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Mark J. Behan

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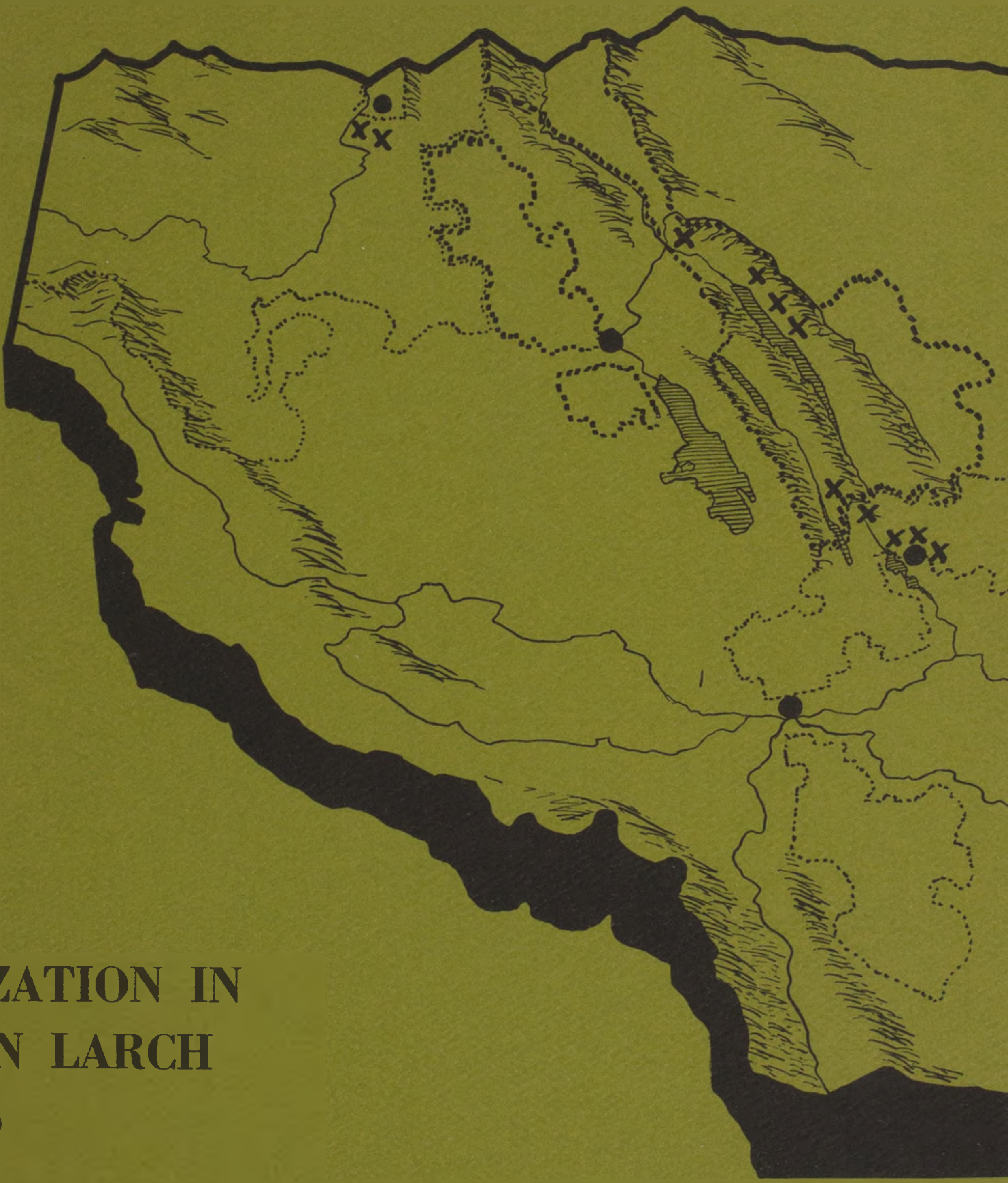

FERTILIZATION IN WESTERN LARCH FORESTS

By MARK J. BEHAN
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University of Montana, Missoula

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Montana Forest and Conservation Experiment Station
School of Forestry
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Mark J. Behan, Ph.D.

Department of Botany, University of Montana

Introduction

The demand for timber products in the United States is expected to increase nearly 80% by the year 2000. It has been predicted that this demand can be met through current levels of forest management for the next two decades, but production will not meet demands in the latter years of this century unless the intensity of management is increased (1).

One indication of a world wood deficiency was noted by Swan (1965) when he stated that the increase in consumption of industrial wood in Europe from 1950 to 1960 was more than twice as great as the increase of the previous 40 years. He also noted that at the end of the last decade, Europe changed from an exporter of 0.7 billion board feet to an importer of 3.5 billion board feet per year. Similar deficits were observed in eastern Europe, Japan, and China. He concluded that on a global basis, wood is becoming an increasingly valuable commodity, and as its value increases, so does the incentive to increase yields per unit land area. Stoeckler and Arneman (1960) based a similar conclusion on the observation that in both Europe and Asia the demand for agricultural crops is at a premium, and as a result timber production has been relegated to lands unfit for agriculture because of low fertility, unfavorable water regimes, or harsh topography or climate. This withdrawal of highly productive forest lands for agricultural use has caused a reduction in potential wood productivity, in spite of increasing demands caused by population growth and increased standards of living.

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In the United States, improvements in agricultural technology have permitted the conversion of some timber producing lands to agricultural use, and other areas have been withdrawn from timber production for recreational use, water production, highways, and cities. The increasing demand and value of wood products, increasing costs of land management, and the decrease of areas devoted to wood production are persuasive arguments in favor of research devoted to finding new ways of increasing timber production per unit of timber land.

Forest fertilization is effective as one means of increasing timber production (27). This report describes the status of fertilization research in the western larch type in Montana, and lists the locations of established experimental forest fertilization plots.

Growth Potential of Western Larch

Western larch (*Larix occidentalis*, Nutt.) has been recognized as one of the most productive trees in the Northern Rocky Mountains. Volumes of 43,500 board feet are expected on site class I lands and 11,200 board feet in site class III lands in 100 years. On the same sites only lodgepole pine (*Pinus contorta*, var. *latifolia*) equals the rapid height growth of larch during the early years, but typically the rate of height increase in larch eventually exceeds that of pine (2). The rapid growth of larch, its comparative ease of regeneration, and its acceptable wood quality combine to make it an ideal species with which to initiate studies of forest fertilization in Montana.

Forest Soil Fertility

Forest soil fertility as a factor affecting site productivity has received little attention in comparison to such factors as soil moisture (Ralston, 1964). Swan (1965) has pointed out that some foresters still mistakenly believe that trees need only water for satisfactory growth. However, evidence has been found throughout the world that forest trees require minerals from the soil in much the same way as agricultural crops, and that tree growth is limited when the supply of these minerals is inadequate. The determination of the level of forest soil fertility is probably more difficult than agricultural soil fertility because of the more complex biological and chemical nature of uncultivated soils, the paucity of information about the mineral requirements of tree species, the long rotation period of trees, and the difference between agricultural crops and trees in ability to absorb minerals in the various chemical forms in which they occur in soils.

Although there are several approaches to the determination of soil fertility, soil analysis, chemical analysis of the plant, diagnosis by visual symptoms, and field or greenhouse fertilizer trials have been the techniques most commonly used in forest tree nutrition (Tamm, 1964, Wallace, 1961). These four methods are discussed below:

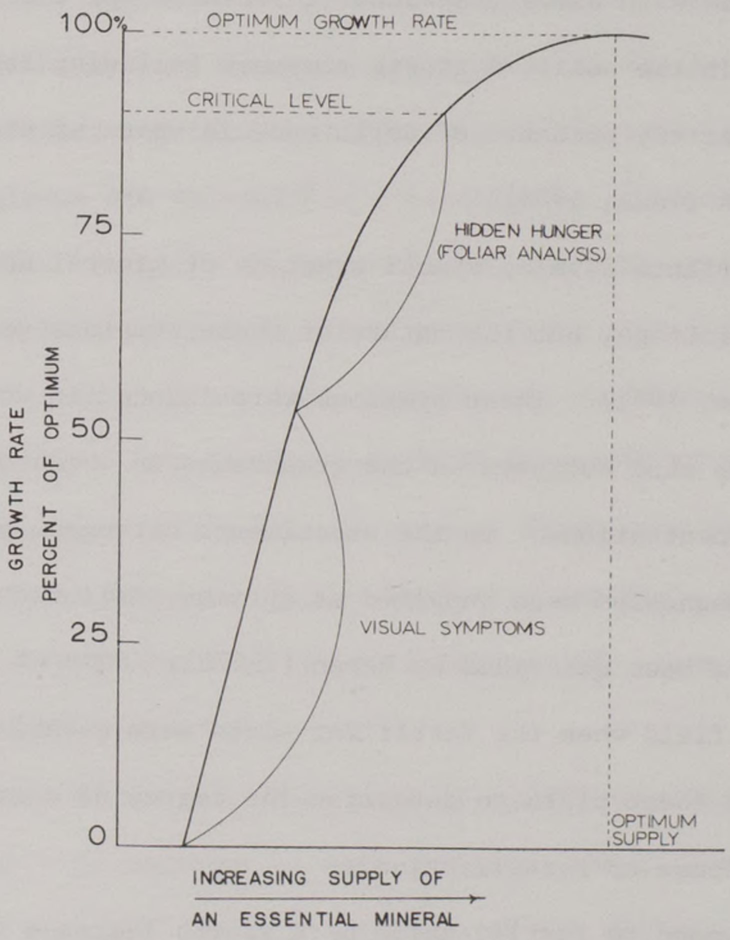
(A) Diagnosis of mineral deficiency by soil analysis. Soil analysis is not yet as reliable in diagnosing forest soil fertility as it is in agriculture. This may be due in part to the practice of using soil testing methods developed for agricultural crops when these methods may not be applicable to forest soils. The nutrient-extracting solutions employed in agriculture are of questionable value in forest soils because of such factors as difference in species, requirements, rooting depths, and additional forms of minerals available to trees because of mycorrhizal associations and longer life plan (Ralston 1965, Gessel 1962). Some minerals also are known to cycle through the forest ecosystem. For example, a mineral may first become available by weathering of the parent rock material, and then be absorbed by the root and transported to the leaves. Eventually these minerals may be leached from the leaves, or may return to the ground in litter, decompose, and return to the rooting zone to be reabsorbed by the tree. This circulation of minerals in the forest ecosystem is an important component of the total mineral economy of the site, and the rate at which the mineral cycle is completed has a bearing on the soil fertility. One of the reasons for the infertility of podzolized forest soils is that some minerals remain fixed in undecomposed litter. Although such minerals are present in the forest ecosystem, their circulation is slowed, and thus the fertility of the site is reduced. The usual type of soil analysis can measure the concentration of minerals only at a single point in the cycle. It gives no indication of the rate of disappearance by root absorption, or replenishment from the mineral cycle or new increments from the parent material. Both forms of replenishment may contribute substantially to forest soil fertility. The complex nature of diagnosis of site fertility by soil analysis has encouraged this author to examine diagnostic systems for western larch based on visual symptoms, foliar analysis, and field fertilizer trials in the hope that the development of these techniques may prove more expedient in the initial stages of this research.

(B) Diagnosis of mineral deficiency by visual symptoms, foliar analysis, and fertilization. In contrast to soil analysis, the diagnosis of mineral deficiency by visual symptoms, chemical analysis of the foliage, and by growth response following fertilization employ the plant as an indicator of its mineral status. The validity of the visual and chemical methods is generally tested by application of a fertilizer containing the mineral diagnosed as deficient. Although a positive response to fertilization is generally indicative of correct diagnosis, there may be cases in which the response is due to an indirect effect. For example, the addition of lime to a forest soil has been known to stimulate tree growth, but this was seldom due to a direct alleviation of calcium deficiency. Generally, the increased growth results from an increase in the availability of other minerals. The absence of a fertilizer response, however, may be due to the inability of the fertilizer to reach the tree roots because of its consumption by the ground cover. The fertilizer also may be transformed into forms unavailable for absorption, or be ineffectual because of an unfavorable water regime -- such as summer drought combined with excessive winter leaching -- or the mineral simply may not be deficient in the soil. A growth response following fertilization is still the most satisfactory evidence of deficiency in spite of the possibility of these indirect effects (Tamm, 1964).

Many species of plants develop visual symptoms of mineral deficiency, such as discoloration of the foliage, but the nature of these symptoms varies considerably among species (Wallace, 1961). These symptoms were induced in western larch by growing the species in sand cultures in the greenhouse in which minerals were supplied at known concentrations. In the experiments nitrogen, potassium, phosphorus, calcium, or magnesium were supplied at optimum, deficient or very deficient levels, and these have been described by Behan (1967a). Some of these symptoms were observed in the field when the fertilizer plots were established. Observations will be made on these plots to determine the degree of correlation between symptoms and the response to fertilization.

