THE EFFECTS OF PRECOMMERCIAL THINNING ON SOIL MOISTURE AND THROUGHFALL IN LOBLOLLY PINE

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TABLE OF CONTENTS

PART I

PART II

LIST OF TABLES

Table Page

PART I

PART II

LIST OF FIGURES

Figure Page

INTRODUCTION

Forest tree growth responds more to water stress than any other single environmental factor. Summer droughts interrupt diameter growth in young, fully stocked loblolly pine (Pinus taeda L.) plantations during nearly every growing season in the Midsouth. Insufficient amounts and poor distribution of rainfall cannot replenish stored soil moisture which is rapidly depleted by high evapotranspirative demand during the summer months. One method of improving soil moisture availability is by reducing stand density through thinning.

Thinning improves soil moisture conditions during the growing season by reducing demand for water by the stand and by increasing throughfall. By budgeting soil moisture through thinning, increased growth can be accumulated on a smaller number of selected crop trees. Stand quality is improved and rotation length is shortened.

This study examines two aspects of the water balance in a young loblolly pine plantation during the two growing seasons following thinning. Two separate and complete manuscripts have been prepared from the study. The first, "Soil Moisture Trends Following Precommercial Thinning in Loblolly Pine", was prepared in the format of the Soil Science Society of America Journal. The second, "Throughfall in a Young Loblolly Pine Plantation Following Thinning", was prepared in the format of the Journal of Soil and Water Conservation. Both manuscripts will be submitted for publication in the respective journals.

PART I

SOIL MOISTURE TRENDS FOLLOWING PRECOMMERCIAL THINNING IN LOBLOLLY PINE

Abstract

Soil moisture was studied under three stand density levels in a young loblolly pine plantation in southeastern Oklahoma. Measurements were made with a neutron probe during the middle and latter portions of two consecutive growing seasons following precommercial thinning. Soil water deficits were significantly greater in unthinned stands during both growing seasons, but differences in soil water deficits between thinned and unthinned treatments were lower in the second year following thinning.

Daily rates of water use, calculated from soil moisture depletion and throughfall, generally did not significantly differ between density levels. Seasonal trends in water use varied in response to differences in rainfall amounts and frequency between the two years. Higher levels of available soil moisture were maintained over a greater proportion of the growing season following thinning, lengthening the period that conditions were favorable for tree growth.

Introduction

Loblolly pine (Pinus taeda L.) is currently the major commercial timber species in the Midsouth (McWilliams and Birdsey, 1984). Throughout the region, water stresses, caused by high evapotranspirative demand and low soil moisture availability, limit diameter growth in forest stands during the middle and latter portions of nearly every growing season (Moyle and Zahner, 1954; Bassett, 1964a). The annual distribution of rainfall in the region does not coincide with the high demand for water during the summer months, and stored soil moisture cannot supply the full amount of water required by a fully stocked stand to maintain diameter growth throughout the growing season (Zahner, 1956).

Seasonal soil moisture loss by undisturbed forest stands, under similiar environmental conditions and at equilibrium with the site, has been shown to be independent of the age and composition of the stands (Moyle and Zahner, 1954; Zahner, 1955; Metz and Douglass, 1959). Reductions in stand density improve soil moisture availability by reducing the water demand of the stand and by increasing throughfall (Langdon and Trousdell, 1977). Improved rates and longer seasonal duration of diameter growth following thinning have been attributed to the improvement in soil moisture availability (Zahner and Whitmore, 1960; Della-Bianca and Dils, 1960; McClurkin, 1961; Bay and Boelter, 1963; Bassett, 1964b).

Radical levels of precommercial thinning have been proposed as a means of shortening the rotation length for sawtimber in loblolly pine (Zahner and Whitmore, 1960; Burton, 1976). The goal of heavy thinning is to improve the value of the stand by increasing seasonal diameter growth of a smaller number of selected crop trees, rather than increasing total volume growth of the entire stand. The reduction in competition increases the proportion of the growing season that soil moisture conditions are favorable for growth.

This study was conducted to determine the effects of precommercial thinning on the soil moisture regime in a young loblolly pine plantation in southeastern Oklahoma. Soil moisture was monitored during the middle and latter portions of the first two growing seasons following thinning. It was hypothesized that growth increases reported in previous studies following thinning are due to a reduction in water stress. Although little can be done to reduce the effects of daily internal water stress caused by the inherent lag between transpiration and water uptake, the seasonal effects of water stress may be alleviated by silvicultural practices such as thinning (Brown, 1977). Maintenance of higher levels of soil moisture, in addition to improved light and nutrient availability, should allow residual trees in thinned stands to increase diameter growth rates over a longer period of the growing season.

Study Area

The study site was located in an 11-year-old loblolly pine plantation near Idabel in eastern McCurtain County, Oklahoma. The soil was mapped as a Typic Hapludult (fine-loamy, siliceous, thermic) of the Cahaba series (USDA, 1974). The upper soil layer is a silt loam to loam, grading to a clay loam or silty clay loam subsoil. The site is on the upper coastal plain (Gray and Galloway, 1959), in close proximity to the Mountain Fork and Little Rivers. The site was bedded before stand establishment due to the frequency of winter flooding.

Rainfall in the area averages 1194 mm annually. Spring is the wettest season, receiving 31% of the average yearly rainfall, and fall is generally the driest, receiving 21% of the average yearly rainfall (USDA, 1974). Rainfall is typically adequate through May, but droughts from 2 to 6 weeks in length are fairly common from June through October. The climate during the growing season is hot and humid.

Methods and Materials

Three adjacent blocks were established in the plantation. Each block contained three 0.10 ha square plots, with each treatment level replicated on each block. The initial treatments were:

1) thinned to 25% of the original stand density (BA25),
2) thinned to 50% of the original stand density (BA50), and
3) unthinned (BA100).

The BA25 and BA50 plots were selectively thinned in early March, 1984. Residual trees on the thinned plots were selected for best size and form, while maintaining minimum spacing guidelines to insure an adequate distribution of trees within the prescribed stand density. Because the experiment was designed to represent a precommercial thinning, no felled trees were removed from thinned plots. No form of brush control was applied to thinned plots in 1984 or 1985. All measurements were taken from the 0.04 ha interior area of each plot to provide a buffer zone. Stand characteristics at the beginning of the growing season in 1984 and 1985 are presented in Table 1.

Volumetric soil moisture content was measured with a Troxler 3223 (10 mc, Am-Be) neutron probe moisture gauge. Three 3.8 cm diameter steel access tubes were installed on each plot in March, 1984 to allow measurements to a depth of 122 cm. An additional access tube, allowing measurements to a depth of 168 cm, was installed on each plot in February, 1985. Access tubes were installed by driving each tube into the ground and augering the soil out before plugging the bottom of the tube. This installation technique reduces soil disturbances and eliminates air voids in contact with the access tube.

Previous studies have shown that soil moisture content is not at uniform levels throughout thinned stands during the growing season (Douglass, 1960). Because our interest was in soil moisture in contact with tree roots and readily available for uptake, all access tubes were uniformly located within the rooting zone of a dominant tree. Access tubes were installed between the bedded rows, approximately 0.75-1 m from the base of the tree.

Measurements of soil moisture content were taken at approximately biweekly intervals from mid-May through mid-September, and monthly in October and November during 1984 and 1985. Monthly measurements were also taken over the winter of 1984-1985 to determine the extent of soil moisture recharge. One-minute neutron counts were taken at 15 cm depth intervals to a depth of 122 cm. Neutron counts were converted to volumetric soil moisture content by calibration equations developed for the study site. Two equations, one for the 15 cm depth and one for all lower depths, were developed from comparisons of neutron counts to soil moisture contents determined gravimetrically.

Undisturbed soil cores were collected from 2 to 4 points on each plot from depth layers of 0-15, 15-30, 30-

61, and 61-122 cm. The cores were processed for bulk density and the 0.06 bar soil moisture tension value. Bulk soil samples were collected from each plot at the same depth layers to determine soil water retention of the < 2mm soil fraction at 1, 3, and 15 bars of soil moisture tension using a ceramic pressure plate apparatus. Soil textural analysis of the bulk soil samples was performed by the hydrometer method. The average moisture-holding capacity of the site was 22.8 cm of water in the 0-122 cm profile at field capacity. Average physical properties and moisture holding characteristics for the three blocks are shown in Table 2.

Rainfall and throughfall were measured following every storm from mid-May through October of 1984 and 1985. Rainfall was collected in 2 standard rain gauges located in openings within the study area. Throughfall was collected in 10 randomly located can gauges on each plot. Expressed as a percentage of individual storms, throughfall averaged 96.6% of gross rainfall on BA25 plots, 90.3% on BA50 plots, and 80.5% on BA100 plots. Monthly rainfall totals from June through October as compared to the long-term means for the area are given in Table 3.

Analysis of biweekly soil moisture measurements was made in terms of soil water deficits, or the deviation of soil moisture content on each measurement date from the maximum moisture content determined at each measurement point during the winter of 1984-1985. Also, percent available water was calculated as the proportion of soil moisture in the 0-122cm profile between the estimated field capacity (0.06 bar value) and the estimated wilting point (15 bar value). Maximum measured soil moisture contents closely corresponded with the 0.06 bar moisture tension values. Analysis of variance and Duncan's multiple-range tests were used to determine treatment effects on soil moisture during the two growing seasons. All differences referred to in this paper are statistically significant at the 0.05 level.

