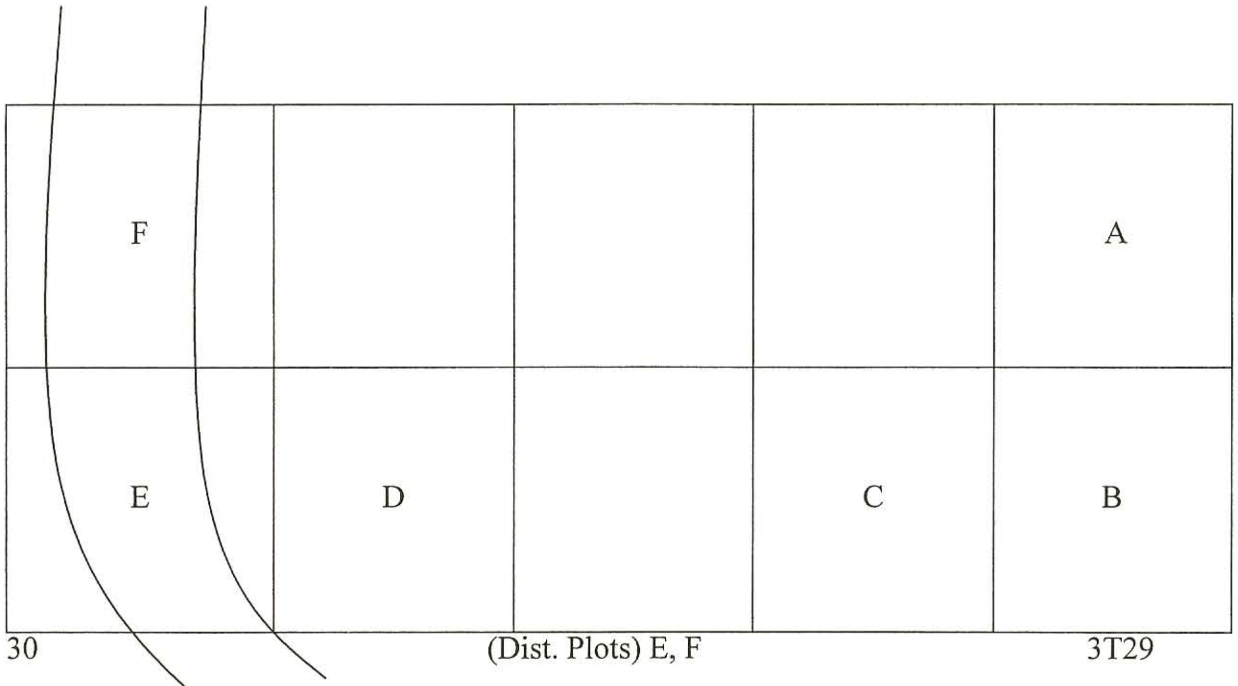
Replication 3 thin plot 5 map.



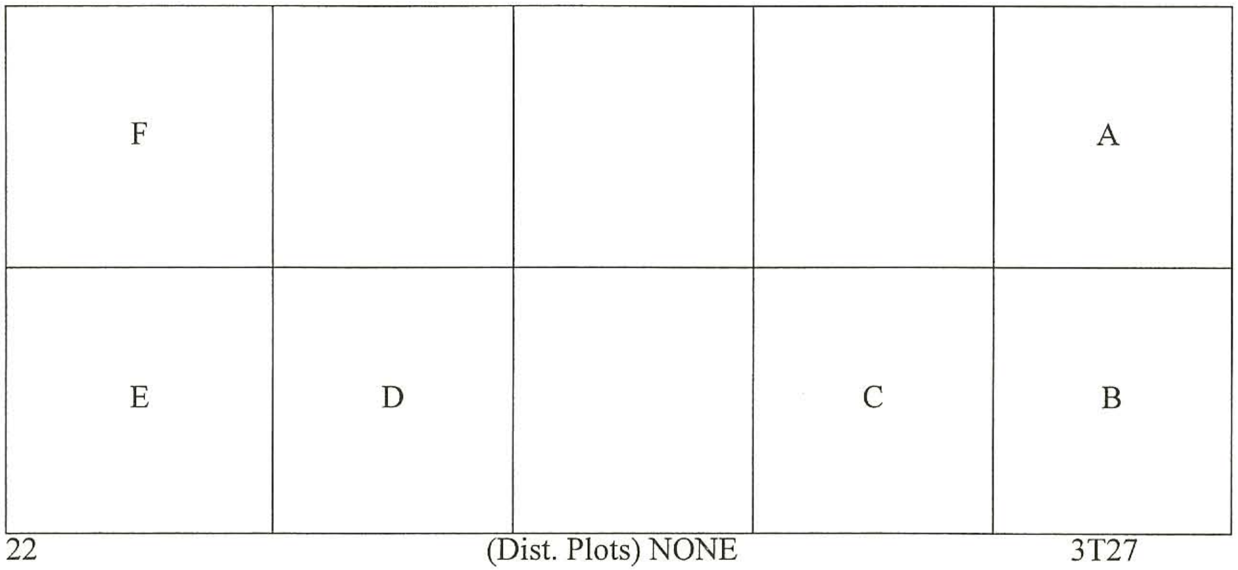
Replication 3 thin plot 6 map.