Plants often respond to fertilization by a growth increase even though no visual symptoms are present. This response has been termed "hidden hunger" because of the absence of visual symptoms. However, in many species there is a correlation between the rate at which minerals are absorbed, the demand for them by the plant, and the concentration of those minerals in the foliage. The concentration of a mineral in the foliage, when it is supplied at just the rate necessary to permit optimum growth, is called the "critical concentration." If the mineral is supplied at less than this rate, growth is reduced and so is the concentration of the mineral in the foliage. This association permits the diagnosis of a deficiency by chemical analysis of the foliage. The relationships between mineral supply, growth, and the development of deficiency symptoms is illustrated in Fig. 1:

FIGURE 1



<u>Effect of the Supply of an Essential Mineral by the Soil on Plant Growth</u>

An optimum supply of all of the minerals essential for plant growth is necessary to achieve the maximum growth rate possible within a given site potential. The growth rate is reduced if the supply falls below the critical level. Many species exhibit visual symptoms if the deficiency is sufficiently severe, but less severe deficiencies can often be detected by foliar analysis. (After Swan, 1965.)

The concentrations of nitrogen, potassium, phosphorus, calcium and magnesium in the foliage which indicates deficiencies have been determined for western larch by growing the species in greenhouse sand cultures (Behan, 1967b). However, the foliar mineral concentration of trees growing in the field varies with season, crown position, and between trees on the same site. The effect of this variation and recommendations for sampling foliage for analyses in larch have been described by Behan and Friedrich (1967). Symptoms based on foliar analysis and visual symptoms of deficiency have been cited for other species of conifers by Tamm (1964) and Mustanoja and Leaf (1965).

Forest Fertilization

Research in forest fertilization has progressed to field application as a management practice in many of the timber-producing areas of the world. For example, Svenska Celluosa AB, a forest industry group in Sweden, plans to spend more than $8 million during the next eight years on a project of aerial nitrogen fertilization of 280,000 hectares of forestland. On the basis of pilot experiments, the company expects to increase timber production by at least 15 percent, which is sufficient to justify the cost (3). The published costs of aerial fertilization range from $10 to $30 per acre, depending chiefly on the type and quantity of fertilizer applied, the type of airplane used, and the distance flown on each trip (Swan, 1965).

Although no previous fertilizer experiments are known to have been conducted with western larch, several other species of this genera have received attention throughout the world. Edwards (1960) noted a phosphorus response in young Japanese larch (*Larix leptolepis*), which demonstrated up to a three-fold increase in height growth in comparison with control plants. Themlitz and Wandt (1960) demonstrated a response to potassium fertilization and reduced drought losses in larch. Krectova (1962) noted an improvement in seed quality from *L. gemlinii* fertilized with nitrogen, potassium, and phosphorus. Harada (1957) obtained a response in *L. kaempferi* seedlings fertilized with phosphorus. Popova (1958) observed a height increase of 50 percent and a weight increase of 100 percent when nitrogen, phosphorus and potassium fertilizers were applied prior to sowing seeds of *L. sibirica*. Leyton (1957) also observed a response to nitrogen fertilization in *L. leptolepis*. Several other responses to fertilization by various species of Larix have been cited by Mustanoja and Leaf (1965). On the basis of these results, some response to forest fertilization in *Larix occidentalis* should be anticipated.

There may be benefits from forest fertilization other than the stimulation of tree growth. One of the major problems in stand regeneration in the Rocky Mountains is overstocking, and there is evidence that fertilization may alleviate this problem. Gessel and Shareeff (1957) and Heilman (1961) have noted an increase in mortality of suppressed Douglas fir following fertilization. Maki (1960) noted that the use of fertilizer as a means of thinning appeared promising in loblolly pine. Such effects have not yet been observed in larch. Forest fertilization also has been observed to effect seed quality and quantity, susceptability to browsing (14, 20), insect and disease resistance (11, 24), growth of competitive vegetation, and cycling of mineral nutrients in the forest ecosystem. These factors have been reviewed by Tamm (1964), Ovington (1962), Kozlowski (1962), Thimann (1958), Youngberg (1965), and cited in the bibliographies prepared by White and Leaf (1956), and Mustanoja and Leaf (1965).

Fertilization Research in Western Larch Forests

During the summer of 1966, 175 experimental forest fertilization plots were established in thirteen locations in western Montana. The primary objectives were: (1) to study the effects of fertilization on height and diameter growth in western larch; (2) to study the effect of the treatments on the survival of subdominants in overstocked stands; and (3) to correlate fertilizer response with mineral deficiency symptoms developed in greenhouse and laboratory studies.

Annual measurements of leader growth will be made in order to determine the effect of the treatments on growth. In 1972 and 1976 trees in each plot will be harvested and the annual growth increment determined by stem analysis (Gessel, *et al.*, 1960). Some forest fertilization recommendations for larch can probably be made before 1970, however, the results of the stem analyses will provide a more accurate assessment.

Methods

A) Selection of Plot Locations

A simple set of fertilizer treatments was applied to a variety of stand types. The fertilizers were applied in ample amounts with respect to responses observed in other coniferous species. Fair to poor, medium, and excellent site classes are represented, as are age classes from one-year-old through sixty-year-old stands. Several levels of stocking also are represented in each site class. It was expected that if a response could be demonstrated it should occur in at least one and probably in several of the stand conditions.

The 10 to 30 year age class was selected for intensive study. Height growth is most rapid at this age (2), therefore this may be the growth period placing the greatest demand on the mineral resources of the site. It also is the age class when management procedures such as thinning are most common, thus an economical time for fertilization application.

The criteria used to select a specific location in each site class were accessibility, designation of the area for timber production, uniform terrain for layout of the treatments. The individual plots varied in size from 1/80 to 1/20 acre, depending on the size of the plants, their density, and the amount of uniform terrain. Two to six treatments were applied at each location, and each treatment was repeated three times.

B) Treatments

The treatments consisted of the application of urea at the rate of 300 pounds nitrogen per acre, treble superphosphate at a rate equal to 200 pounds P_2O_5 (phosphorus pentoxide) per acre, potassium chloride at the equivalent of 200 pounds K_2O (potassium oxide) per acre, or a combination of these. The order of treatments in the first of the three replications was obtained by random selection. The order in the second and third replications was staggered so as to avoid error caused by having identical treatments in the same rank or file. The fertilizers were taken to the field in weighed amounts for each plot, and were applied with a hand spreader. No attempt to premix fertilizers on plots requiring more than one type was made, but rather, the different fertilizers were applied in successive applications.

Acknowledgements

The author's appreciation is extended to Michael Rutledge for his valued assistance in the field, and to Cominco Products, Inc., and Simplot Co., who donated the fertilizers.

APPENDIX

Each fertilizer plot location map contains the geographic and U. S. Forest Service Compartment location, stand age and site index, and approximate heights as noted in 1966. More detailed information concerning density, number of trees in each plot, specific objectives at the location, and soil analyses for some of the plots may be obtained from the Experimental Forest Fertilization Plot Establishment Report filed with the Director, Intermountain Forest and Range Experiment Station, Ogden, Utah, or from the author.

A five-foot reference post was placed in a conspicuous location near the principal access road at each location. All measurements to the plots originate from this post. Stakes were placed in the corner of each treatment plot, and a grey painted sign about 6 inches square was also placed in the plot. The sign contained the following information: "R-n" representing the replicate number; "P-n" representing the plot number in that replicate; and "T-a," the code identifying the treatment given. A sign with the code "R-1, P-6, T-F" would therefore be the sixth plot in the first series of replicates, and would have received treatment "F." Two, three, or six treatments were applied at a location, and the treatment code is defined on the map describing the location. The fertilizers are abbreviated in the treatment code described on the maps as follows: N = nitrogen; P = phosphorus (as P_2O_5) and K = potassium (as K_2O), with the subscripts 0, 2, or 3 indicating the rate of application in pounds per acre. Thus the treatment code "A $N_3P_2K_0$" signifies that all plots labelled "A" at that location received a fertilizer application of 300 pounds nitrogen per acre and phosphorus at the equivalent of 200 pounds P_2O_5 per acre, and no potassium fertilizers.

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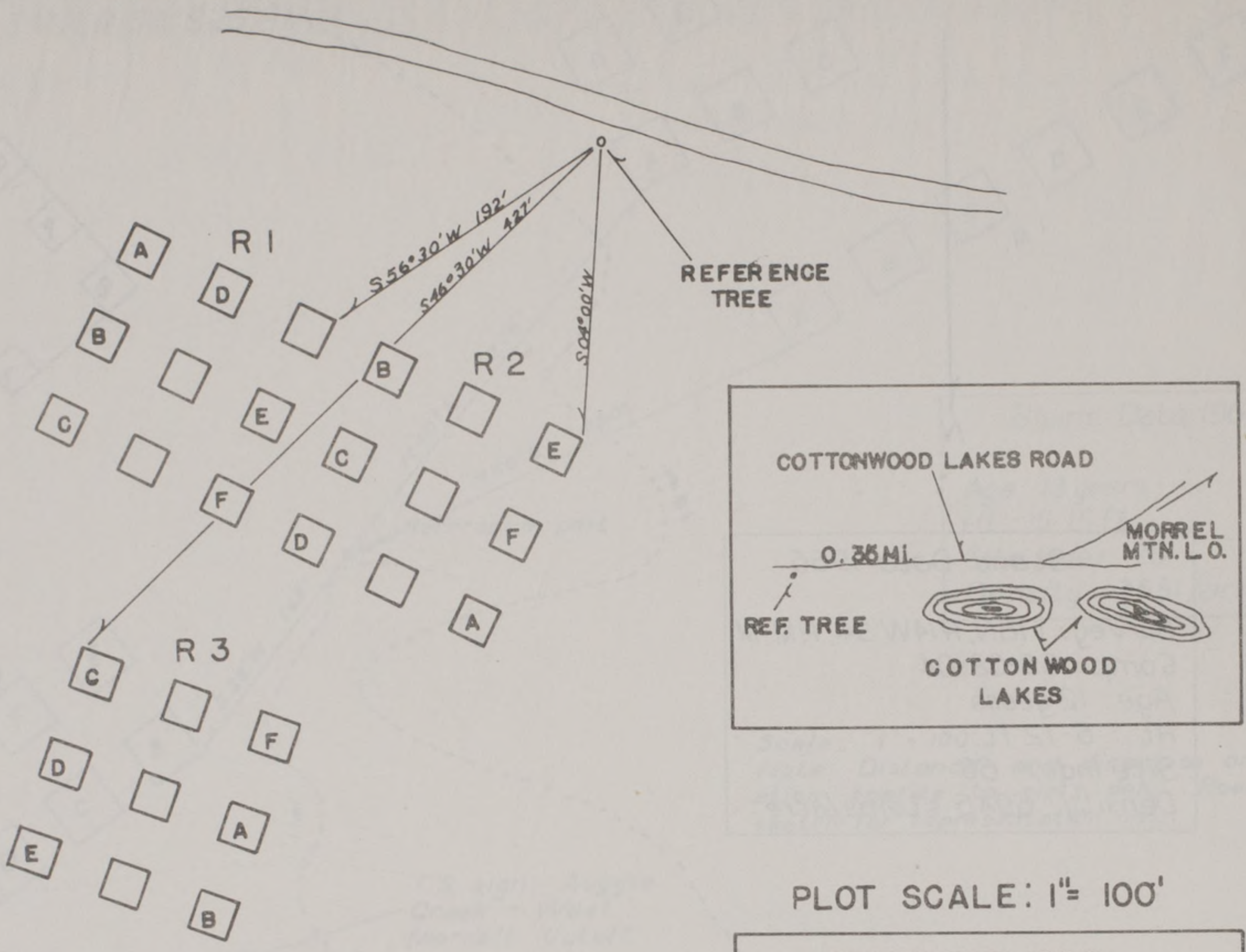
LOWER COTTONWOOD LAKES