Results and Discussion

Soil Moisture Regime During the 1984 Growing Season

Rainfall during the middle and latter portions of the growing season in 1984 was above normal and well distributed during every month except June (Table 3). Late season rainfall was particularily heavy. Other than a drought of 19 days in length during June, no significant rainless periods were recorded during the growing season.

Soils on the site were near field capacity when measurements began in early May. Depletion of soil moisture began with the onset of warm weather and reduced rainfall in mid-May. By late May, total soil water deficits on unthinned plots had diverged to significantly higher levels than on thinned plots (Table 4). Soil moisture depletion proceeded rapidly on all treatments throughout June and July. Heavy rainfall in early August caused soils to recharge, but was followed by a period of very rapid depletion. Significant differences in total soil water deficits between BA25 and BA50 plots were noted during August (Table 4). Extremely heavy rainfall during October caused soils on all treatments to approach field capacity by mid-November, although soils in the region are not typically recharged until late winter. The level of soil moisture in the 0-122 cm profile was generally proportional to stand density throughout the entire growing season in 1984.

Maximum soil water deficits in the 0-122 cm profile on unthinned plots during 1984 were recorded in late August. The average maximum deficit on unthinned plots was 15.8 cm of water. On the same date, a deficit of 11.4 cm, or 72% of unthinned, had been accumulated on BA50 plots. Only 9.4 cm of stored soil moisture, 59% of unthinned, had been depleted on BA25 plots.

The effects of thinning on soil moisture depletion from the total profile were not cumulative over the entire growing season. From mid-May through late August, soil moisture deficits on unthinned plots generally increased at faster rates than on thinned plots. After late August, differences in total soil water deficits between the treatments remained relatively constant. This was probably caused by increased rainfall received on the site and the greater supply of soil moisture remaining on thinned plots during the late summer and early fall.

Analysis of soil water deficits by 30 cm depth intervals (Figure 1) showed that seasonal fluctuations in soil moisture deficits decreased with increasing depth in the profile, due to decreased root density and reduced effects of precipitation at lower depths. No accretion of moisture was observed below 60 cm from June through October, although rainfall was fairly frequent. Additions of water from rainfall were rapidly depleted before reaching this depth. Total seasonal losses of stored soil moisture were greatest in the surface layers, but differences between the treatments, particularily between the two thinned treatments, increased with increasing depth in the profile. In late August, soil water deficits on unthinned plots averaged 5.0 cm in the 0-30 cm layer, 3.9 cm in the 30-61 cm layer, 3.7 cm in the 61-91 cm layer, and 3.2 cm in the 91-122 cm layer. Soil water deficits at the same depth intervals were 3.6 cm, 2.9 cm, 2.7 cm, and 2.2 cm on BA50 plots and 3.5 cm, 2.4 cm, 2.0 cm, and 1.5 cm on BA25 plots. Soil water deficits were greatest on unthinned plots at every depth throughout the growing season, but significant differences between the BA25 and BA50 treatments were not found in surface layers.

Nnyamah and Black (1977) reported that the zone of maximum moisture depletion under thinned and unthinned Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) stands gradually shifted downward as the soil dried. Although no extended drying periods were measured during the 1984 growing season, similiar trends were observed in this study. Excluding the rapid loss of rainfall additions from surface layers, a greater proportion of the total amount of water lost through evapotranspiration was supplied from lower depths in the profile as the growing season progressed. This trend appeared to be affected by stand density. As the basal area of the stand was reduced, the lower demand of the stand for water had a conserving effect on soil moisture in lower depths.

Soil moisture depletion curves (Figure 2) illustrate changes in soil moisture content under tree crowns, in relation to the 15 bar moisture content, during the summer of 1984. At no point during the period were soils depleted to the wilting point on any treatment. Although total depletion of soil moisture was greatest under trees on unthinned plots, it was evident that the uniformity of depletion throughout the profile was related to stand density. The smaller amount of water removed from lower depths in the profile under residual trees on thinned plots seems to indicate that residual trees had expanded their root systems and were utilizing more readily available water from openings between trees. Zahner and Whitmore (1960) found that roots incompletely occupied soils in heavily thinned loblolly pine stands and soil moisture content increased with greater distance from the tree. Bassett (1964b) reported that trees in heavily thinned stands were able to maintain diameter growth at soil moisture levels measured near the tree, which caused growth to cease in lightly thinned stands. This was attributed to the ability of trees in heavily thinned stands, which had developed larger root systems, to utilize soil moisture held at lower tensions from openings between trees.

Soil Moisture Regime During the 1985 Growing Season

Rainfall during the June-October period of 1985 was deficient during every month except October (Table 3). A drought of 6 weeks in length occurred from early August through mid-September.

Soils on the site were slightly below field capacity in mid-May, but heavy rainfall in late May caused soils to recharge. From that point, depletion of stored soil moisture was rapid and continued steadily under all treatments throughout the dry summer. Although total soil water deficits were consistently highest on unthinned plots, significant differences between the treatments did not appear until August (Table 5). The improvement in soil moisture availability on thinned plots, as compared to unthinned plots, was greatly reduced. At no point during the growing season were significant differences in total soil water deficits found between BA25 and BA50 plots (Table 5). Soil moisture increased slightly in September, due to increased rainfall and reduced atmospheric demand for water, but low levels of soil moisture were observed when measurements ceased in November.

Losses of stored soil moisture from the 0-122 cm profile occurred at faster rates on unthinned plots during the period, but differences in depletion between BA25 and BA50 plots were not apparent. Maximum soil water deficits were found in late August and again in early October.

Total seasonal depletion of soil moisture was greater in 1985 than in 1984 because of the lower rainfall, but the decrease in soil moisture availability on thinned plots, as compared to unthinned plots, was evident. An average soil water deficit of 17.4 cm had been accumulated in the 0-122 cm profile on unthinned plots by late August. At the same time, 14.6 cm, or 84% of unthinned, had been depleted on BA50 plots. The average soil water deficit observed on BA25 plots was 14.4 cm, or 83% of unthinned.

As in 1984, the loss of soil moisture with increasing depth in the profile appeared to be affected by stand density (Figure 3). Soil water deficits on unthinned plots were again generally greatest on unthinned plots at each depth interval, and the difference in soil water deficits between thinned and unthinned plots increased with increasing depth in the profile. Late August soil water deficits by 30 cm intervals on unthinned plots averaged 5.5 cm in the 0-30 cm layer, 4.3 cm in the 30-61 cm layer, 4.0 cm in the 61-91 cm layer, and 3.6 cm in the 91-122 cm layer. Soil water deficits from the same depth intervals were 5.2 cm, 3.6 cm, 3.2 cm, and 2.6 cm on BA50 plots and 5.3 cm, 3.8 cm, 3.1 cm, and 2.2 cm on BA25 plots. Except in the 91-122 cm layer, no significant differences in soil water deficits were found between BA25 and BA50 plots at any depth. Soil moisture depletion curves during the summer of 1985 (Figure 4) illustrate the lack of differences in the depletion pattern between the two thinned treatments.

Some reduction of soil moisture availability in thinned stands is expected during the second year following thinning due to crown expansion and increased root competition as the residual trees gradually reoccupy the site. A 30% reduction in available soil moisture under trees in thinned loblolly pine stands during the second year following thinning was reported by Douglass (1960). Zahner and Whitmore (1960) found that even in extremely heavily thinned stands, trees were no longer competition-free for water after only 5 years.

Although some decrease in moisture availability was expected on thinned plots in 1985, the large extent of the decrease observed in this study, particularily on BA25 plots, was attributed to the excessive herbaceous understory which invaded the thinned plots. The understory was predominantly composed of dewberry (*Rubus spp.*), trumpet creeper (*Campsis radicans*), and native grasses. Hardwood sprouting on the site was negligible. Herbaceous and grass understory vegetation was sampled in July, 1985 from ten randomly located 1 m^2 samples collected from each plot.

Previous studies have shown that the presence of understory vegetation can reduce soil moisture availability in forest stands. Zahner (1958) reported that water loss rates in a loblolly-shortleaf pine (*P. echinata* Mill.) stand with a hardwood understory present were approximately 25% faster than in a similar stand without understory vegetation. Seasonal water use in ponderosa pine (*P. ponderosa* Laws.) stands with understory vegetation was up to 45% greater than water use in stands without an understory (Barrett and Youngberg, 1965).

Understory leaf area (Table 6) on BA25 plots was over 27 times that of unthinned plots, and over double that of BA50 plots. The similar soil water deficits found on BA25 and BA50 plots seem to indicate that the additional understory leaf area on BA25 plots was depleting almost as much soil moisture as the greater stocking on BA50 plots. Jarvis (1985) suggested that the total leaf area of vegetation occupying a site will reach equilibrium with the site and that this equilibrium level is dependent upon the particular locality and climate. Zahner (1959) explained that the heavier the thinning, the longer the amount of time that should elapse before water loss in thinned stands equals that of unthinned stands, but as Jarvis (1985) explained, thinning stimulates growth of ground vegetation, so is unlikely to affect total transpiration from a site unless accompanied by control of the understory. It was apparent from this experiment that both the extent and duration of the improvement in soil moisture availability following heavy thinning will be reduced unless some form of control is applied to reduce competition from the understory.