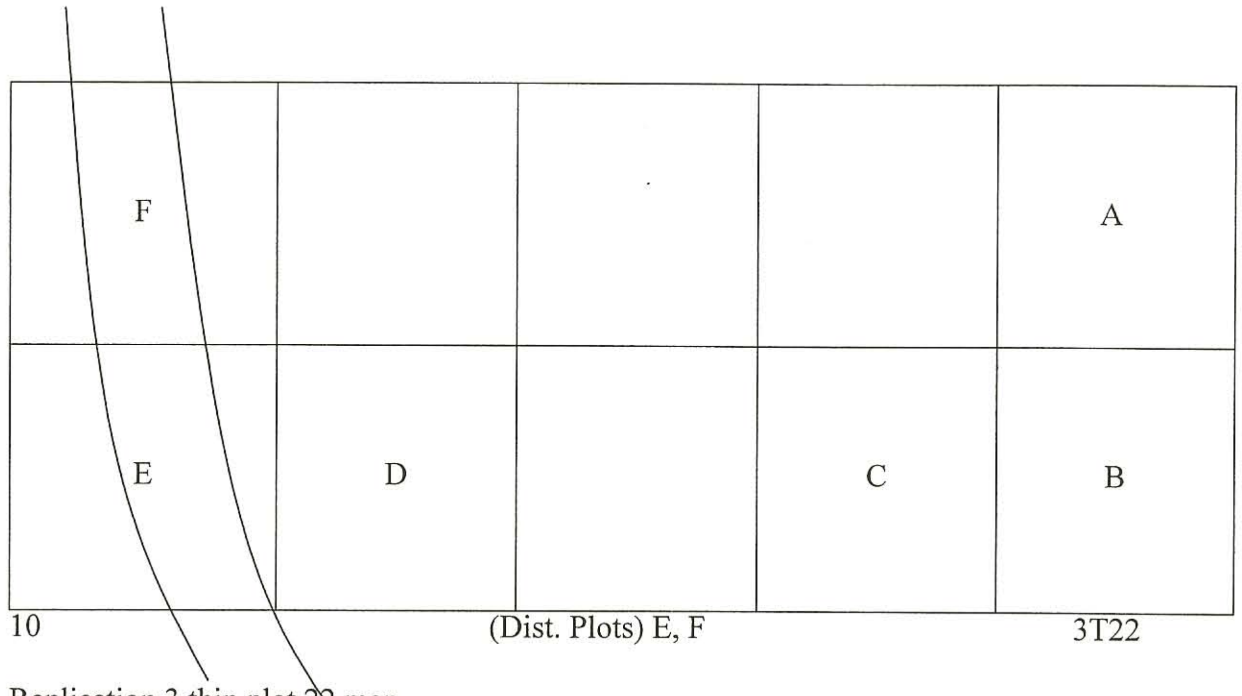
Replication 3 thin plot 38 map.