SEELEY LAKE RANGER DISTRICT
LOLO NATIONAL FOREST 69-01-12, T16N R14W SEC. 3 PMM



TREATMENT CODE

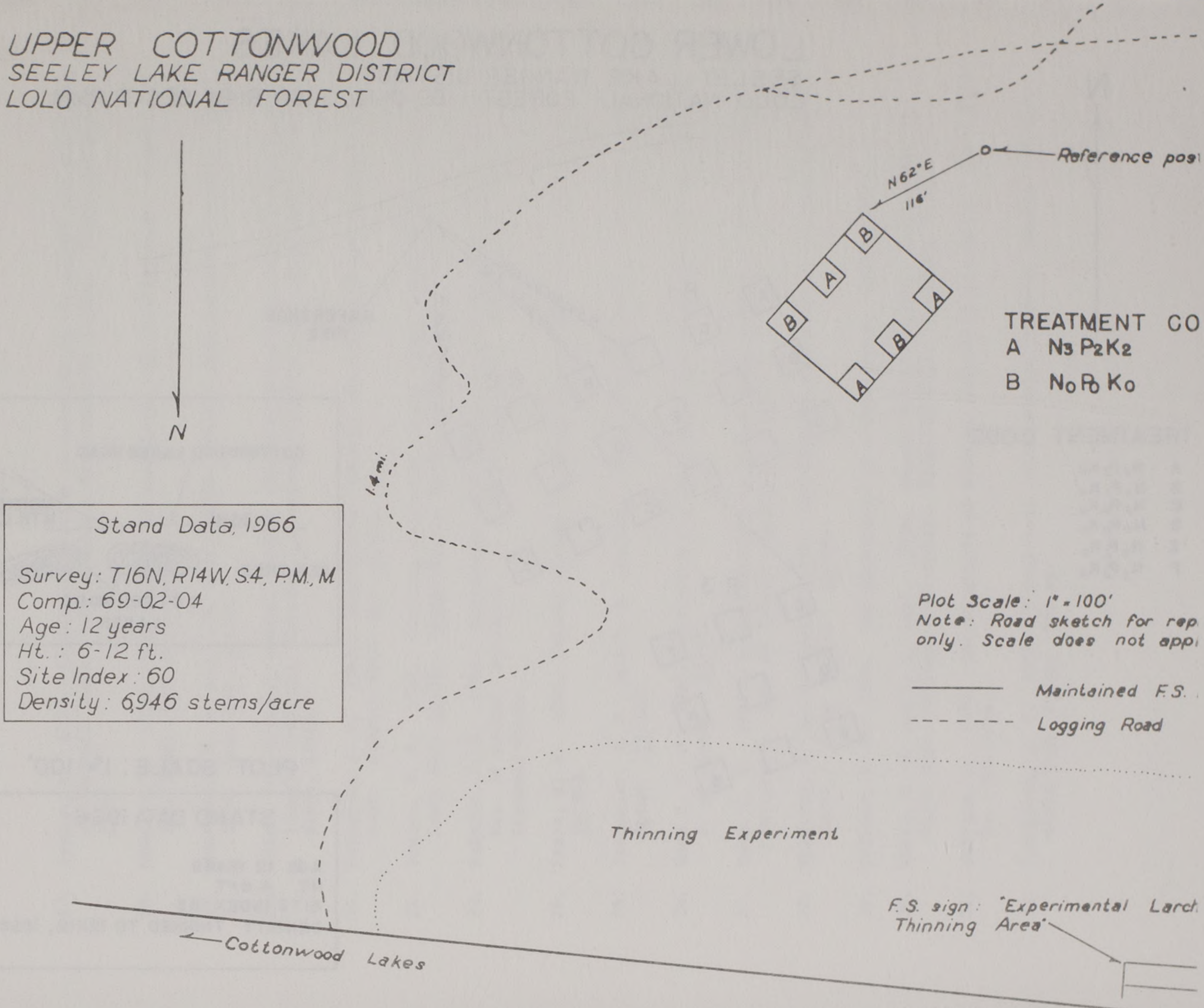
A	$N_3 P_2 K_0$
B	$N_3 P_0 K_0$
C	$N_3 P_0 K_2$
D	$N_0 P_0 K_0$
E	$N_0 P_2 K_2$
F	$N_3 P_2 K_2$

PLOT SCALE: 1" = 100'

STAND DATA 1966

AGE 12 YEARS
HT. 4-8 FT.
SITE INDEX 65
DENSITY THINNED TO 12X12, 1966

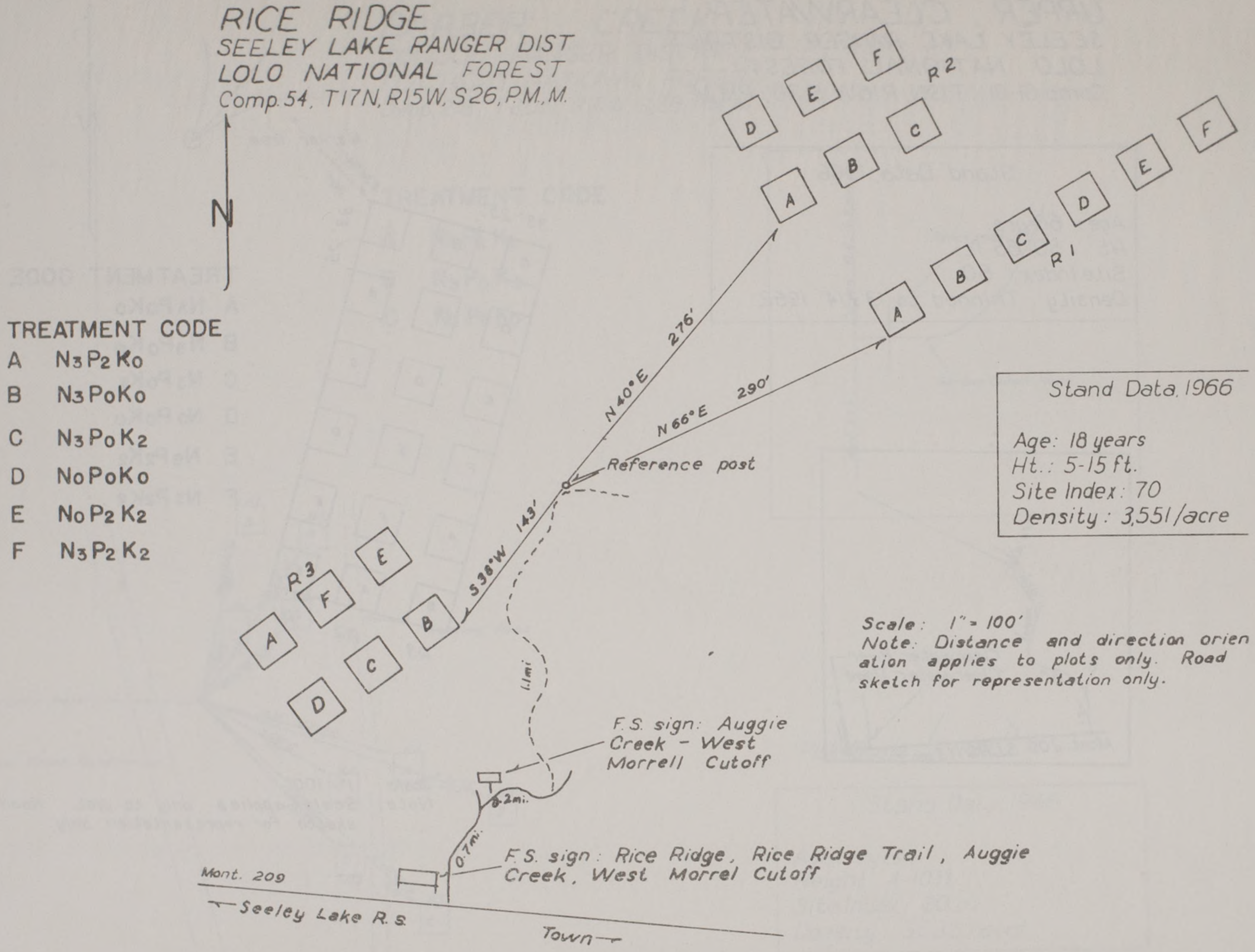
UPPER COTTONWOOD
SEELEY LAKE RANGER DISTRICT
LOLO NATIONAL FOREST



Stand Data, 1966

Survey: T16N, R14W, S.4, P.M., M.
Comp.: 69-02-04
Age: 12 years
Ht.: 6-12 ft.
Site Index: 60
Density: 6,946 stems/acre

Plot Scale: 1" = 100'
Note: Road sketch for rep
only. Scale does not appl



RICE RIDGE

SEELEY LAKE RANGER DIST
LOLO NATIONAL FOREST
Comp. 54, T17N, R15W, S26, P.M.M.

TREATMENT CODE

A	$N_3P_2K_0$
B	$N_3P_0K_0$
C	$N_3P_0K_2$
D	$N_0P_0K_0$
E	$N_0P_2K_2$
F	$N_3P_2K_2$

Stand Data, 1966

Age: 18 years
Ht.: 5-15 ft.
Site Index: 70
Density: 3,551/acre

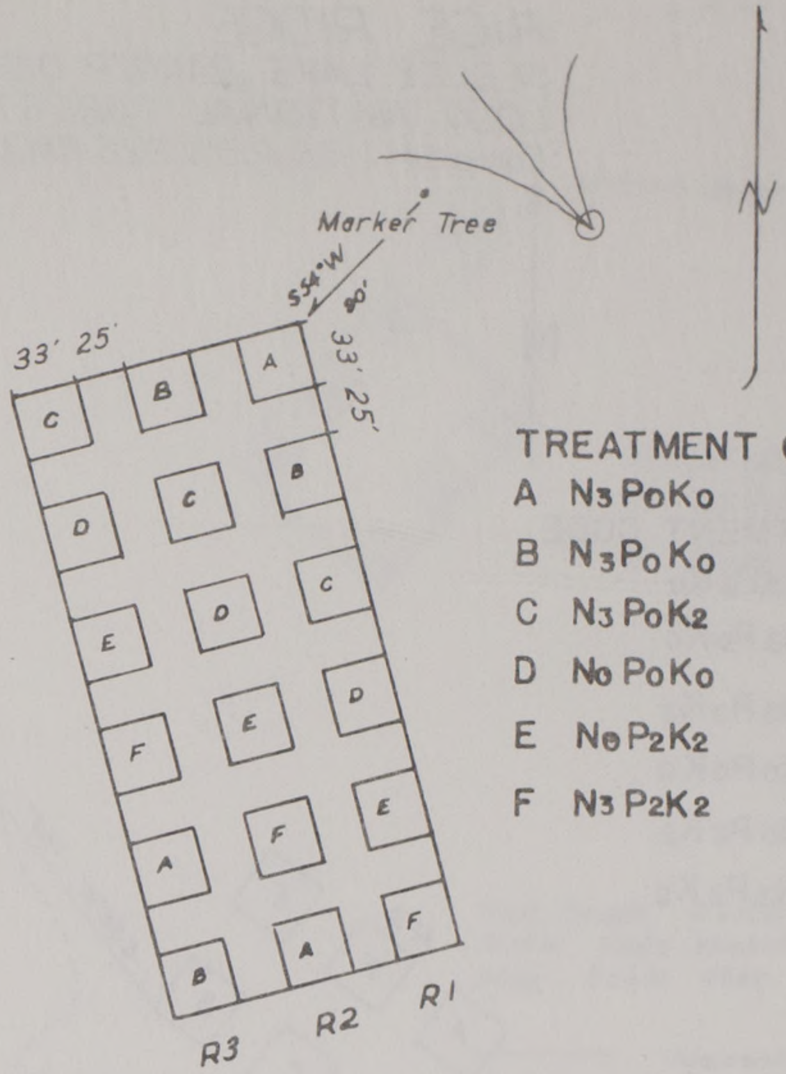
Scale: 1" = 100'
Note: Distance and direction orienation applies to plots only. Road sketch for representation only.

UPPER CLEARWATER

SEELEY LAKE RANGER DISTRICT
LOLO NATIONAL FOREST
Comp. 61-01, T19N, R16W, S26, P.M., M.

Stand Data, 1966

Age: 60 yrs.
Ht: 50-65 ft.
Site Index: 60
Density: Thinned to 13'x14', 1962



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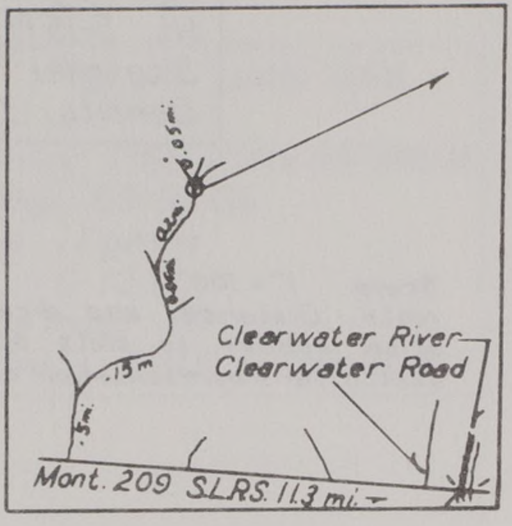
E $N_0P_2K_2$
F $N_3P_2K_2$



Scale: 1" = 100'
Note: Scale applies only to plot. Road sketch for representation only.

BARBER CREEK

CONDON RANGER DISTRICT
FLATHEAD NATIONAL FOREST
Comp. 218, T20N, R16W, S28, P.M., M.