Daily Water Use

Water use between measurement dates was calculated by adding the amount of throughfall received on a plot to the change in soil moisture content in the 0-122 cm profile. Although intercepted rainfall is included in estimates of evapotranspiration, it was not included in the calculation of water use rates in this study because intercepted rainfall evaporates from the forest canopy without any appreciable savings of stored soil moisture (Rutter, 1975). Analysis of water use rates was limited to the June through mid-September periods of 1984 and 1985 when soils were below field capacity to reduce the effects of runoff.

Except for one period in early September, 1984, no significant differences in the average daily rate of water use between treatments were detected in 1984 or 1985 (Table 7). Although the rate of depletion of stored soil moisture was generally greatest on unthinned plots, the input of water as throughfall increased as stand density was reduced. Actual water use on thinned plots may have been greater than measured rates due to root expansion into openings between the trees where soil moisture was not measured.

Although treatment effects on daily water use were not observed throughout either year, the trends in water use were quite different in comparing the two years, due to the large difference in rainfall amounts and frequency between

1984 and 1985. During 1984, frequent rainfall allowed daily water use to be maintained at relatively high levels throughout the summer. Water use averaged 3.9 mm/day and ranged from 2.6 to 5.4 mm/day. Water use dropped to below 3.0 mm/day at several times during periods of low soil moisture and low rainfall. Rates of water use on all treatments fluctuated throughout the growing season as soil moisture was recharged by rainfall.

Water use averaged 2.7 mm/day during the same period in 1985. Rates of water use of greater than 3.0 mm/day were maintained through July as soil moisture was depleted and rainfall was near normal. The rate of water use dropped sharply in response to the August drought, as soil moisture had already been depleted to low levels. Water use of less than 1.0 mm/day was observed during August and September, showing that diameter growth was probably limited by water stress.

Estimates of water use rates on a daily basis would be more precise with more frequent measurements, but the trends in water use illustrate the effect of atmospheric conditions. Soil moisture on thinned plots was at consistantly higher levels throughout both growing seasons. Trees on thinned plots were utilizing moisture held at lower tensions, possibly alleviating water stress, although measured water use on thinned plots was equal to that of unthinned plots.

Soil Moisture Availability as Related to Diameter Growth

The physiological processes of trees do not depend directly upon the supply of soil moisture, but on the balance between water uptake and transpiration, which may result in water stress (Bassett, 1964b). Zahner (1968) explained that field studies of soil moisture only allow qualitative estimates of tree water stress, but information yielded in previous studies seems to show that limited soil moisture availability induces water stress, causing reduced diameter growth.

Moehring and Ralston (1967) and Bassett (1964b) reported that when available soil moisture dropped below 40%, the diameter growth of loblolly pine was reduced because soil moisture could not be absorbed as fast as it was transpired. Although rainfall was above normal during the June-October period of 1984, available soil moisture on unthinned plots was at levels potentially limiting to diameter growth for approximately 2 months during the period (Figure 5). Available soil moisture on BA25 and BA50 plots never dropped below 40% during the entire period. Although growth during the period may have been limited by rapid depletion rates (McClurkin, 1961; Moehring and Ralston, 1967) for short periods when atmospheric demand was high, the amount of soil moisture in the profile probably never limited diameter growth on thinned plots.

During 1985, available soil moisture on unthinned plots dropped below 40% in mid-July and remained at low levels through the remainder of the growing season (Figure 6). Available soil moisture was below 40% for almost 2 months on BA50 plots, and for just over a month on BA25 plots. Even during the drier summer of 1985, and with increased competition for water on thinned plots, thinning was beneficial in maintaining better conditions for growth over a greater proportion of the growing season.

Conclusions

Precommercial thinning improved soil moisture availability during the middle and latter portions of the two growing seasons following thinning. Soil water deficits were greatest on unthinned stands during both growing seasons, but differences in soil water deficits between thinned and unthinned stands decreased during the second year. The decrease in soil moisture availability on thinned stands was attributed to increased crown and root competition between residual trees and to a dense herbaceous understory which invaded thinned plots.

Seasonal losses of soil moisture with increasing depth in the profile were affected by stand density. Although total water loss was greatest in surface soil layers, differences in soil water deficits between the treatments increased with depth. Depletion of soil moisture through the profile on thinned stands was less uniform than on unthinned stands, probably due to root expansion of residual trees on thinned plots.

Daily rates of water use generally did not significantly differ between treatments. Depletion of soil moisture was proportional to stand density, but throughfall increased as stand density was reduced. Although residual trees in thinned stands had greater amounts of low tension water available for uptake, measured rates of water use were not significantly affected by stand density.

Thinning resulted in higher levels of available soil moisture over a greater proportion of the growing season, extending the length of time that soil moisture conditions were favorable to diameter growth. It was apparent that the extent and duration of the improvement in soil moisture availability following radical reductions in stand density may be reduced unless some form of control is applied to reduce competition from herbaceous vegetation.

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Table 1. Stand Characteristics at beginning of growing season in 1984 and 1985.

Treatment	Stocking (trees/ha)	Basal Area (m^2/ha)		Avg.Diameter (cm)		Avg.Height (m)	
		1984	1985	1984	1985	1984	1985
BA25	341	6.5	7.6	15.7	17.5	9.1	10.3
BA50	659	11.9	13.8	15.1	16.8	9.7	10.2
BA100	2134	25.5	27.9	11.9	13.2	9.2	9.5

Table 2. Physical properties and moisture holding characteristics for soils on the three blocks.

		Water-holding capacity (cm) at					
Block	Depth (cm)	0.06 bar	1 bar	3 bars	15 bars	Bulk Density (g/cm^3)	Texture
1	0-15	4.3	2.1	1.3	0.7	1.62	L
	15-30	4.4	2.8	2.1	1.5	1.68	CL
	30-61	9.5	8.4	6.7	5.0	1.74	CL
	61-122	19.1	16.7	14.1	10.4	1.74	CL
2	0-15	4.2	2.0	1.3	0.7	1.61	L
	15-30	4.3	2.5	1.8	1.1	1.66	CL
	30-61	9.4	6.8	4.6	3.3	1.74	CL
	61-122	19.1	14.8	11.1	7.9	1.76	CL
3	0-15	4.6	2.6	1.6	1.0	1.64	L
	15-30	4.7	3.0	2.0	1.4	1.66	CL
	30-61	10.0	7.8	5.3	3.8	1.71	CL
	61-122	20.2	16.4	11.7	8.6	1.69	SiCL

Table 3. Normal rainfall for June through October compared to rainfall in 1984 and 1985.

Month	Normal	1984	Deviation from normal	1985	Deviation from normal
	----------------------mm----------------------				
June	93.7	60.2	-33.5	79.0	-14.7
July	90.2	103.6	+13.4	72.4	-17.8
August	66.5	113.5	+47.0	0	-66.5
September	115.1	165.1	+50.0	48.3	-66.8
October	97.5	303.3	+205.8	109.0	+11.5
Total	463.0	745.7	+282.7	308.7	-154.3

Table 4. Mean soil water deficits in the 0-122 cm profile during 1984.

Date	Treatment		
	BA25	BA50	BA100
	cm		
5/09/84	-0.2a	-0.2a	0.2a
5/31/84	0.4a	0.6a	2.5b
6/14/84	3.5a	4.2a	6.0b
7/18/84	6.7a	7.8a	11.5b
8/02/84	9.7a	10.9a	14.6b
8/15/84	6.4a	8.6b	11.8c
8/30/84	9.4a	11.4a	15.8b
9/13/84	9.0a	10.8a	14.5b
10/11/84	4.6a	5.9a	10.6b
11/13/84	1.4a	1.7a	1.6a

Means within rows followed by the same letter are not significantly different at the 0.05 level.

Table 5. Mean soil water deficits in the 0-122 cm profile during 1985.

Date	Treatment BA25	 BA50	 BA100
	cm		
5/16/85	1.6a	2.2a	1.8a
5/29/85	0.2a	0.5ab	1.2b
6/17/85	3.0a	3.3a	4.0a
7/01/85	7.0a	7.5a	8.6a
7/15/85	9.1a	9.5a	11.2a
8/01/85	10.7a	11.3a	13.7b
8/13/85	12.7a	13.1a	16.2b
8/30/85	14.4a	14.6a	17.4b
9/16/85	12.9a	13.8a	15.5b
10/07/85	14.5a	14.7a	17.4b
11/06/85	11.2a	12.0a	13.9b

Means within rows followed by the same letter are not significantly different at the 0.05 level.

Table 6. Understory leaf area index in July, 1985.

Treatment	Herbaceous LAI	Grass LAI	Total LAI
	------------	m^2/m^2	------------
BA25	1.275a	0.063a	1.338a
BA50	0.588b	0.040a	0.628b
BA100	0.047c	0.002b	0.049c

Means within columns followed by the same letter are not significantly different at the 0.05 level.

Table 7. Average daily water use between measurement dates.

Period	Treatment		
	BA25	BA50	BA100
	---------	mm/day	---------
5/31-6/14/84	3.28a	3.89a	3.91a
6/14-7/18/84	4.65a	4.60a	4.83a
7/18-8/2/84	2.69a	2.67a	2.62a
8/2-8/15/84	5.28a	5.41a	4.70a
8/15-8/30/84	2.59a	2.57a	3.30a
8/30-9/13/84	4.14a	3.63ab	2.79b
5/29-6/17/85	4.93a	4.72a	4.67a
6/17-7/1/85	3.68a	3.89a	3.99a
7/1-7/15/85	3.78a	3.63a	3.63a
7/15-8/1/85	3.00a	3.02a	3.30a
8/1-8/13/85	1.65a	1.50a	2.08a
8/13-8/30/85	1.02a	0.91a	0.69a
8/30-9/13/85	0.76a	1.09a	0.25a

Means within rows followed by the same letter are not significantly different at the 0.05 level.