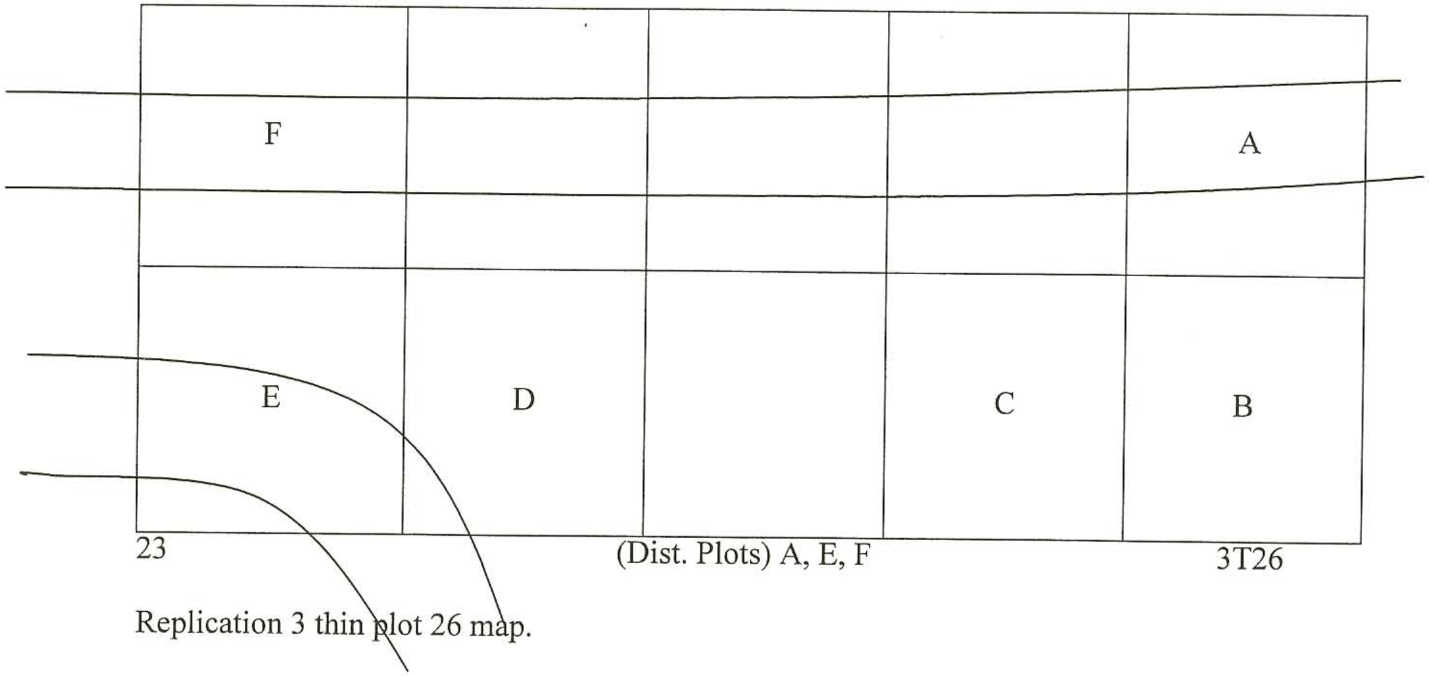
Replication 3 thin plot 29 map.



Replication 3 thin plot 27 map.



Replication 3 thin plot 22 map.



Replication 3 thin plot 26 map.

Appendix C

2000 Pre-treatment Carbon, Nitrogen, and C:N for the O-Horizon.

Stand	%C	%N	C:N
1 Control	16.05	0.50	31.85
2 Control	17.55	0.89	19.67
3 Control	15.93	0.73	22.12
1 Thin	15.89	0.72	21.71
2 Thin	14.11	0.58	24.43
3 Thin	13.88	0.67	20.82
1 Burn	17.87	0.68	26.47
2 Burn	19.64	0.98	19.90
3 Burn	15.24	0.67	22.68

2000 Pre-treatment Carbon, Nitrogen, and C:N for the O-Horizon.

Stand	%C	%N	C:N
1 Control	2.35	0.02	8.07
2 Control	2.98	0.16	19.00
3 Control	2.18	0.03	6.05
1 Thin	1.90	0.09	14.48
2 Thin	1.16	0.01	1.32
3 Thin	1.93	0.04	10.06
1 Burn	1.85	0.03	8.86
2 Burn	2.11	0.06	13.97
3 Burn	2.92	0.05	18.19

2000 Bulk Density in gm/cm^3.

Stand	gm/cm^3
1 Control	1.35
2 Control	0.97
3 Control	1.22
1 Thin	1.48
2 Thin	1.34
3 Thin	1.13
1 Burn	0.78
2 Burn	1.04
3 Burn	1.05

2000 Net and Proportional Mineralization.

Stand	NET	PROP
1 Control	2.11	0.03
2 Control	-2.15	0.22
3 Control	-1.85	0.16
1 Thin	2.22	0.39
2 Thin	0.68	0.11
3 Thin	2.56	0.20
1 Burn	2.43	-0.19
2 Burn	1.48	-0.01
3 Burn	2.79	0.04

2000 Macronutrient Analysis.

Stand	TEC	pH	Sulfur ppm	EE_ppm	Ca_ppm	Mg_ppm	K_ppm	Na_ppm
1 Control	2.52	5.50	36.30	11.55	232.20	31.10	46.80	10.40
2 Control	3.38	5.37	31.55	10.45	280.90	55.50	44.85	8.85
3 Control	3.19	5.41	54.55	15.50	270.50	54.25	54.65	10.20
1 Thin	4.34	5.76	35.80	13.50	410.90	96.90	99.15	10.60
2 Thin	2.43	5.11	40.35	9.80	174.50	22.60	45.25	12.90
3 Thin	4.75	5.29	29.65	8.95	331.50	90.20	80.35	9.30
1 Burn	2.37	5.24	37.35	10.70	191.90	22.90	46.70	9.90
2 Burn	3.47	5.36	36.45	8.80	278.95	56.85	54.60	8.20
3 Burn	2.08	5.30	46.95	13.85	167.65	25.25	40.35	9.55