TREATMENT CODE

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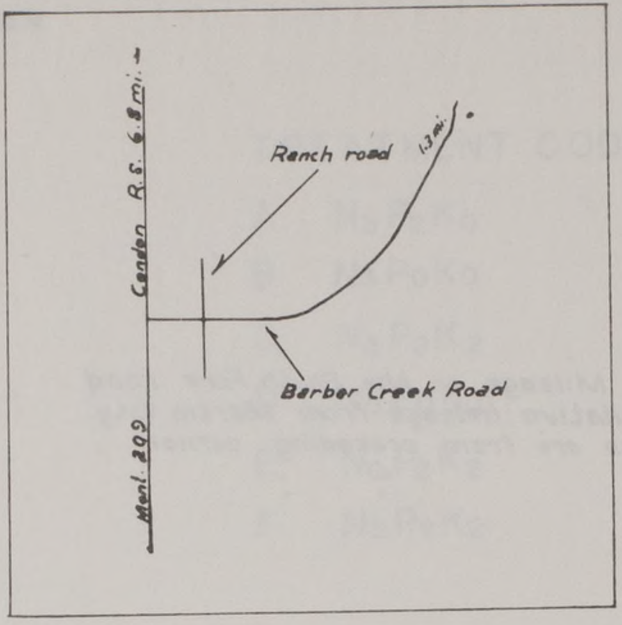
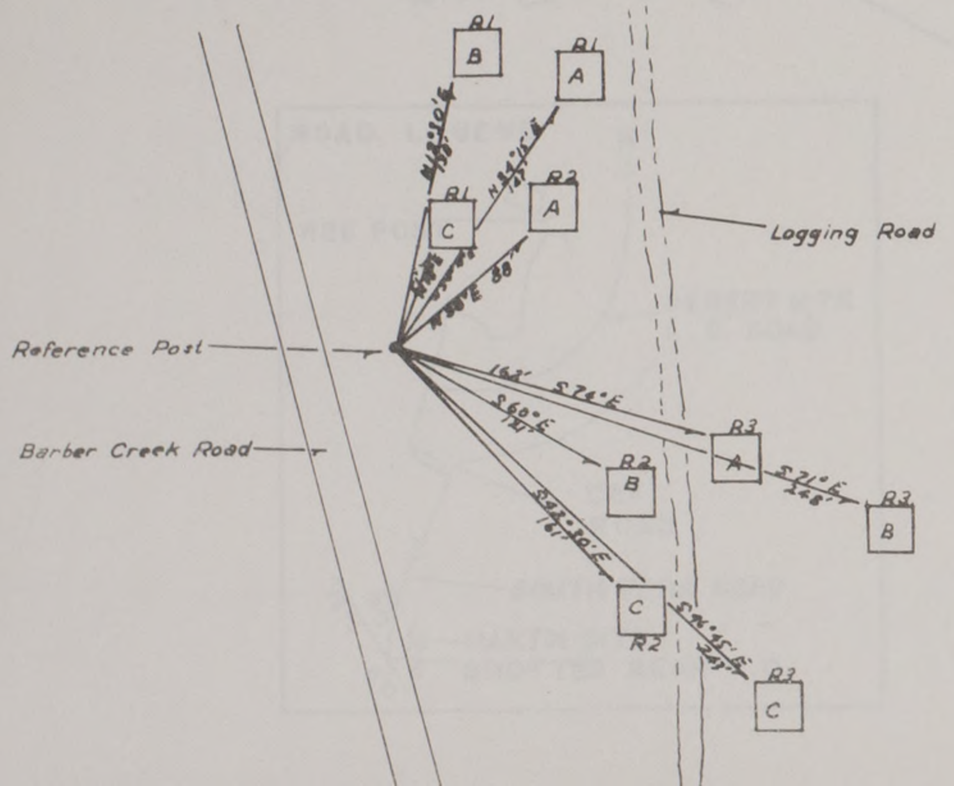


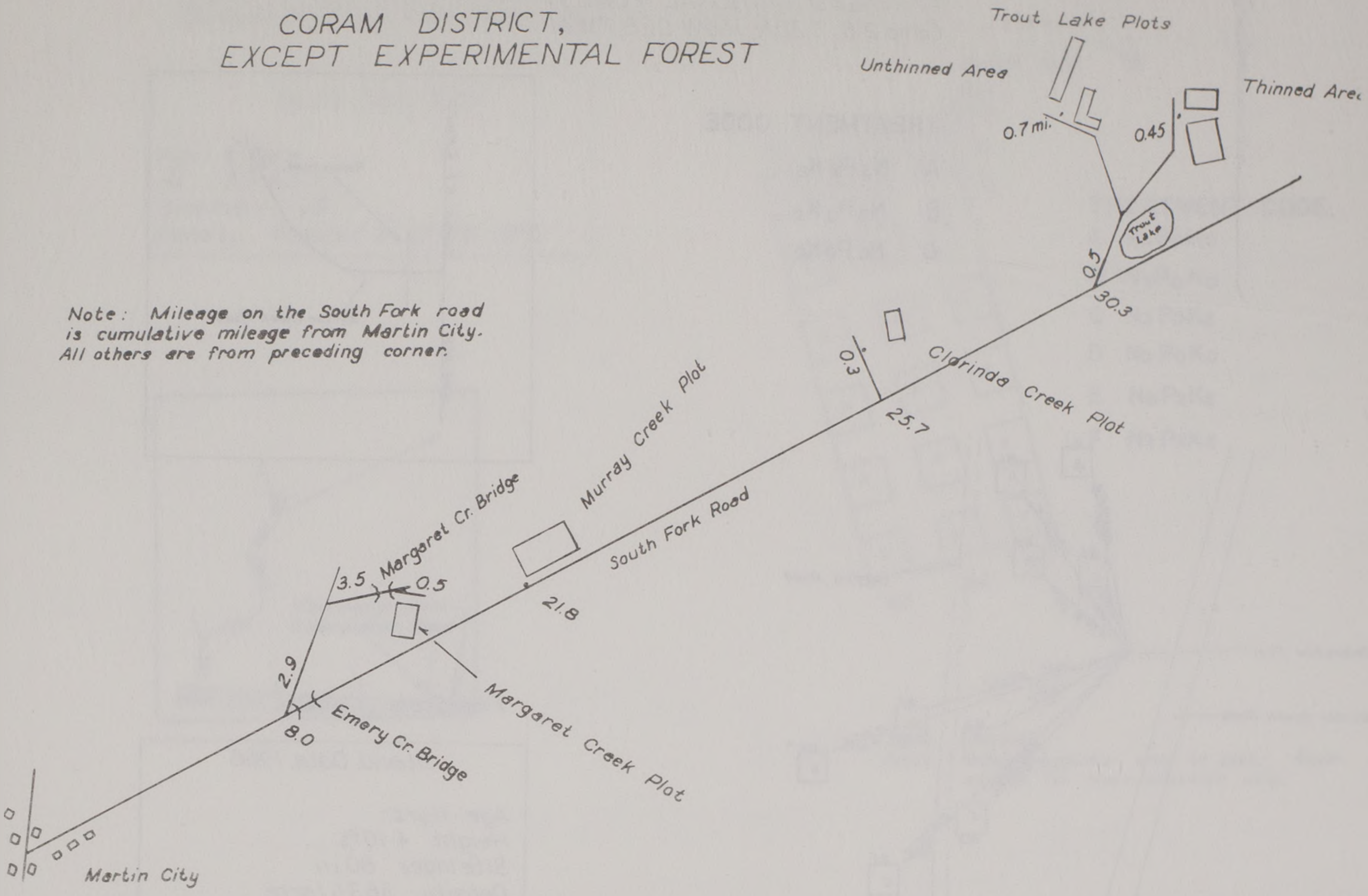


Plot Scale: 1"=100'

Stand Data, 1966

Age: 11 yrs.
Height: 4-10 ft.
Site Index: 80 (?)
Density: 3635/acre

CORAM DISTRICT,
EXCEPT EXPERIMENTAL FOREST



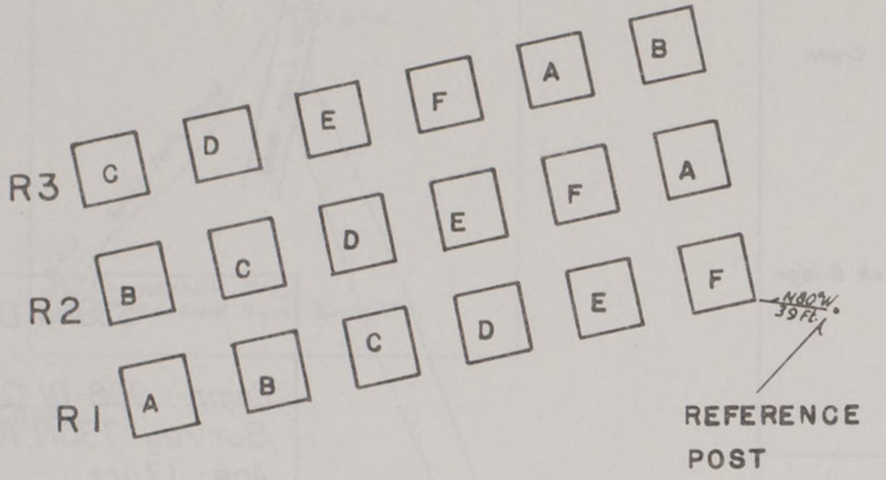
Note: Mileage on the South Fork road is cumulative mileage from Martin City. All others are from preceding corner.

CORAM EXPERIMENTAL FOREST

CORAM RANGER DISTRICT

FLATHEAD NATIONAL FOREST

COMP. 306-01-07 T30N R18W S6 PMM



TREATMENT CODE

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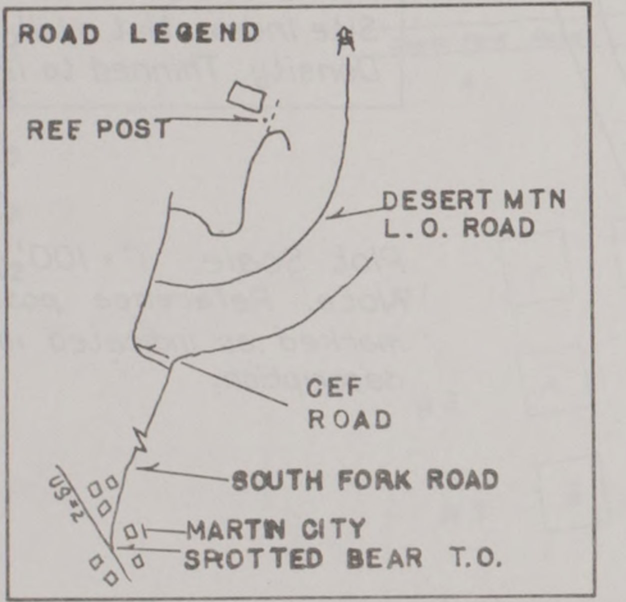
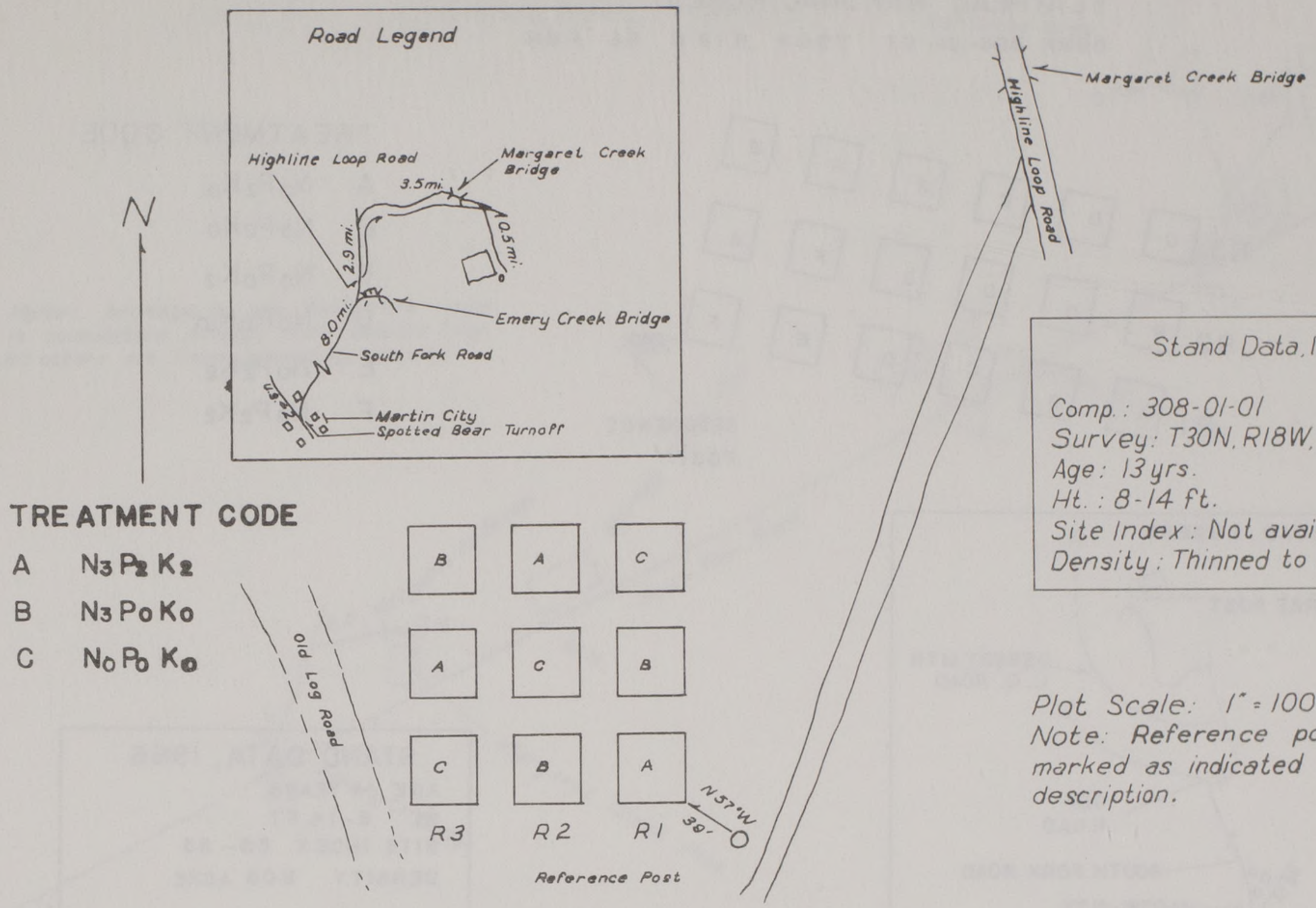