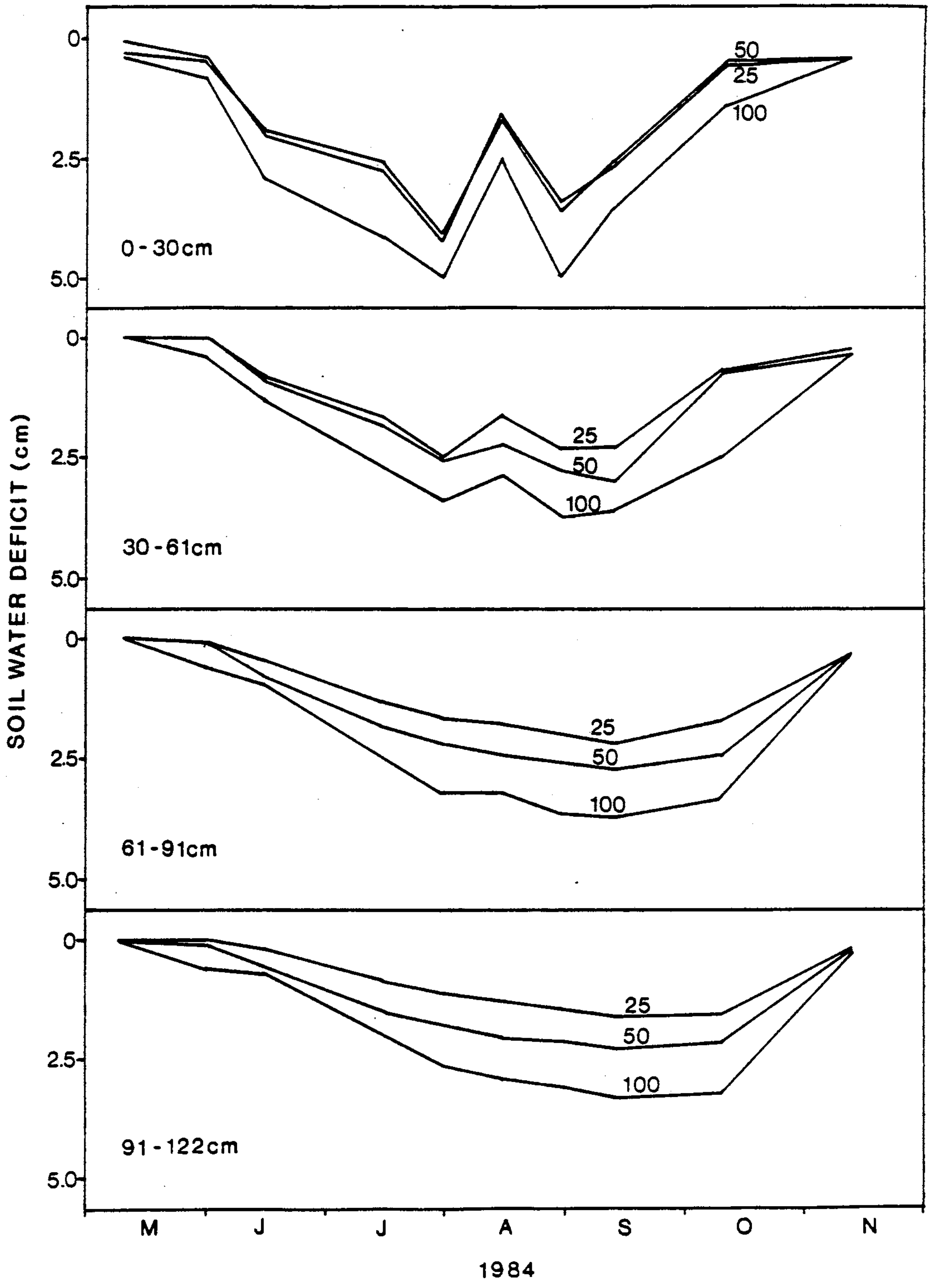

Figure 1. Soil water deficits by 30 cm depth intervals during the 1984 growing season.

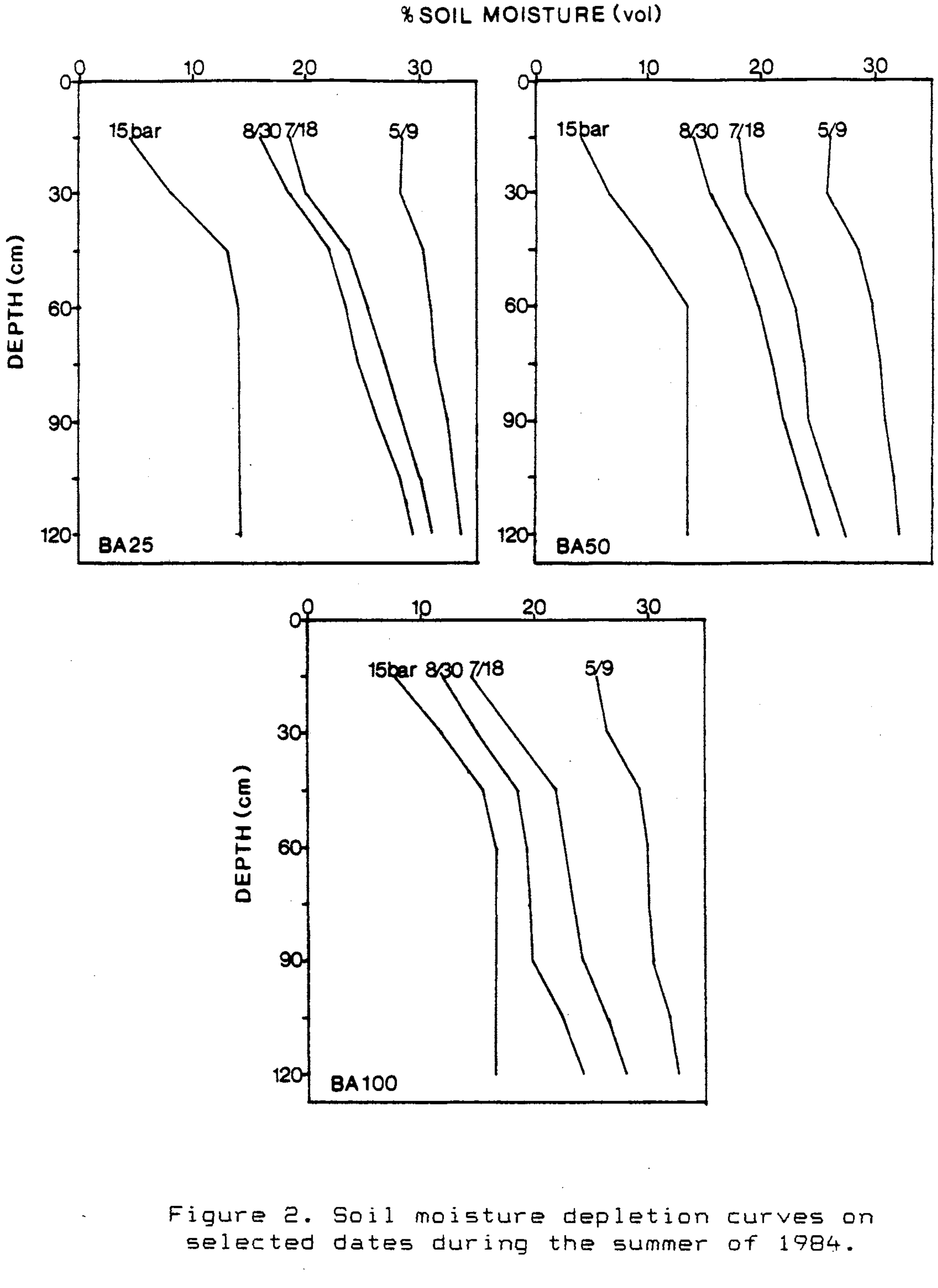

Figure 2. Soil moisture depletion curves on selected dates during the summer of 1984.