Stand	Other_pct	H_pct	B_ppm	Fe_ppm	Mn_ppm	Cu_ppm	Zn_ppm	Al_ppm
1 Control	6.41	30.15	0.12	138.50	31.90	0.98	1.81	1106.45
2 Control	6.66	33.85	0.16	82.25	21.40	0.44	0.98	1049.60
3 Control	6.58	32.65	0.38	86.50	32.95	0.61	1.59	953.95
1 Thin	5.91	22.65	0.42	117.10	67.30	0.51	1.50	956.25
2 Thin	7.19	41.55	0.15	128.30	17.70	0.23	1.29	871.90
3 Thin	6.83	36.35	0.34	87.75	28.20	0.44	1.16	764.20
1 Burn	6.93	37.80	0.44	138.75	15.90	0.69	1.87	941.40
2 Burn	6.69	34.30	0.08	118.15	24.40	0.98	1.35	857.40
3 Burn	6.80	36.00	0.44	153.00	31.55	1.11	2.25	1131.40

2001 Post-treatment C, N, and C:N for the O-Horizon.

Stand	%C	%N	C:N
1 Control	23.03	0.84	27.05
2 Control	28.96	1.33	22.12
3 Control	24.50	0.94	25.94
1 Thin	16.30	0.61	26.97
2 Thin	20.34	0.83	25.70
3 Thin	23.89	0.98	24.74
1 Burn	15.22	0.62	24.75
2 Burn	21.86	1.02	20.80
3 Burn	21.42	0.83	25.88

2001 Post-treatment C, N, and C:N for the A-Horizon.

Stand	%C	%N	C:N
1 Control	2.68	0.11	18.67
2 Control	2.71	0.13	18.36
3 Control	2.31	0.09	14.46
1 Thin	2.07	0.13	17.60
2 Thin	1.54	0.02	3.48
3 Thin	2.17	0.10	15.57
1 Burn	1.88	0.04	6.46
2 Burn	2.23	0.05	9.21
3 Burn	3.38	0.14	26.64

2001 Post-treatment Bulk Density in gm/cm^3.

Stand	gm/cm^3
1 Control	0.79
2 Control	0.81
3 Control	0.80
1 Thin	0.86
2 Thin	0.90
3 Thin	0.86
1 Burn	0.89
2 Burn	0.84
3 Burn	0.73

2001 Post-treatment Net and Proportional Mineralization.

Stand	Net	Prop
1 Control	0.16	0.04
2 Control	0.05	0.02
3 Control	-0.31	0.40
1 Thin	0.81	-0.01
2 Thin	0.25	0.06
3 Thin	0.47	0.13
1 Burn	0.39	-0.06
2 Burn	0.52	-0.03
3 Burn	0.40	0.02

2001 Post-treatment Macronutrient Analysis.

Stand	TEC	pH	Sulfur ppm	P_ppm	Ca_ppm	Mg_ppm	K_ppm	Na_ppm
1 Control	3.18	5.06	31.50	8.55	212.60	37.13	45.33	7.55
2 Control	4.45	4.90	28.40	13.10	286.00	54.65	56.40	8.35
3 Control	5.38	5.04	39.35	16.95	422.50	50.15	52.10	6.65
1 Thin	4.56	5.52	29.75	11.00	378.45	97.10	86.15	7.65
2 Thin	3.43	4.97	30.35	10.80	232.05	37.40	50.20	7.25
3 Thin	5.60	5.32	24.00	13.30	449.30	89.55	92.30	6.95
1 Burn	3.11	4.99	34.50	9.65	208.95	35.30	46.70	7.65
2 Burn	3.87	5.14	28.35	11.80	286.20	53.40	61.30	6.75
3 Burn	3.16	5.10	33.45	14.00	248.75	30.60	45.45	5.75
Stand	Other_pct	H_pct	B_ppm	Fe_ppm	Mn_ppm	Cu_ppm	Zn_ppm	Al_ppm
1 Control	7.28	42.50	0.29	123.58	30.75	0.79	1.38	1036.90
2 Control	7.60	46.60	0.33	100.10	28.55	0.60	1.18	1115.20
3 Control	7.32	43.10	0.31	99.10	36.50	0.50	1.82	1062.45
1 Thin	6.38	29.63	0.37	114.20	62.40	0.42	1.02	995.65
2 Thin	7.46	45.25	0.31	140.45	18.60	0.40	1.19	988.70
3 Thin	6.77	35.30	0.36	119.30	41.30	0.48	1.26	987.90
1 Burn	7.42	44.65	0.31	109.80	19.10	0.51	1.05	1034.40
2 Burn	7.12	40.60	0.33	145.15	30.40	0.80	1.27	984.40
3 Burn	7.20	41.65	0.32	137.45	30.00	0.90	1.42	1180.40

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