STAND DATA, 1966

AGE 14 YEARS
HT. 8-14 FT.
SITE INDEX 50-55
DENSITY 905 ACRE

MARGARET CREEK
CORAM RANGER DISTRICT
FLATHEAD NATIONAL FOREST



TREATMENT CODE

A $N_3 P_2 K_2$

B $N_3 P_0 K_0$

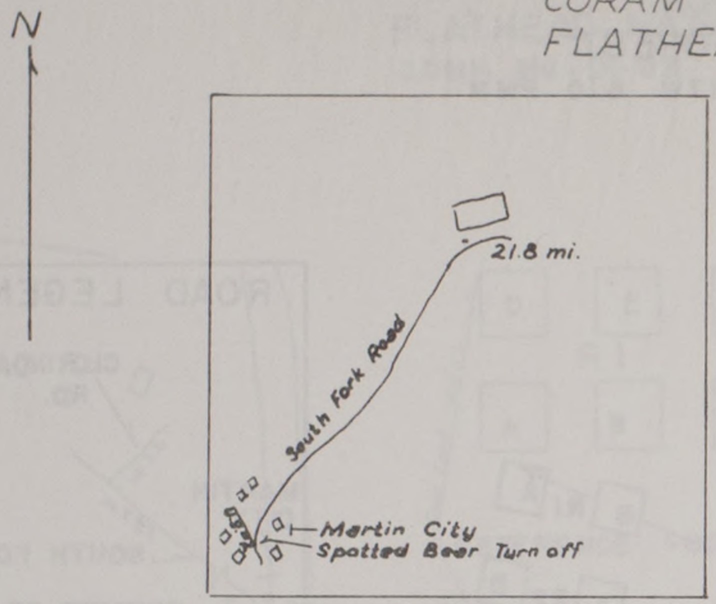
C $N_0 P_0 K_0$

Stand Data, 1966

Comp.: 308-01-01
Survey: T30N, R18W, S11, P.M., M.
Age: 13 yrs.
Ht.: 8-14 ft.
Site Index: Not avail.
Density: Thinned to 12' x 12', 1964

Plot Scale: 1" = 100'
Note: Reference post is a stump, marked as indicated in attached description.

MURRAY CREEK
CORAM RANGER DISTRICT
FLATHEAD NATIONAL FOREST

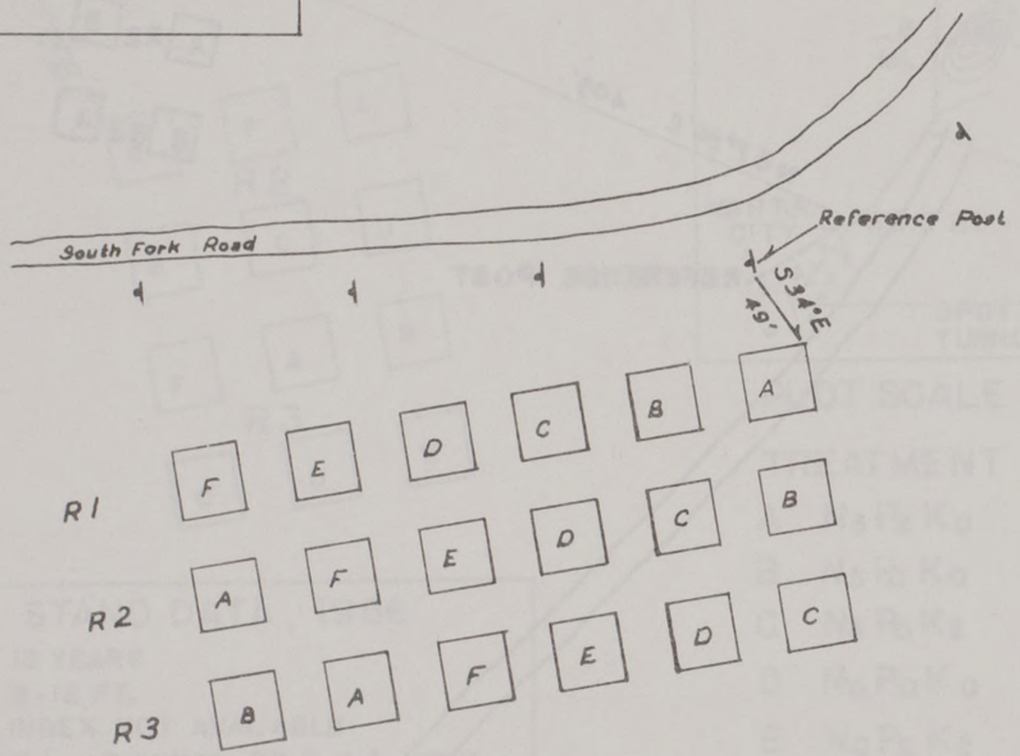


Stand Data, 1966

Comp.: 312-06-01
Survey: T29N, R17W, S29, P.M., M.
Age: 35 yrs.
Ht.: 35-50 ft.
Site Index: "Med.-good"
Density: Thinned to 10'x 10', 1962

TREATMENT CODE

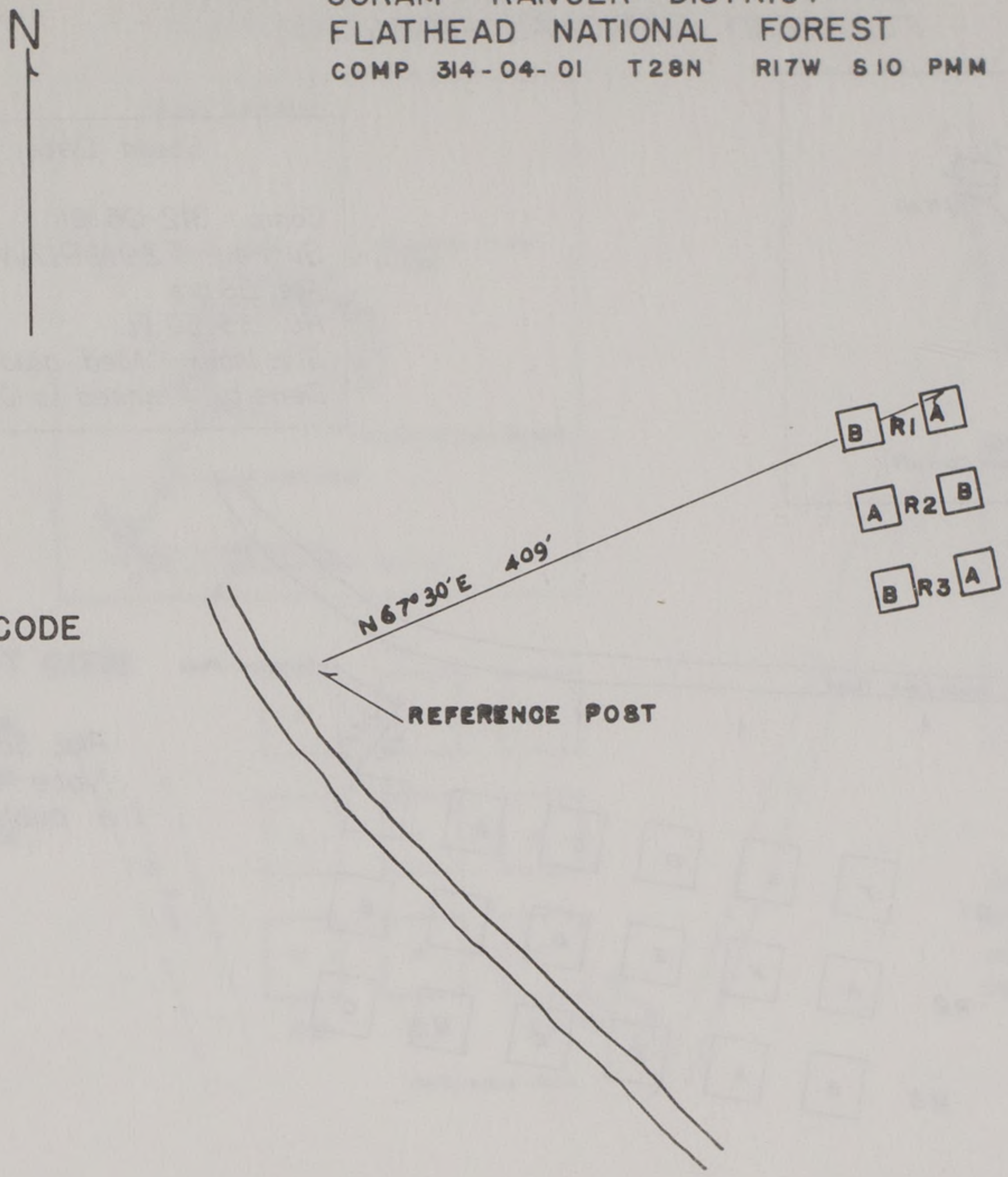
A	$N_3P_2K_0$
B	$N_3P_0K_0$
C	$N_3P_0K_2$
D	$N_0P_0K_0$
E	$N_0P_2K_2$
F	$N_3P_2K_2$

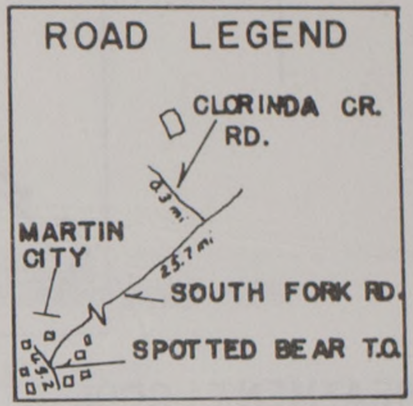


Plot Scale: 1" = 100'
Note: Reference po
a public utility pole

CLORINDA CREEK

CORAM RANGER DISTRICT
FLATHEAD NATIONAL FOREST
COMP 314-04-01 T28N R17W S10 PMM





TREATMENT CODE

A	$N_3 P_2 K_2$
B	$N_0 P_0 K_0$

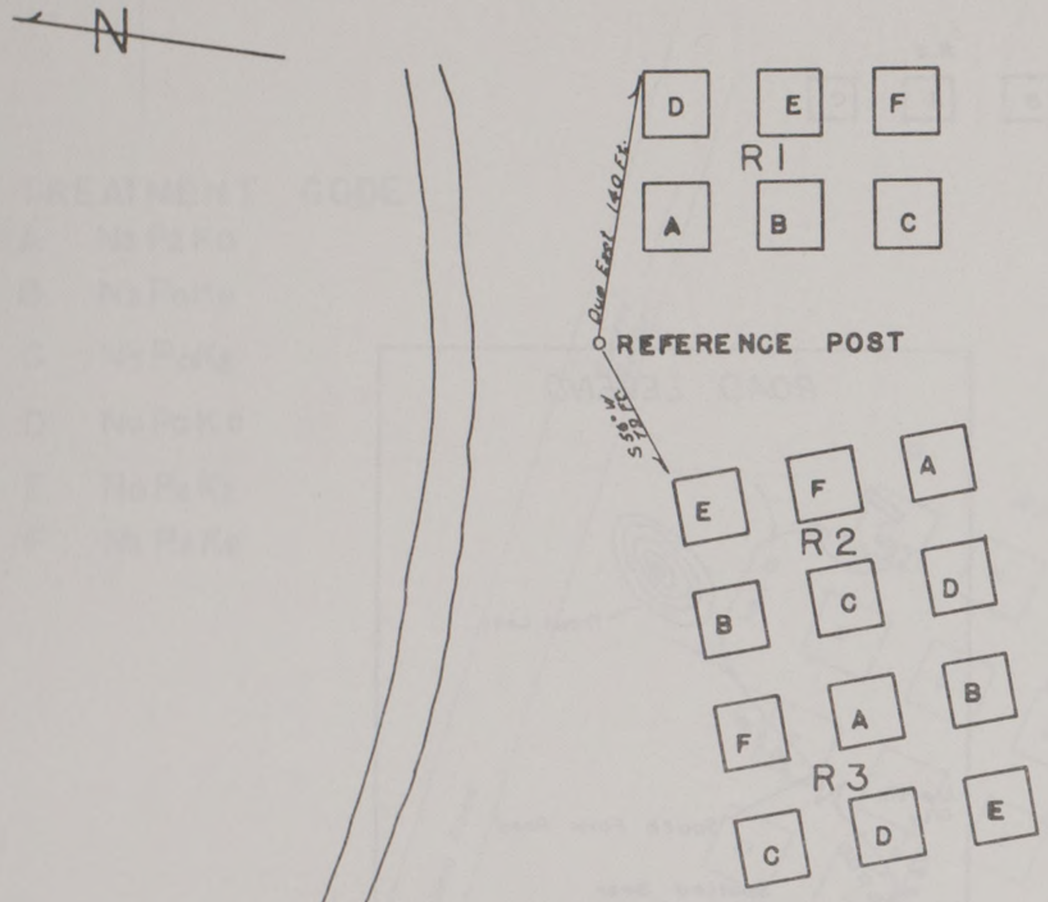
PLOT SCALE: 1" = 100'