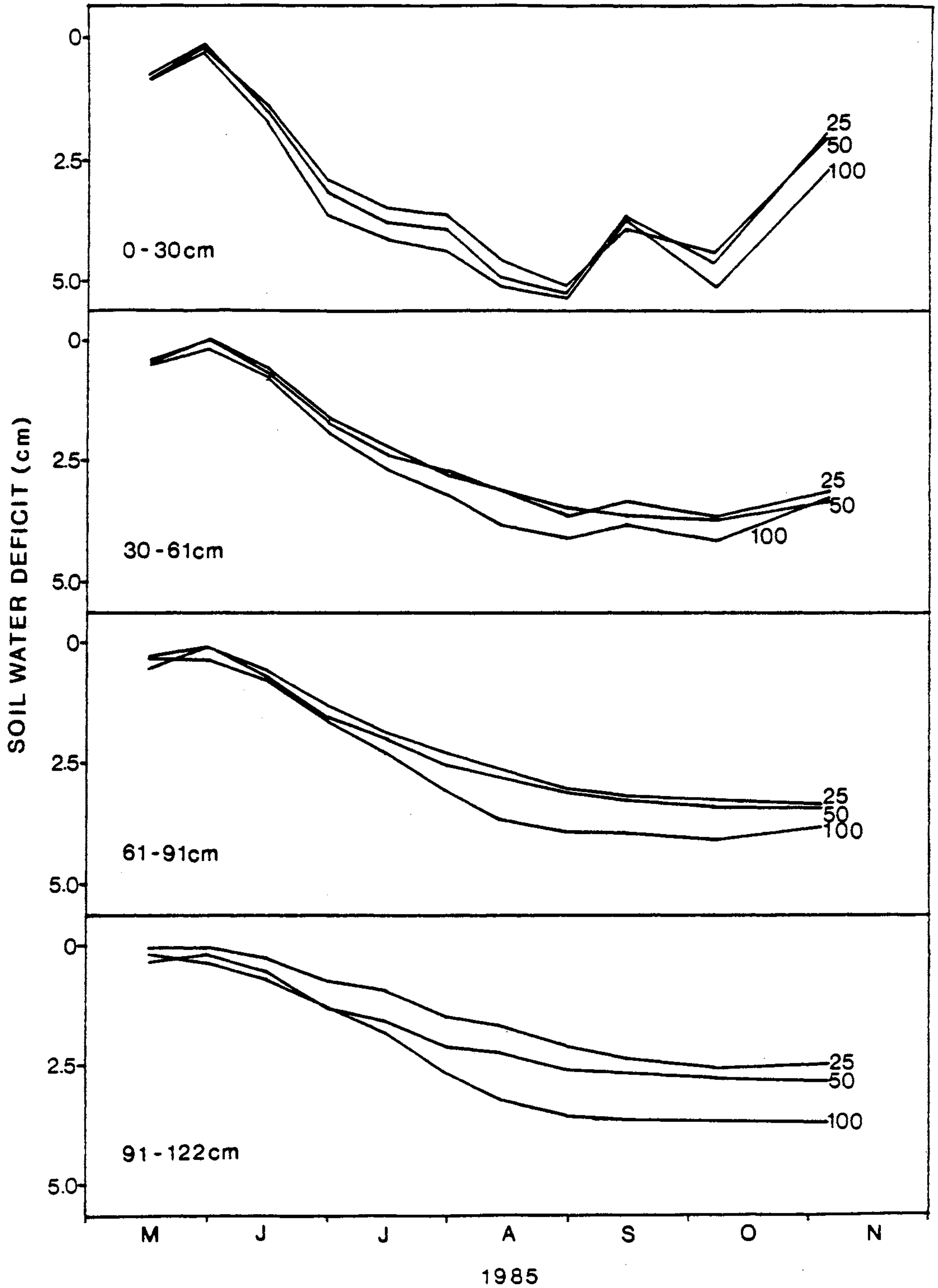

Figure 3. Soil water deficits by 30 cm depth intervals during the 1985 growing season.

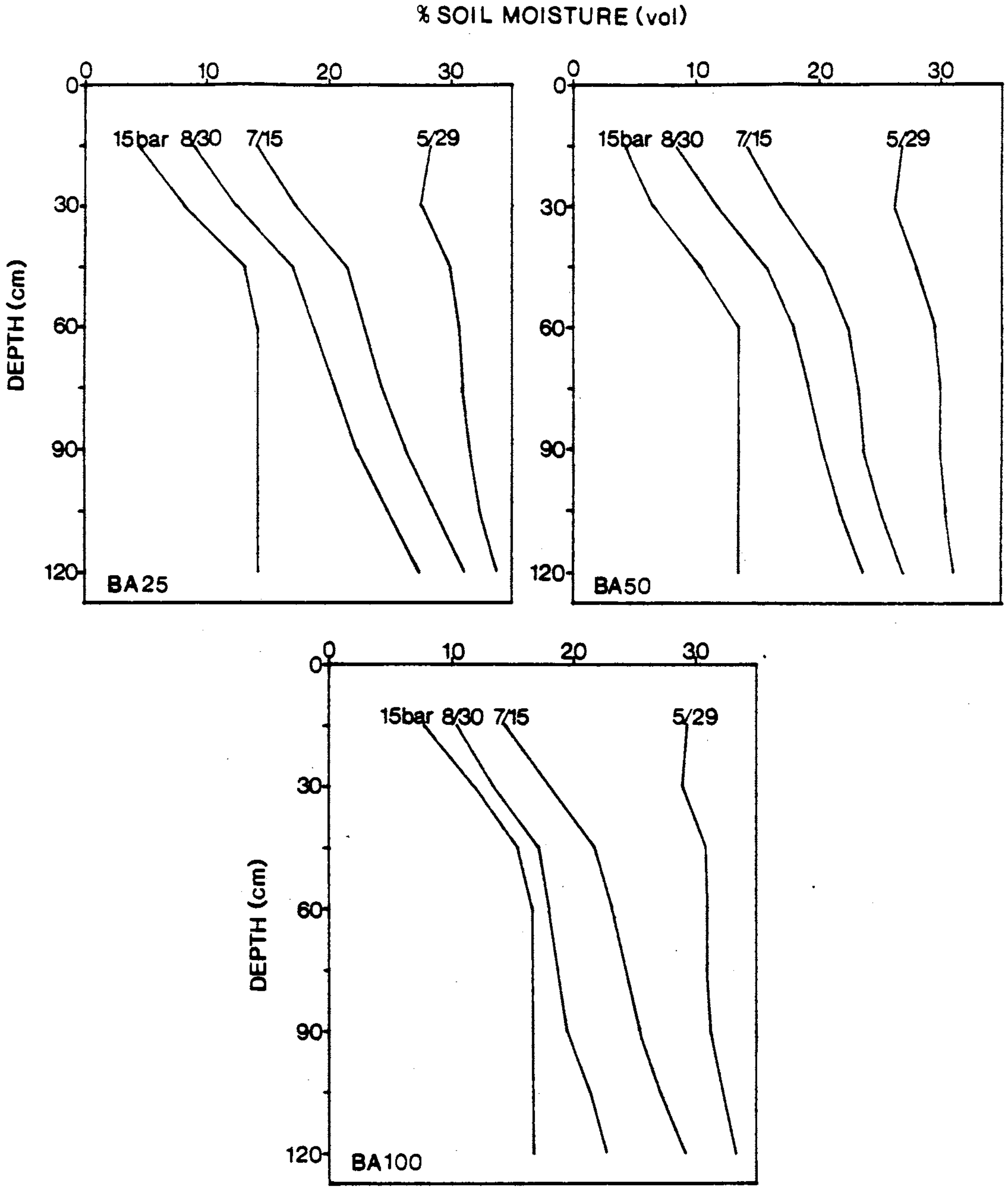

Figure 4. Soil moisture depletion curves on selected dates during the summer of 1985.

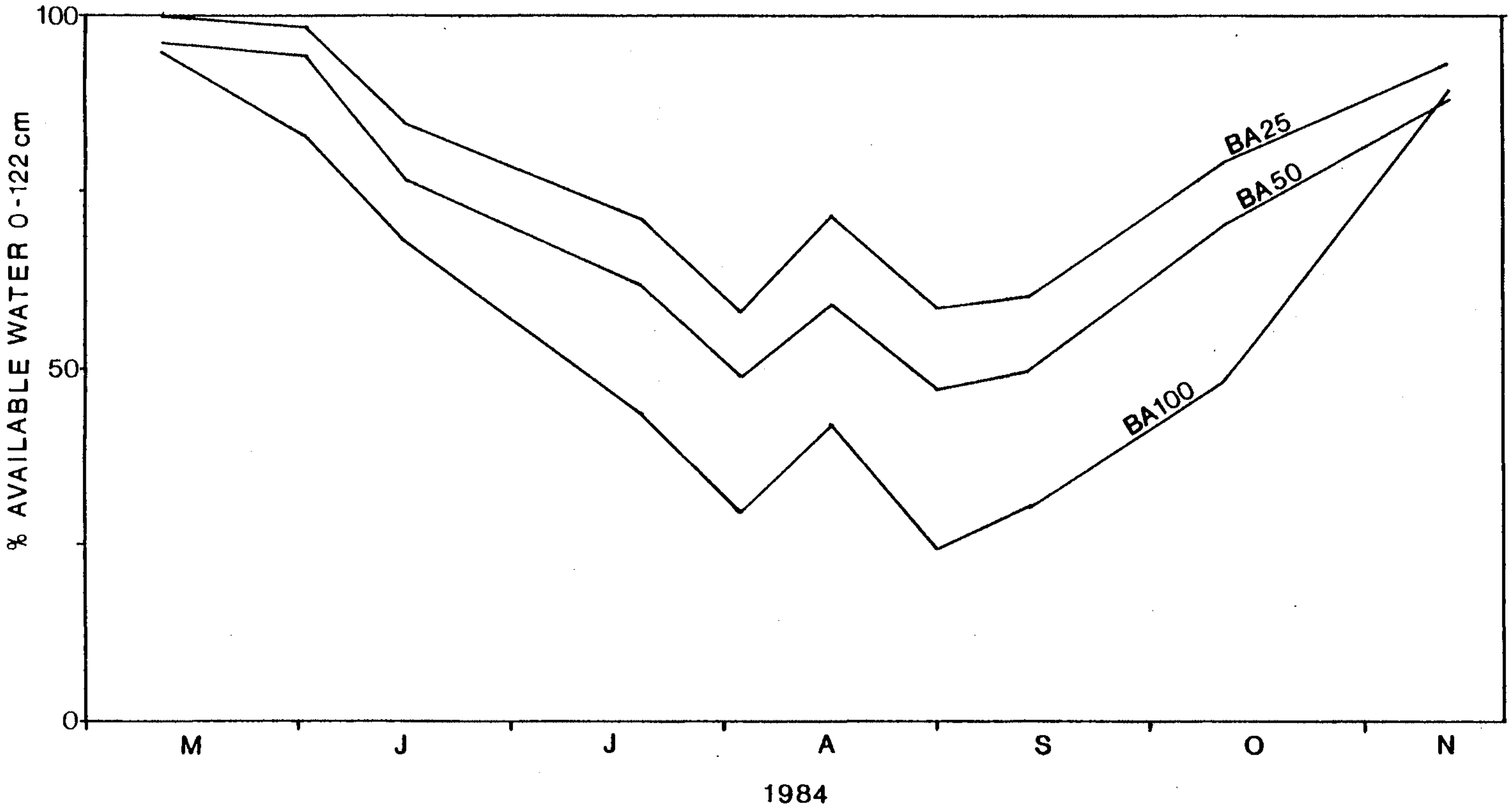

Figure 5. Available water (percent) in the 0-122 cm profile during the 1984 growing season.