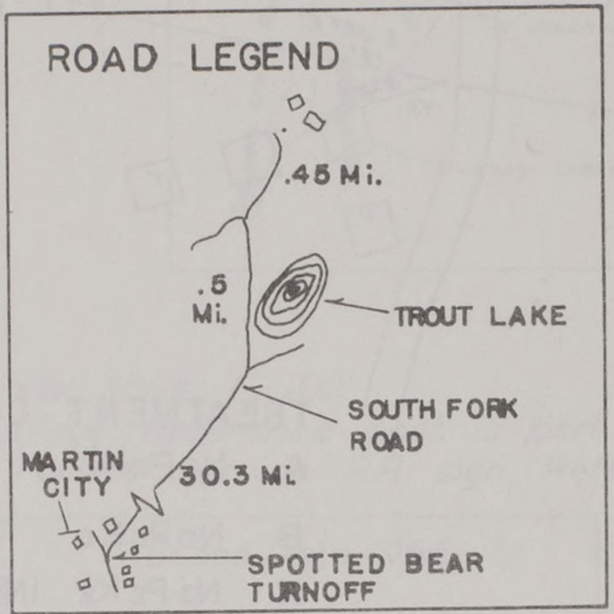
STAND DATA, 1966

AGE 1-2 YEARS
HT. 4"-1'
SITE INDEX NOT AVAILABLE
DENSITY 4,280 ACRE

TROUT LAKE - THINNED

CORAM RANGER DISTRICT
FLATHEAD NATIONAL FOREST
COMP. 316-01-02 T28N R17W S22 PMM





PLOT SCALE: 1" = 100'

STAND DATA, 1966

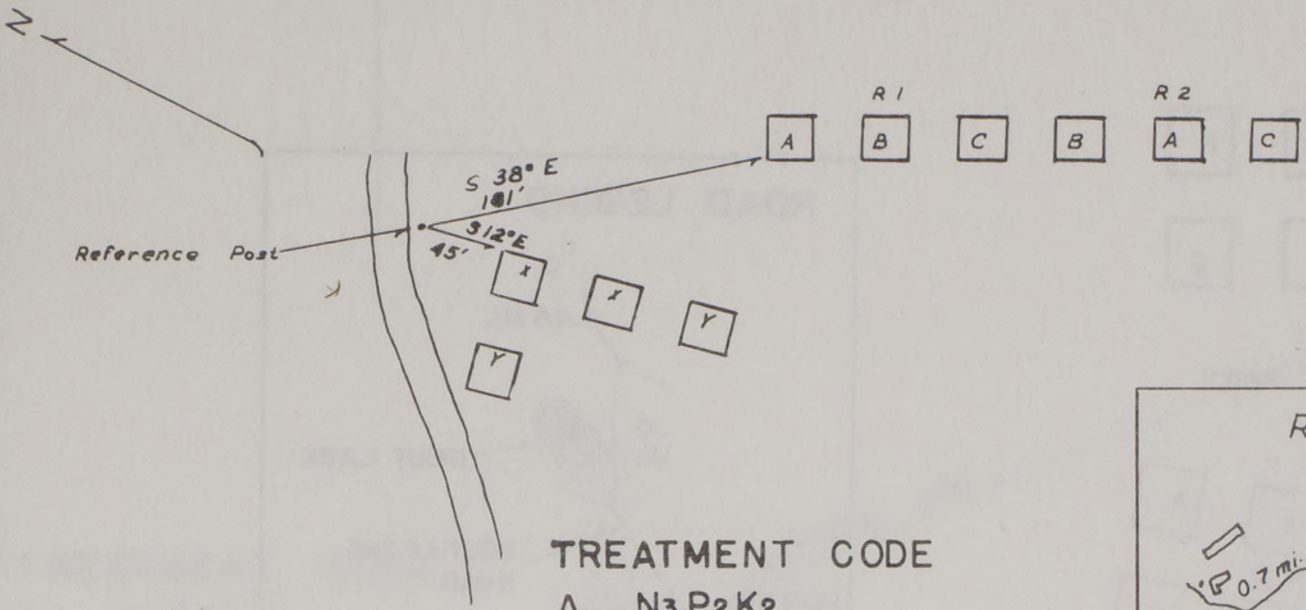
AGE 13 YEARS
HT. 8-12 FT.
SITE INDEX NOT AVAILABLE
DENSITY THINNED TO 9 X 9, 1962

TREATMENT CODE

A	$N_3P_2K_0$
B	$N_3P_0K_0$
C	$N_3P_0K_2$
D	$N_0P_0K_0$
E	$N_0P_2K_2$
F	$N_3P_2K_2$

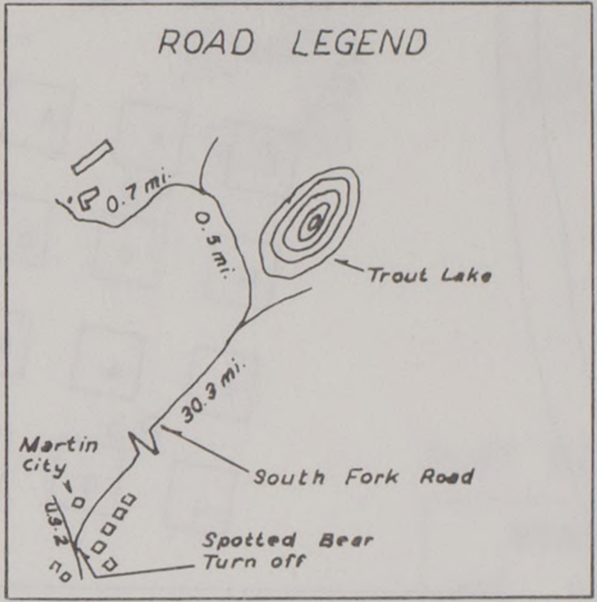
TROUT LAKE - UNTHINNED

CORAM RANGER DISTRICT
FLATHEAD NATIONAL FOREST
Comp. 315-01-01, T28N, R17W, S21, P.M., M.



TREATMENT CODE

A	$N_3P_2K_2$
B	$N_0P_0K_0$
X	$N_3P_2K_2$ IND. TREES*
Y	$N_0P_0K_0$ " "



Plot Scale: 1" = 100'

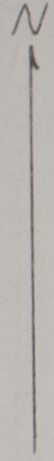
Stand Data, 1966

Age: 13 years
Ht: 8-12 ft
Site Index: Not avail.
Density: 4,150 / acre

* NOTE: FERTILIZER APPLIED TO INDIVIDUAL TREES (PAINTED YELLOW) RATHER THAN BROADCAST.

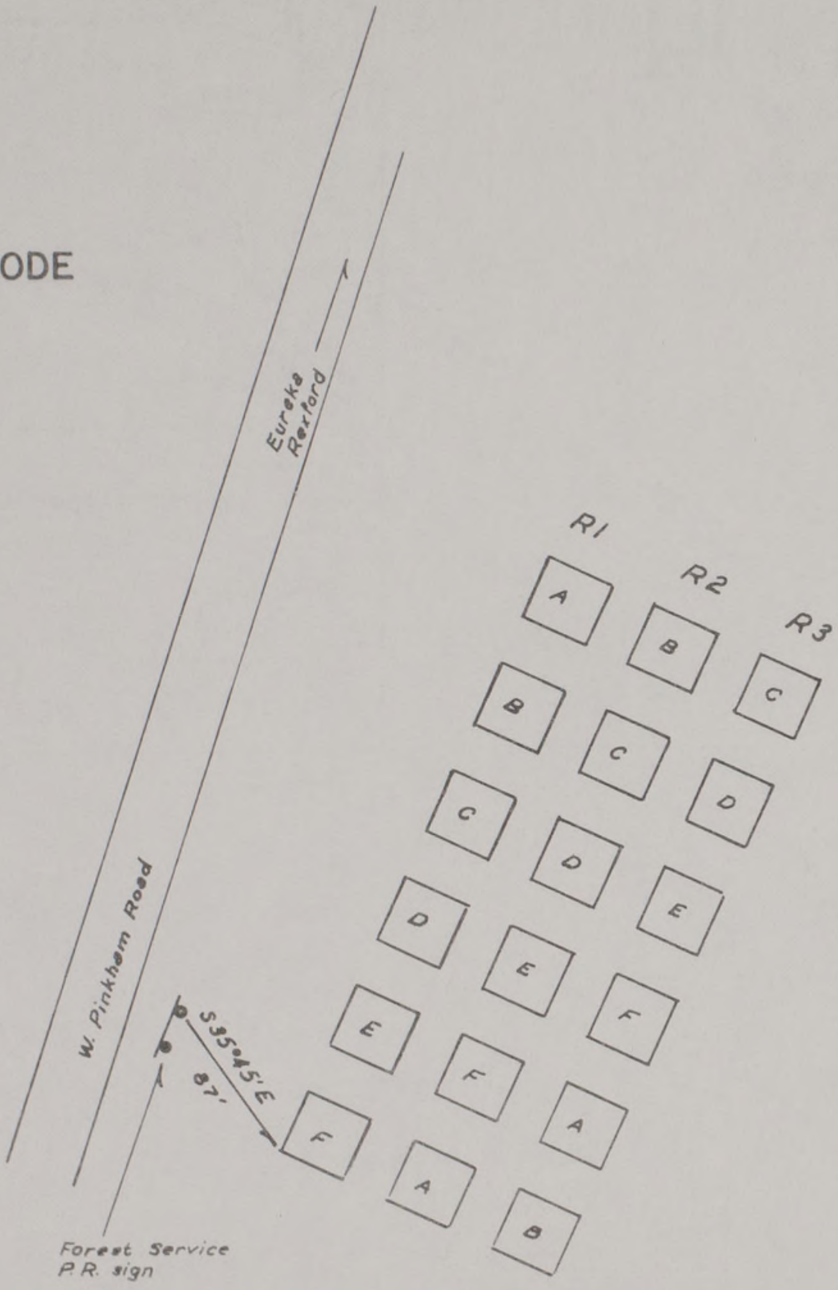
SKID CREEK

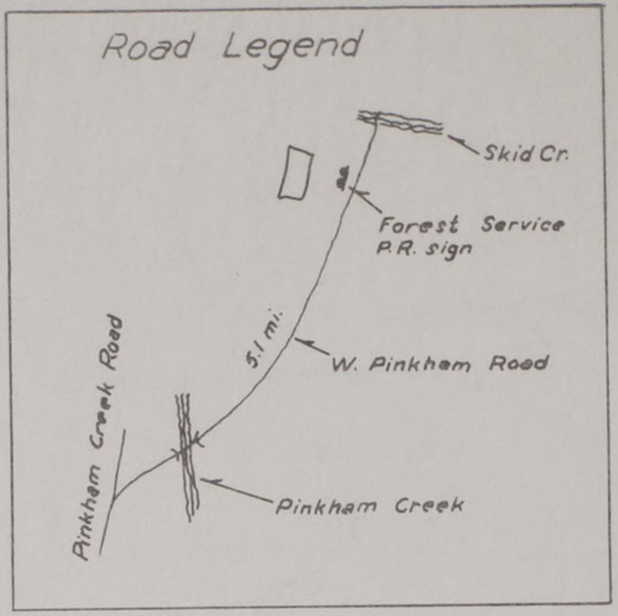
EUREKA RANGER DISTRICT
KOOTENAI NATIONAL FOREST
Comp. 21-04-02, T34N, R27W, S29, P.M., M.



TREATMENT CODE

A	$N_3 P_2 K_0$
B	$N_3 P_0 K_0$
C	$N_3 P_0 K_2$
D	$N_0 P_0 K_0$
E	$N_0 P_2 K_2$
F	$N_3 P_2 K_2$




Road Legend

Plot Scale: 1" = 100'
Note: Reference post is part of Forest Service P.R. sign, "Reforestation"

Stand Data, 1966

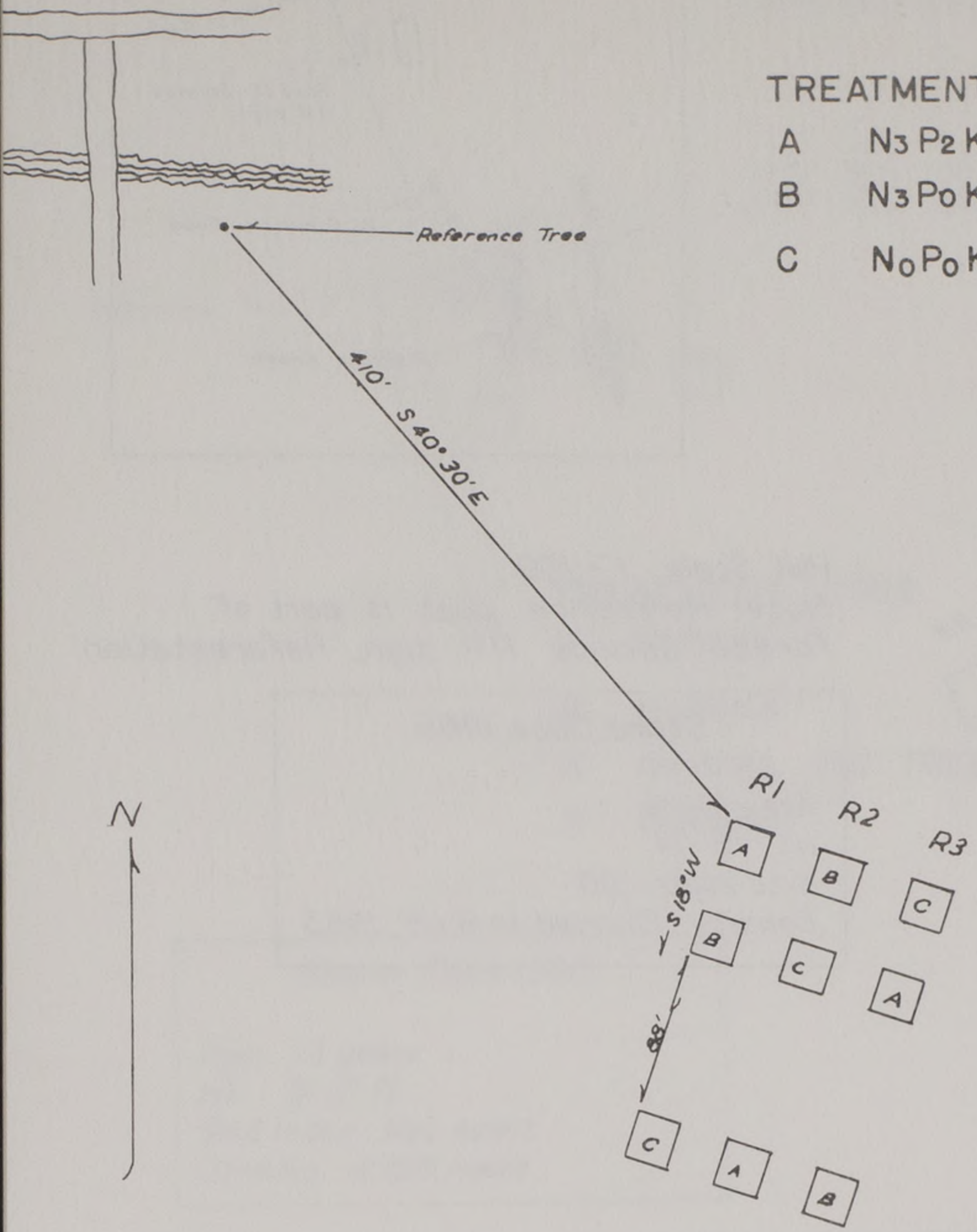
Age: 10 yrs.
Ht: 8'-14'
Site Index: 90
Density: Thinned to 8' x 8', 1965

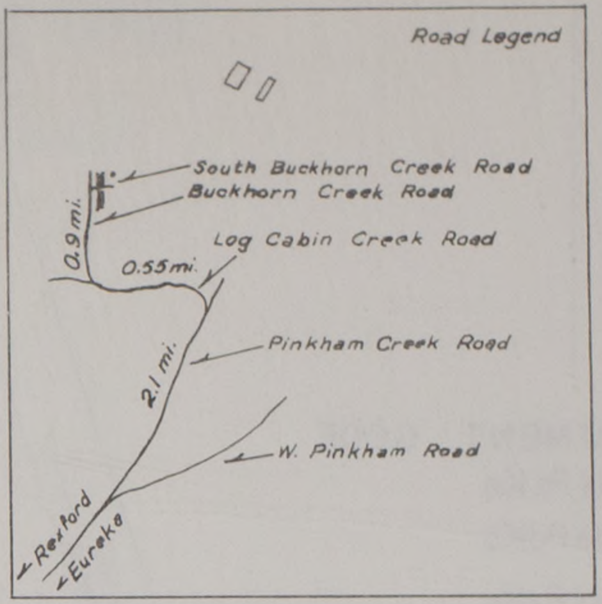
BUCKHORN CREEK

EUREKA RANGER DISTRICT
KOOTENAI NATIONAL FOREST
Comp. 20-03-04, T34N, R27W, S14, P.M., M.

TREATMENT CODE

A	$N_3 P_2 K_2$
B	$N_3 P_0 K_0$
C	$N_0 P_0 K_0$





Stand Data, 1966

Age : 10 yrs.
Ht : 2-14 ft.
Site Index : 90
Density : 6,835 / acre

Plot Scale: 1" = 100'
Note: Reference post is a large tree, Picea spp. Stream indicated is 75' up S. Buckhorn Cr. Road.

Supplement A to Note 6

Montana Forest and Conservation Experiment Station
School of Forestry/University of Montana/Missoula

June 1970

FERTILIZATION IN LODGEPOLE PINE FORESTS[1]

By Mark J. Behan, Department of Botany
University of Montana, Missoula

Abstract

Note 6[2] and its supplements are reports on the establishment of forest fertilization trials in Montana by the author. The original note presented the objectives of these trials and provided field descriptions of the 13 stands of western larch involved in the project. This supplement contains similar information regarding trials initiated in four lodgepole pine stands during July and August 1969. The results of these trials will be reported separately when they are determined.

Introduction

The objectives and general methods of these forest fertilization trials were described in Note 6. That note and this supplement have been distributed for several reasons. First, the test plots must be protected from other silvicultural treatments for at least five and preferably 10 years following application of the

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[1] This study was supported by McIntire-Stennis funds allocated to the School of Forestry, University of Montana, Missoula.

[2] Mark J. Behan, Fertilization in Western Larch Forests. Montana Forest and Conservation Experiment Station, Missoula. Note 6, January 1968.

fertilizers. Forest managers cannot avoid the plots without an accurate knowledge of their location. Second, the knowledge that such plots exist may stimulate related research. This has been the case with the publication of Note 6 which has facilitated an investigation by the U.S. Forest Service of the effect of fertilization on spruce budworm damage in western larch. Such related studies are encouraged so long as they do not interfere with the basic objective of the fertilization project, i.e. to measure the effect of fertilization on tree yield and foliar mineral content. Third, interested foresters may wish to examine the plots in order to observe firsthand the effects of the treatments. Finally, because the experiments are of a long-term nature, I may be unable to bring them to conclusion. If the original data are easily available, however, others should have no trouble in completing the work.

Design of Experiment

Four stands of lodgepole pine were selected for this study -- two on the Lolo National Forest and one each on the Lewis and Clark and Gallatin National Forests. Within each stand eight 0.1 acre experimental plots were established. Five to 10 representative trees on each plot were selected as "site" trees and tagged, and their diameters and heights were recorded.

Two replicates of each of the treatments described in Table 1 were applied in each stand. The treatments were randomly assigned in both replicate series.

I suspect that nitrogen is the fertilizer most likely to stimulate a response. The design of the experiment does not permit a full evaluation of the effects of phosphorus or potassium because their individual influences cannot be distinguished from their effects in interaction with nitrogen. Therefore, if responses to treatments #3 or #4 differ significantly from the response to treatment #2 additional plots should be established for complete evaluation.

TABLE 1

Fertilizer Treatments

#1	#2	#3	#4
Control	N_3	N_3 P_2	N_3 P_2 K_2

N = Nitrogen fertilization, applied as urea

P = Phosphorus fertilization, applied as treble superphosphate

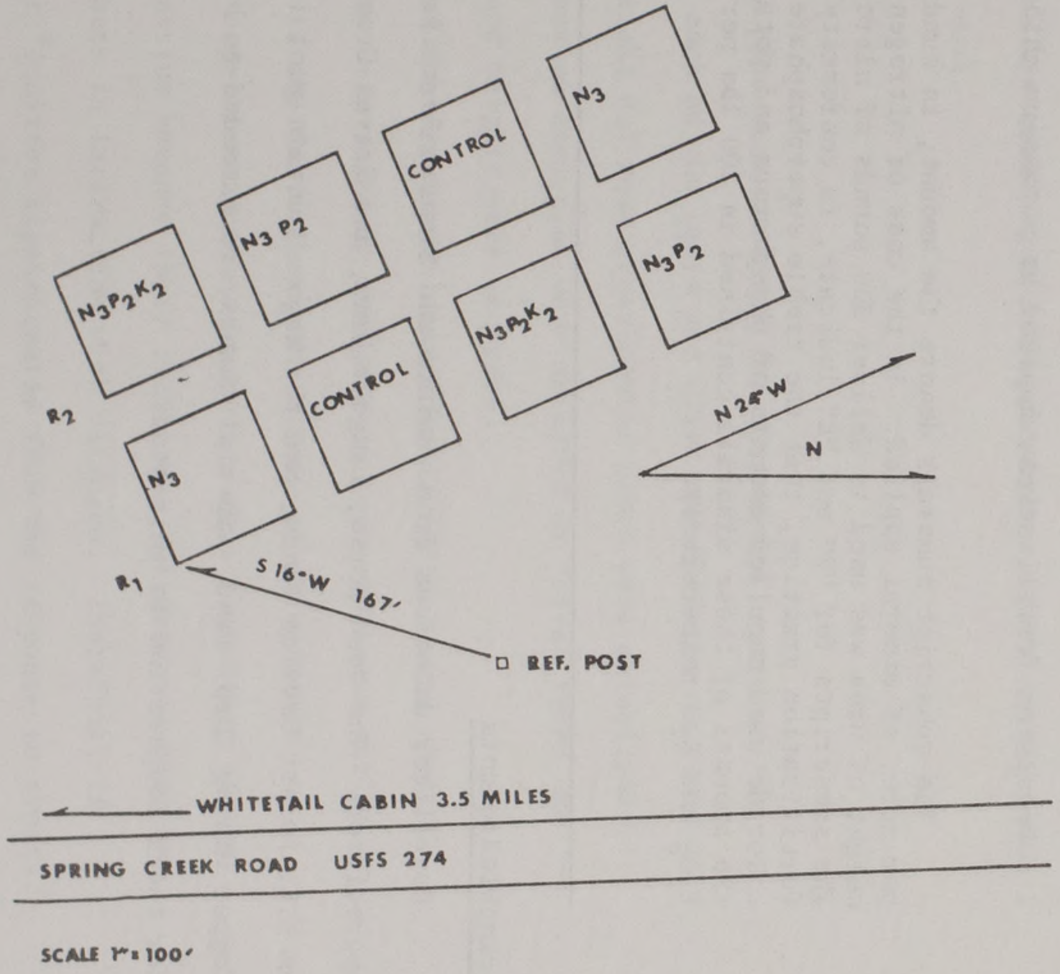
K = Potassium fertilization, applied as potassium chloride

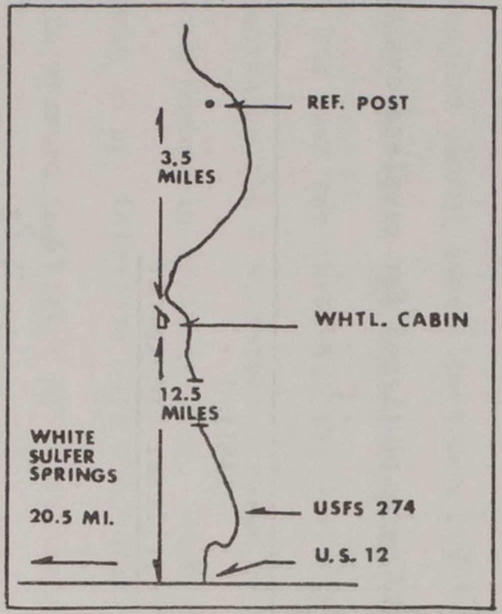
The subscript numerals denote the amount, in hundreds of pounds per acre, of mineral applied. In the case of nitrogen, a sufficient weight of urea was used to deliver 300 pounds of nitrogen per acre. The subscripts for "P" and "K" indicate, in conformity with standard fertilization practice, that the treble superphosphate and potassium chloride used supplied amounts of phosphorous and potassium equal to the amounts of those minerals contained in 200 lbs per acre of P_2O_5 and K_2O respectively.

Acknowledgements

Fertilizer donations from Cominco and Simplot Fertilizer Companies are appreciated. The Dead Horse, Langohr Draw, and Graves Creek plots were located on U.S. Forest Service lands; and the Wagon Mountain plot is on Anaconda Copper Mining Corp. land. Special thanks are extended to both organizations for their cooperation in this study.