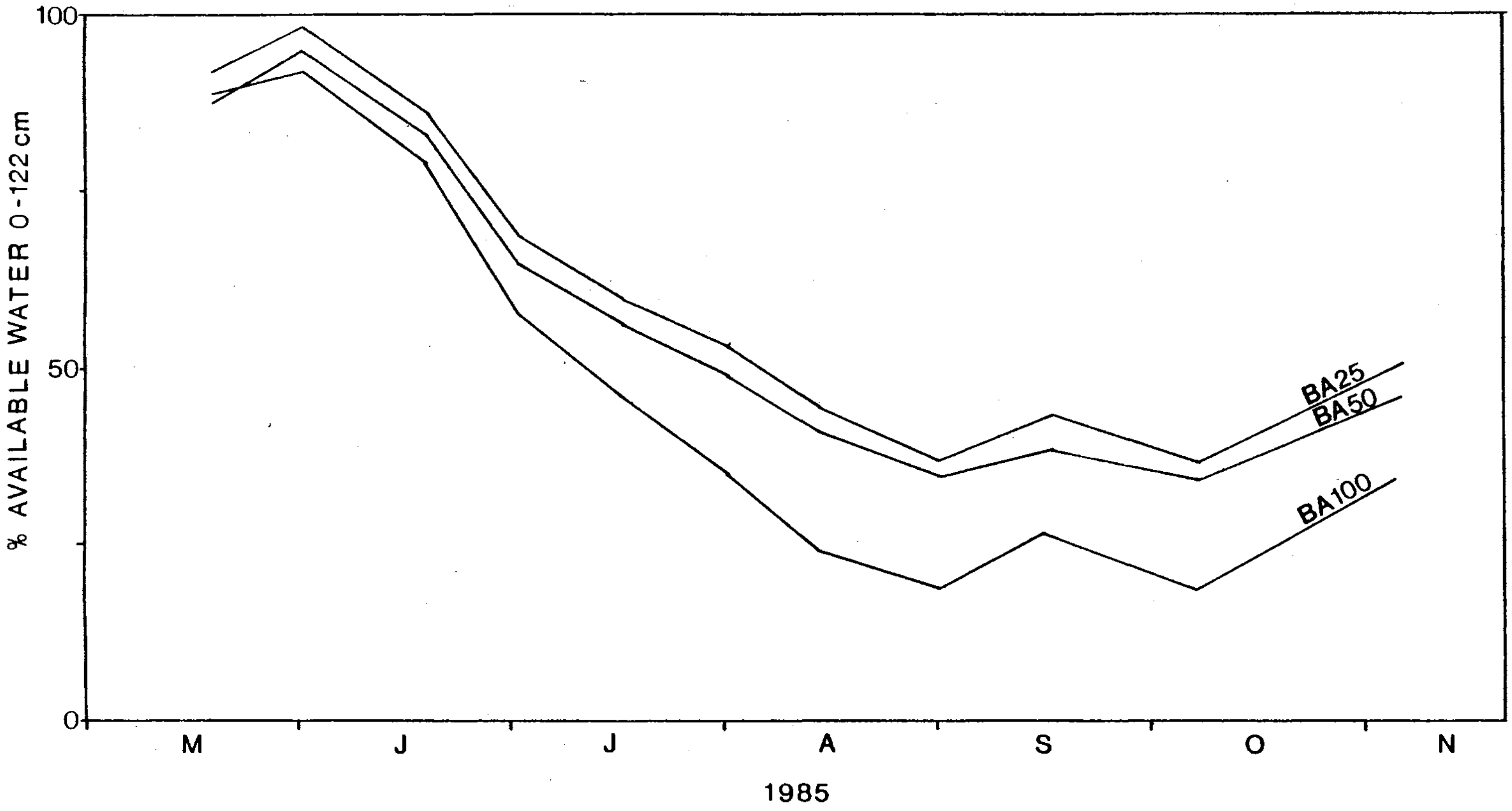

Figure 6. Available water (percent) in the 0-122 cm profile during the 1985 growing season.

PART II

THROUGHFALL IN A YOUNG LOBLOLLY PINE PLANTATION FOLLOWING THINNING

Abstract

Throughfall was measured in an 11-year-old loblolly pine (*Pinus taeda* L.) plantation in southeastern Oklahoma under various levels of stand density during the middle and latter portions of two growing seasons. The best prediction of throughfall for individual storms was by the equation : Throughfall = 1.023(Gross Rainfall) - 0.002(Gross Rainfall X Basal Area) - 0.009. Throughfall increased by approximately 2 percent of gross growing season rainfall for every 10 square foot reduction in basal area. The additional water supplied as throughfall should be beneficial in alleviating summer water deficiencies.

Introduction

Throughout the Midsouth, a deficiency of water limits diameter growth in forest stands during nearly every growing season (1). The availability of water is dependant upon the soil water-holding capacity of a site, additions of water through precipitation, and losses of soil moisture and intercepted rainfall through evapotranspiration. Evaporation of rainfall intercepted by the forest canopy represents a major loss of water which would have been available for the recharge of soil moisture storage. Silvicultural practices cannot affect the water storage capacity or the amount and frequency of gross precipitation received on a site, but can greatly affect water losses from the site by reducing the demand for water and by increasing the proportion of rainfall reaching the ground as throughfall.

Precommercial thinning is a common silvicultural treatment applied to young loblolly pine plantations in order to increase the value of the stand and shorten the rotation length by increasing the rate and seasonal duration of diameter growth. It is apparent from previous studies that the improvement in soil moisture availability following thinning greatly impacts diameter growth (1,7, 15). Soil moisture availability is improved following thinning because of reduced water use by the residual stand and increased throughfall (5). This study was undertaken to determine the effects of precommercial thinning on throughfall in a young loblolly pine plantation and to develop a model which would predict throughfall as affected by varying levels of stand density. The equation was to be similar to the model presented by Rogerson (8,9), but applicable to loblolly pine plantations suitable for precommercial thinning.

Many previous studies of a hydrologic nature have examined the process of rainfall interception as affected by both storm and stand variables and reported the effects of throughfall over the entire year as related to the total water yield from a site. From a silvicultural viewpoint, the implications of manipulating the water balance of a site by reducing interception losses have received little attention. Although increasing the amount of throughfall over the entire year is important to the total water yield from a site, it is less important during the dormant season when the objective is improving tree growth, because most sites in the Midsouth typically begin the growing season with fully recharged soil moisture storage.

It has been debated whether or not intercepted water represents a complete loss from the water balance of a site, due to the observed reduction in transpiration when forest vegetation is wetted (2). Singh and Szeicz (13) found that the rate of evaporation of intercepted rainfall in forests was much greater than the transpiration rate would be if the foliage was dry. Also, transpiration is often already limited by low soil moisture availability during the growing season, so that evaporation of intercepted rainfall only alleviates water deficiencies for the period of time when the canopy is actually wet (2). For these reasons, Rutter (12) suggested that the interception of rainfall does represent an apparent loss from the water balance of a site, without any appreciable savings of stored soil moisture.

Hoover (4) and Swank, et al, (14) both found that throughfall averaged 73 percent of gross annual precipitation in 10-year-old, fully stocked loblolly pine plantations in South Carolina. Helvey (3) reported that throughfall in young eastern white pine (P. strobus L.) stands averaged 80 percent of gross precipitation, while Rogerson and Byrnes (10) reported the same percentage in red pine (P. resinosa Ait.). Lawson (6) observed that 84.9 percent of gross precipitation reached the ground as throughfall in a mixed pine-hardwood stand in the Ouachita Mountains of Arkansas. He reported that throughfall during the growing season averaged 80.6 percent, but increased to 88.3 percent during the dormant season. The best prediction of throughfall used variables of gross precipitation for each storm and the long-term mean temperature on the date when the storm occurred. He stated that the use of temperature in a prediction equation should reflect seasonal changes, particularily changes in foliage. Roth and Chang (11) found that throughfall in Southern pine stands was greater during the growing season than during the dormant season, due to the occurrence of storms of high intensity and short duration during the summer months.

Rogerson (8,9) examined the effects of different levels of thinning on throughfall in a 25-year-old loblolly pine stand in Mississippi and found that throughfall ranged from 93.8 percent of gross rainfall at a basal area of 38 square feet per acre to 77.4 percent at 183 square feet per acre. He found the best estimate of throughfall from the equation :

$$\text{Throughfall} = 0.980(\text{Gross Rainfall}) - 0.00097(\text{Gross Rainfall} \times \text{BA}) - 0.0184$$

The R^2 of the equation was 0.9933. It was estimated that throughfall increased by 2 percent of gross annual precipitation for every reduction of 20 square feet per acre of basal area. Rogerson (9) estimated that reducing the basal area of a stand from 150 square feet per acre to 70 square feet per acre would increase ground-level rainfall by 4 inches annually.

Methods

An 11-year-old loblolly pine plantation located in eastern McCurtain County, Oklahoma was selected for the study. Three adjacent blocks were established in the plantation. Each block contained three 0.25 acre square plots with each of the three treatment levels randomly applied to each block. The three initial treatment levels were :

1) thinned to 25 percent of the original basal area,
2) thinned to 50 percent of the original basal area, and
3) unthinned.

The plots were selectively thinned from below to these levels in early March, 1984. The residual trees on the thinned plots were selected for best size and form, while maintaining minimum spacing requirements to insure an adequate distribution of trees within the desired treatment level. Treatment means of actual stand characteristics are shown in Table 1. Because the experiment was designed to represent a precommercial thinning, no harvested material was removed from the site. A 0.10 acre square interior plot was established on each plot, from which all measurements were collected.

Throughfall was sampled using ten No.10 tin can throughfall collectors randomly located on each of the plots. The cans were placed directly on the ground to measure any interception by brush or slash left from the thinning. Throughfall volumes were measured with a graduated cylinder following storms during the periods of May 15 through November 1 in both 1984 and 1985. Stemflow was not measured, because most of the rainfall intercepted by the forest canopy evaporates before reaching the ground, except in very young stands (9). Gross precipitation was measured at the same time as throughfall in two standard rain gauges located in openings within the study site.

Annual precipitation in the study area averages 47 inches, with approximately one-half occurring during the May through October period. Spring is usually the wettest season and fall is the driest. Rainfall is generally adequate for stand growth until late May, but droughts of 2 to 6 weeks in length are fairly common during the remainder of the growing season. Convective summer storms are characterized by short duration and high intensity.

Results and Discussion

Between May 15 and November 1, 1984, 21 storms were recorded, with a total of 34.74 inches of rain falling onto the study area. Rainfall during the fall was greatly above the long-term mean. Storm size during the period ranged from 0.21-4.15 inches and averaged 1.65 inches. The May 15 through November 1, 1985 period was much dryer, with one rainless period of 6 weeks. A total of 15 storms brought 16.20 inches of rain to the area during the period. In 1985, storm size ranged from 0.25-2.73 inches and averaged 1.08 inches. Monthly rainfall totals during both years and the long-term monthly means of the area from June through October are shown in Table 2. An additional 2.88 inches were recorded from May 15-31, 1984, 2.50 inches on November 1, 1984, and 4.05 inches from May 15-31, 1985. A breakdown of the storms into size classes is given in Table 3.

Throughfall totaled 97.9 percent of gross rainfall during the 1984 growing season on plots thinned to 25 percent of the original basal area, but decreased to a total of 96.3 percent in 1985 (Table 4). The same trend was noted on the other treatments, with throughfall totals decreasing from 92.2 percent of gross rainfall in 1984 to 90.3 percent in 1985 on plots thinned to 50 percent of the original basal area. Throughfall on the unthinned plots totaled 83.2 percent of gross rainfall in 1984 and decreased to 80.6 percent in 1985. The decrease in throughfall totals may be explained by the decrease in the average storm size from 1984 to 1985. The totals seemed fairly high in 1984, probably because of the high number of larger sized storms.

Throughfall increased with increasing storm size and with reductions in stand density. Expressed as a percentage of individual storms, throughfall averaged 96.6 percent on plots thinned to 25 percent, 90.3 percent on plots thinned to 50 percent, and 80.5 percent on unthinned plots. Differences in throughfall percentages between the treatment levels were significant at the p=0.001 level. Although rainfall totals were quite different between the 2 years, the average percentage of throughfall for individual storms within a treatment level did not significantly differ from 1984 to 1985. Stand regrowth apparently did not greatly affect the proportion of throughfall from individual storms in the second year following thinning.

When Rogerson's (8,9) equation was applied to the stand densities encountered in this study, throughfall was underestimated for least dense stands and overestimated for unthinned stands. In developing a model to predict throughfall for individual storms within the range of stand densities examined in this study, the use of gross precipitation alone as a variable accounted for 97.91 percent of the variation in predicting throughfall. The addition of basal area into the equation was done by using the multiple of gross precipitation and basal area as an independent variable. This variable was chosen because, as Rogerson (8) explained, the use of basal area alone as a variable assumes that only the level, and not the slope of the relationship between throughfall and gross rainfall changes with basal area. Rogerson (8) stated that the slope of the relationship does change with different basal area levels. The equation developed in this study to predict throughfall as related to gross rainfall and basal area is :

$$\text{Throughfall} = 1.023(\text{Gross Rainfall}) - 0.002(\text{Gross Rainfall} \times \text{BA}) - 0.009.$$

The equation accounted for 98.98 percent of the variation in predicting throughfall for individual storms within the range of basal area levels examined in the study. The standard error of estimate for the equation is 0.1013 inches.

Removing 50 percent of the original basal area increased throughfall by an average of 9.35 percent, while removal of 75 percent of the basal area increased throughfall by 15.2 percent. Throughfall increased by approximately 2 percent of gross rainfall for every 10 square foot reduction in basal area. Although this is double the increase following thinning reported by Rogerson (8,9), there are great differences in stand age and characteristics between the two studies. Thinning in young loblolly pine plantations, to the levels examined in this study, creates large openings in the forest canopy. Even the smallest storms deliver water to these openings. As the root systems of the residual trees in thinned stands rapidly expand to reoccupy the openings, the additional water received as throughfall becomes readily available for uptake and may help alleviate summer water deficiencies.

Although removal of 75 percent of the original basal area is drastic compared to conventional precommercial thinning practices, thinning to 50 percent of the original level is feasible in areas where water deficiencies limit tree growth during the middle and latter portions of the growing season. During a typical growing season, stands thinned to 50 percent may receive as much as 2.5 inches of additional ground-level rainfall from May through October. The additional water should be beneficial in increasing the rate and seasonal duration of diameter growth, allowing the stand to be harvested in a shorter period of time.

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Table 1. Stand Characteristics at the beginning of the two growing seasons.

Treatment	Stocking (trees/ac)	Basal Area (ft^2/ac)		Avg.Diameter (inches)		Avg.Height (feet)	
		1984	1985	1984	1985	1984	1985
BA25	138	28.3	33.3	6.2	6.9	29.7	33.7
BA50	267	51.7	60.3	5.9	6.6	31.7	33.5
BA100	864	111.3	121.7	4.7	5.2	30.2	31.0

Table 2. Rainfall from June through October.

Month	Normal	1984	Deviation from normal	1985	Deviation from normal
	inches				
June	3.69	2.37	-1.32	3.11	-0.58
July	3.55	4.08	+0.53	2.85	-0.70
August	2.62	4.47	+1.85	0	-2.62
September	4.53	6.50	+1.97	1.90	-2.63
October	3.84	11.94	+8.10	4.29	+0.45
Total	18.23	29.36	+11.13	12.15	-6.08

Table 3. Storm size classes.

Rainfall amount (inches)	Number of Storms 1984	1985
0.00-0.25	2	1
0.26-0.50	3	1
0.51-0.75	2	7
0.76-1.00	2	0
1.01-1.50	2	3
1.51-2.00	1	0
2.01-2.50	2	1
2.51-3.00	5	2
+3.00	2	0
Total	21	15

Table 4. Throughfall totals in 1984 and 1985.

May 15-November 1, 1984 Gross rainfall 34.74 inches			
Treatment	Throughfall (inches)	Percent of gross rainfall	Deviation from unthinned (inches)
BA25	34.00	97.9	+5.09
BA50	32.02	92.2	+3.11
BA100	28.91	83.2	------

May 15-November 1, 1985 Gross rainfall 16.20 inches			
Treatment	Throughfall (inches)	Percent of gross rainfall	Deviation from unthinned (inches)
BA25	15.60	96.3	+2.54
BA50	14.63	90.3	+1.57
BA100	13.06	80.6	------