DEADHORSE CREEK
LEWIS & CLARK NATL. FOREST
HARLOWTOWN RANGER DIST.
T11N R10E SEC. 16

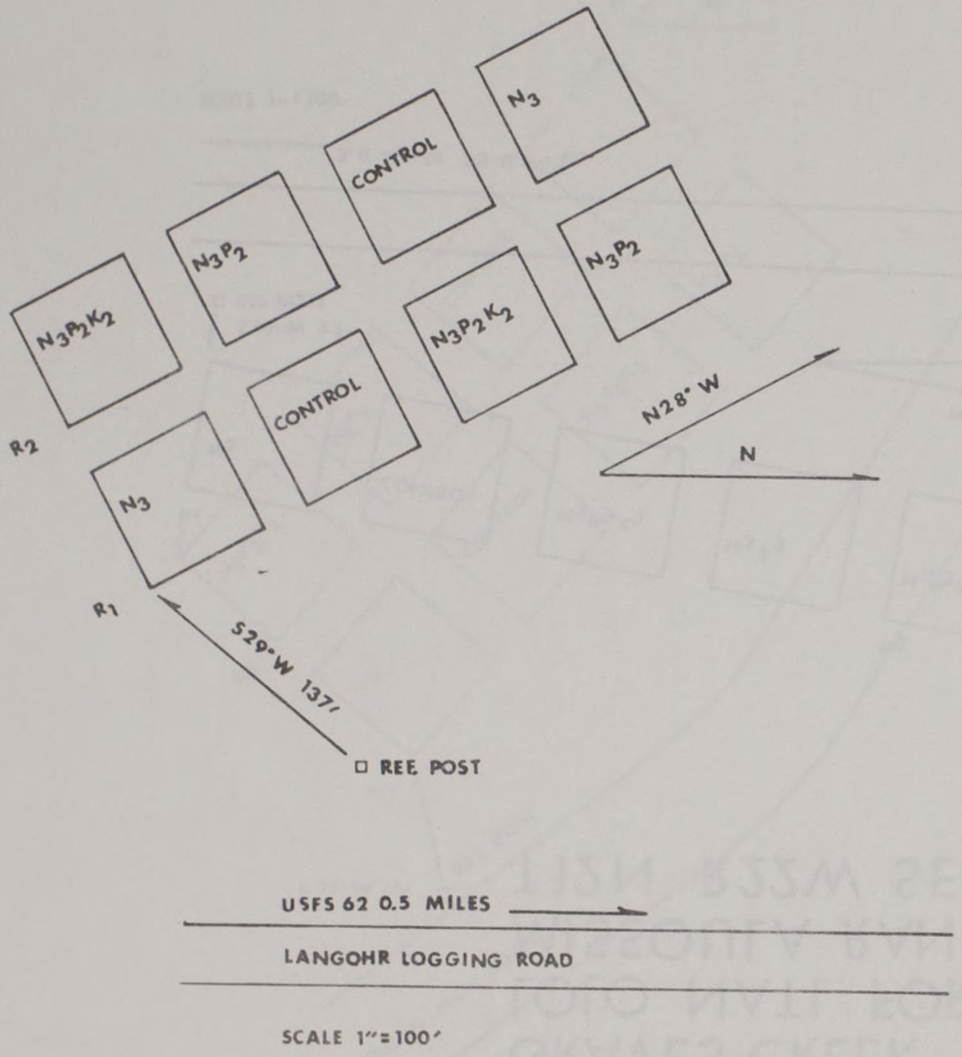


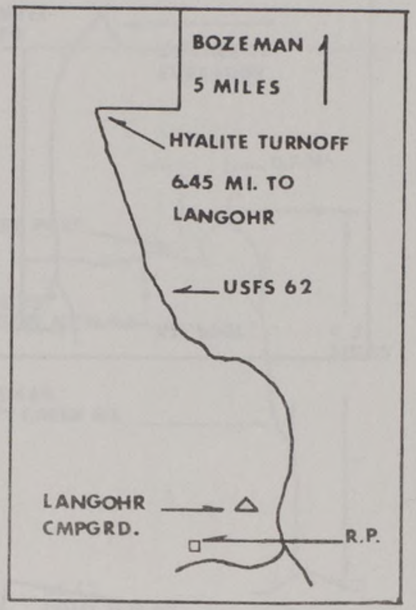


STAND DATA

Density = 470 lodgepole pine/acre
Mean DBH = 2.2"
Mean Height = 11.5'

LANGOHR DRAW
GALLATIN NATL. FOREST
BOZEMAN RANGER DISTRICT
T3S R6E SEC. 5

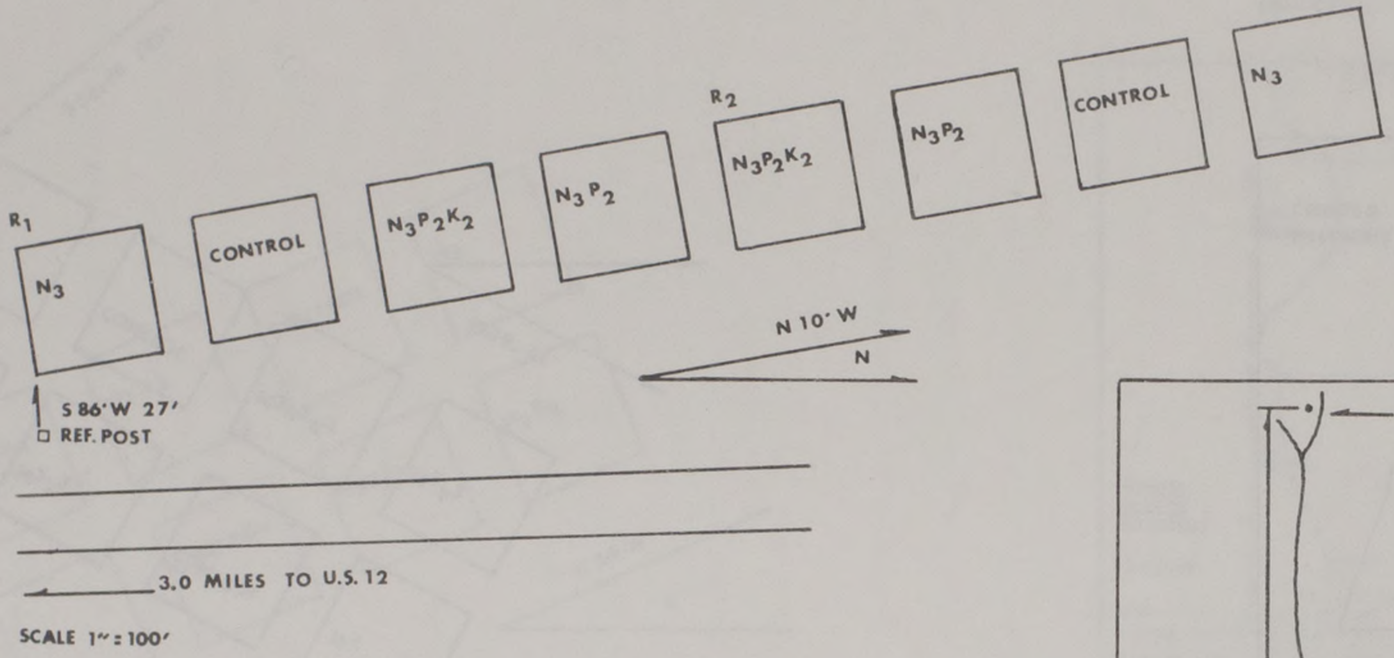


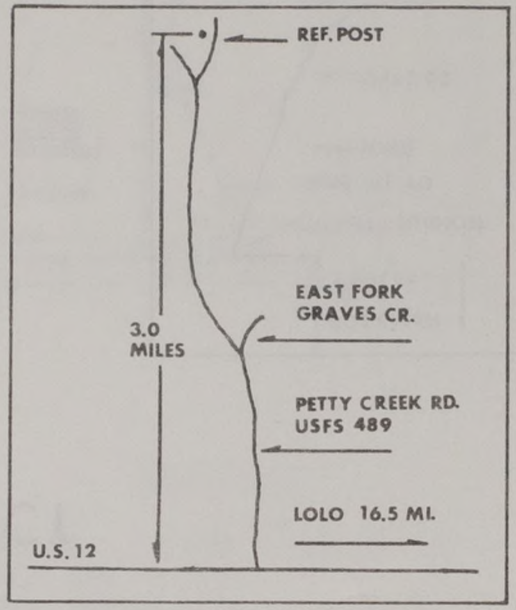


STAND DATA

Density = 280 Lodgepole pine per acre
Mean DBH = 5.0"
Mean Height = 23.3'

GRAVES CREEK
LOLO NATL. FOREST
MISSOULA RANGER DIST.
T12N R22W SEC. 6

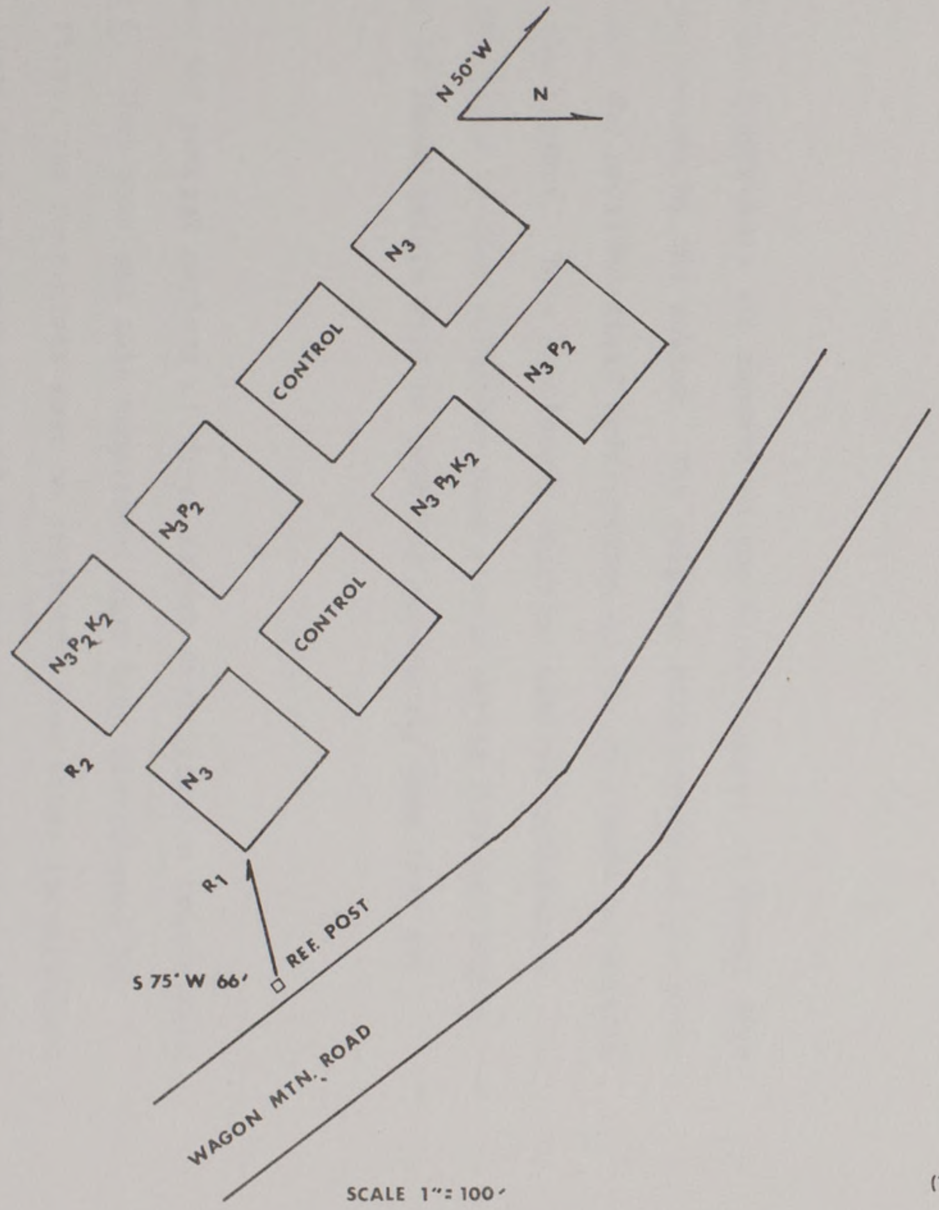


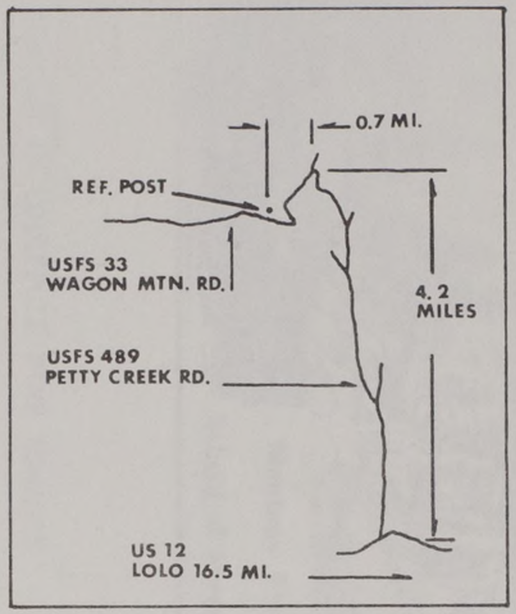


STAND DATA

Density = 500 lodgepole pine/acre
Mean DBH = 6.3"
Mean Height = 48.4'

WAGON MOUNTAIN ROAD
LOLO NATL. FOREST
MISSOULA RANGER DIST.(1)
T12N R23W SEC. 1





STAND DATA

Density = 760 lodgepole pine/acre
Mean DBH = 7.4"
Mean Height = 62.3'

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(1) OWNED BY ANACONDA COMPANY