APPENDIXES

APPENDIX A

SOIL PHYSICAL PROPERTIES AND WATER-HOLDING CHARACTERISTICS

Location	Depth (in.)	BD (g/cc)	Texture	0.06 Bar	1Bar	3Bar	15Bar
				---------in. water---------			
B1T25	0-6	1.62	L	1.77	0.75	0.44	0.25
	6-12	1.69	CL	1.80	1.04	0.74	0.51
	12-24	1.72	CL	3.80	3.39	2.91	2.17
	24-48	1.74	C	7.49	6.93	5.80	4.30
B1T50	0-6	1.59	L	1.68	0.71	0.44	0.24
	6-12	1.69	CL	1.77	0.96	0.70	0.49
	12-24	1.79	CL	3.46	2.91	1.98	1.48
	24-48	1.80	CL	7.38	6.07	5.11	3.81
B1T100	0-6	1.64	L	1.73	1.00	0.65	0.38
	6-12	1.66	CL	1.76	1.35	1.13	0.77
	12-24	1.72	CL	3.78	3.44	2.86	2.17
	24-48	1.68	CL	7.64	6.73	5.73	4.19
B2T25	0-6	1.57	L	1.78	0.93	0.67	0.34
	6-12	1.65	CL	1.79	1.10	0.80	0.50
	12-24	1.78	CL	3.79	2.54	1.87	1.21
	24-48	1.75	C	7.79	5.89	4.44	2.97
B2T50	0-6	1.62	L	1.63	0.65	0.41	0.25
	6-12	1.66	CL	1.74	0.83	0.56	0.37
	12-24	1.73	CL	3.48	2.43	1.48	1.12
	24-48	1.75	CL	7.54	5.53	3.63	2.77
B2T100	0-6	1.65	L	1.67	0.77	0.48	0.29
	6-12	1.68	CL	1.65	1.00	0.76	0.50
	12-24	1.70	CL	3.59	2.96	2.02	1.47
	24-48	1.77	C	7.17	6.09	5.01	3.62
B3T25	0-6	1.63	L	1.66	0.72	0.39	0.23
	6-12	1.63	CL	1.76	0.91	0.64	0.44
	12-24	1.75	CL	3.74	2.78	1.93	1.34
	24-48	1.74	CL	7.48	5.90	4.01	2.92
B3T50	0-6	1.63	L	1.70	0.79	0.45	0.27
	6-12	1.67	CL	1.77	0.90	0.57	0.35
	12-24	1.73	CL	3.55	2.46	1.68	1.15
	24-48	1.71	CL	7.47	6.16	4.39	3.15
B3T100	0-6	1.67	SiCL	2.13	1.59	1.04	0.70
	6-12	1.68	SiC	2.11	1.79	1.21	0.86
	12-24	1.66	SiC	4.32	3.77	2.57	1.89
	24-48	1.63	SiC	8.91	7.30	5.44	4.11

APPENDIX B

SOIL TEXTURE

Location	Depth (inches)	% sand	% silt	% clay	Class
B1T25	0-2	40.3	40.3	19.4	L
	5-7	34.8	39.8	25.4	L
	11-13	31.2	36.9	31.9	CL
	23-25	25.6	31.0	43.5	C
B1T50	0-2	34.9	47.7	17.4	L
	5-7	32.4	43.4	24.2	L
	11-13	32.4	39.4	28.1	CL
	23-25	28.0	35.0	37.0	CL
B1T100	0-2	31.9	47.9	20.2	L
	5-7	30.2	42.4	27.4	L
	11-13	25.4	37.3	37.3	CL
	23-25	24.3	36.6	39.1	CL
B2T25	0-2	34.8	47.1	18.1	L
	5-7	31.2	41.7	27.1	L
	11-13	26.4	41.2	32.4	CL
	23-25	20.7	38.4	40.9	C
B2T50	0-2	33.9	50.9	15.2	SiL
	5-7	30.2	44.4	25.4	L
	11-13	25.7	43.5	30.8	CL
	23-25	22.2	41.2	36.6	CL
B2T100	0-2	32.4	48.3	19.3	L
	5-7	30.6	44.9	24.5	L
	11-13	24.8	39.8	35.4	CL
	23-25	21.6	37.6	40.8	C
B3T25	0-2	28.3	51.5	20.2	SiL
	5-7	26.8	49.6	23.6	L
	11-13	25.2	45.1	29.7	CL
	23-25	21.9	44.5	33.6	CL
B3T50	0-2	34.1	51.7	14.2	SiL
	5-7	27.0	47.9	25.1	L
	11-13	26.8	45.7	27.5	CL
	23-25	24.4	40.2	35.4	CL
B3T100	0-2	31.7	39.5	28.8	CL
	5-7	19.3	43.6	37.1	SiCL
	11-13	16.6	40.3	43.1	SiC
	23-25	13.3	41.6	45.1	SiC

APPENDIX C

SOIL WATER DEFICITS IN THE 0-1 FOOT DEPTH INTERVAL

	Treatment		
Date	BA25	BA50	BA100
	inches		
5/09/84	0.01a	0.10a	0.13a
5/31/84	0.13a	0.18a	0.32b
6/14/84	0.79a	0.75a	1.16b
7/18/84	1.09a	1.01a	1.65b
8/02/84	1.68ab	1.62a	1.98b
8/15/84	0.61a	0.66a	1.01b
8/30/84	1.37a	1.43a	1.98b
9/13/84	1.05a	1.02a	1.41b
10/11/84	0.20a	0.18a	0.54b
11/13/84	0.24a	0.26a	0.25a
5/16/85	0.26a	0.30a	0.31a
5/29/85	0.02a	0.06a	0.09a
6/17/85	0.58ab	0.52a	0.68b
7/01/85	1.25ab	1.14a	1.44b
7/15/85	1.50a	1.37a	1.65a
8/01/85	1.56ab	1.42a	1.75b
8/13/85	1.96a	1.82a	2.04a
8/30/85	2.11a	2.04a	2.15a
9/16/85	1.45a	1.54a	1.50a
10/07/85	1.85a	1.77a	2.04b
11/06/85	0.76a	0.81a	1.09b

Means within rows followed by the same letter are not significantly different at the 0.05 level.

APPENDIX D

SOIL WATER DEFICITS IN THE 1-2 FOOT DEPTH INTERVAL

	Treatment		
Date	BA25	BA50	BA100
	------------inches------------		
5/09/84	-0.06a	-0.05a	-0.05a
5/31/84	0.00a	0.00a	0.17b
6/14/84	0.34a	0.36a	0.53b
7/18/84	0.68a	0.75a	1.11b
8/02/84	1.01a	1.05a	1.39a
8/15/84	0.67a	0.91ab	1.18b
8/30/84	0.94a	1.14a	1.51b
9/13/84	0.94a	1.22ab	1.46b
10/11/84	0.29a	0.31a	1.01b
11/13/84	0.10a	0.15a	0.14a
5/16/85	0.17a	0.22a	0.20a
5/29/85	-0.01a	0.01a	0.09a
6/17/85	0.28a	0.24a	0.32a
7/01/85	0.70a	0.66a	0.77a
7/15/85	0.96a	0.90a	1.10a
8/01/85	1.13a	1.15a	1.33a
8/13/85	1.30a	1.29a	1.57a
8/30/85	1.48a	1.43a	1.68a
9/16/85	1.38a	1.48a	1.57a
10/07/85	1.49a	1.52a	1.70a
11/06/85	1.29a	1.37a	1.34a

Means within rows followed by the same letter are not significantly different at the 0.05 level.

APPENDIX E

SOIL WATER DEFICITS IN THE 2-3 FOOT DEPTH INTERVAL

Date	Treatment BA25	 BA50	 BA100
	------------	inches	------------
5/09/84	-0.01a	-0.07b	-0.04ab
5/31/84	0.02a	0.01a	0.24b
6/14/84	0.17a	0.31ab	0.39b
7/18/84	0.52a	0.73b	0.98c
8/02/84	0.67a	0.89a	1.30b
8/15/84	0.71a	0.97b	1.27c
8/30/84	0.80a	1.04b	1.47c
9/13/84	0.89a	1.10a	1.49b
10/11/84	0.68a	0.97a	1.34b
11/13/84	0.13a	0.13a	0.11a
5/16/85	0.14a	0.22a	0.11a
5/29/85	0.04a	0.05a	0.15b
6/17/85	0.23a	0.29a	0.31a
7/01/85	0.53a	0.64a	0.65a
7/15/85	0.75a	0.81a	0.92a
8/01/85	0.93a	1.03a	1.24b
8/13/85	1.06a	1.14a	1.48b
8/30/85	1.23a	1.25a	1.59b
9/16/85	1.28a	1.33a	1.58b
10/07/85	1.33a	1.38a	1.66b
11/06/85	1.36a	1.39a	1.54a

Means within rows followed by the same letter are not significantly different at the 0.05 level.

APPENDIX F

SOIL WATER DEFICITS IN THE 3-4 FOOT DEPTH INTERVAL

Date	Treatment		
	BA25	BA50	BA100
	inches		
5/09/84	-0.01a	-0.04a	0.02a
5/31/84	-0.01a	0.03a	0.25b
6/14/84	0.07a	0.24b	0.28b
7/18/84	0.35a	0.61b	0.78c
8/02/84	0.47a	0.72a	1.08b
8/15/84	0.53a	0.84b	1.18c
8/30/84	0.59a	0.87b	1.25c
9/13/84	0.66a	0.92b	1.34c
10/11/84	0.63a	0.88b	1.30c
11/13/84	0.09a	0.10a	0.12a
5/16/85	0.04a	0.13a	0.09a
5/29/85	0.02a	0.09ab	0.15b
6/17/85	0.10a	0.23a	0.27a
7/01/85	0.29a	0.52b	0.52b
7/15/85	0.38a	0.65b	0.72b
8/01/85	0.60a	0.85b	1.08c
8/13/85	0.68a	0.90b	1.30c
8/30/85	0.85a	1.04a	1.43b
9/16/85	0.95a	1.07a	1.46b
10/07/85	1.02a	1.13a	1.46b
11/06/85	1.00a	1.14a	1.49a

Means within rows followed by the same letter are not significantly different at the 0.05 level.

VITA

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Candidate for the Degree of

Master of Science

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