

EFFECT OF WIND AND WIND PROTECTION ON THE
EARLY GROWTH RESPONSE OF BLACK
WALNUT (*JUGLANS NIGRA*)

Thesis for the Degree of Ph. D.
MICHIGAN STATE UNIVERSITY
RANDALL BRUCE HEILIGMANN
1971



This is to certify that the
thesis entitled
Effect of Wind and Wind Protection
on the Early Growth Response of
Black Walnut (Juglans Nigra)

presented by
Randall Bruce Heiligmann

has been accepted towards fulfillment
of the requirements for
Ph.D. degree in Forestry

G. Schneider
Major professor

Date May 20, 1971

MAR 22 1973

APR

1973

ABSTRACT

EFFECT OF WIND AND WIND PROTECTION ON THE EARLY GROWTH RESPONSE OF BLACK WALNUT (JUGLANS NIGRA)

By

Randall Bruce Heiligmann

This study examined the growth response of black walnut to (1) the influence of wind barriers on field planted seedlings, and (2) the effects of a controlled environment where wind velocity approximates that to which field-grown black walnut seedlings are normally exposed.

The influence of wind barriers on 18-week-old black walnut seedlings was examined by comparing the growth response and microenvironment of seedlings growing on the leeward side of wooden lath wind barriers with that of seedlings growing in adjacent unprotected areas. Wind, solar radiation, air temperature, relative humidity, soil temperature, and soil moisture were monitored. Seedling stem height and diameter were periodically measured throughout the growing season. The study was concluded with determination of total leaf area, oven-dry weight of stem, foliage, and root, and depth of root penetration. Xylem sap tensions were measured with a

pressure bomb to evaluate wind barrier effects on seedling internal water status.

Wind barriers significantly affected wind velocity, solar radiation, and air temperature. Compared to the exposed plots, the protected plots had reductions in wind velocities and solar radiation of 67 percent and 18 percent, respectively. Maximum and minimum air temperatures averaged 2.9°C and 1.6°C higher, respectively, in the protected plots. Differences between the exposed and protected plots in the amount of solar radiation received and in air temperature were closely associated with the degree of cloudiness.

The wind barriers significantly increased the size of the black walnut seedlings in all growth parameters measured except depth of root penetration. Leaf senescence began on seedlings growing in the exposed plots by mid-August while those in the protected plots showed little evidence of senescence by mid-September. No significant difference was found in xylem sap tension of seedlings in the protected and exposed plots.

The effects of wind under controlled environmental conditions were studied by examining the growth responses of germinating black walnut seedlings for 80 days under two wind velocities (<0.1 m/sec and 2.8 m/sec) and two soil moisture regimes (0.2 atm to 0.75 atm soil water suction and 0.20 atm to 7 atm soil water suction).

Stem diameter, stem height, and leaf area of each seedling were measured over the study period. The oven-dry weights of the seedlings' leaves, stems, and roots were determined at the conclusion of the study. Transpiration rates and average stomatal aperture were determined during the last 20 days of the study for each seedling at 0.20 atm, 0.75 atm, and 7 atm soil water suction after exposure to its corresponding wind treatment.

Exposure to the higher wind velocity had no significant effect on seedling stem height and diameter or number of leaflets but did significantly reduce all other growth parameters measured. There was no significant difference between the root/shoot ratio in the two wind treatments. The low soil moisture regime resulted in significant decreases in both the observed growth parameters and the root/shoot weight ratio.

Exposure to the higher wind velocity significantly increased the average transpiration rate at all soil moisture levels by an average of 50 percent but had no significant effect on the stomatal aperture. The transpiration rates and stomatal apertures at 0.02 atm and 0.75 atm were not significantly different. However, at 7 atm soil water suction the transpiration rate was 70 percent less than that at either 0.20 atm or 0.75 atm soil water suction and the average stomatal aperture was significantly smaller.

EFFECT OF WIND AND WIND PROTECTION ON THE
EARLY GROWTH RESPONSE OF BLACK
WALNUT (JUGLANS NIGRA)

By

Randall Bruce Heiligmann

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Forestry

1971

ACKNOWLEDGMENTS

The author wishes to express his gratitude to Dr. G. Schneider, chairman of his guidance committee, for his indispensable guidance and assistance throughout the course of this study and in the preparation of this manuscript. Appreciation is also extended to the other members of the guidance committee, Dr. J. Hanover, Dr. R. Kunze, and Dr. D. P. White.

The author is indebted to Mr. R. Heninger for his assistance in the collection of data, to Dr. W. Tai, Department of Botany, Michigan State University, for the microphotograph used in this manuscript, and to Dr. C. Cress, Department of Crops and Soil Science, Michigan State University, for his consultation on the statistical aspects of this study.

Finally, the author will be forever grateful to his wife, Lynne, for her constant encouragement and assistance throughout all phases of this study.

TABLE OF CONTENTS

	Page
ACKNOWLEDGMENTS.	ii
LIST OF TABLES	iv
LIST OF FIGURES.	vi
VITA	viii
 Chapter	
I. INTRODUCTION	1
II. THE EFFECTS OF WIND BARRIERS ON THE GROWTH OF FIRST-YEAR BLACK WALNUT	4
Introduction.	4
Methods	7
Results and Discussion of Micrometeoro- logical Factors.	23
Results and Discussion of Plant Measurements.	33
III. CONTROLLED ENVIRONMENTAL STUDY OF THE EFFECTS OF A MODERATE WIND VELOCITY ON FIRST-YEAR BLACK WALNUT SEEDLINGS	50
Introduction.	50
Methods	52
Results and Discussion	65
IV. SUMMARY AND CONCLUSIONS	88
LITERATURE CITED	96
APPENDIX	102

LIST OF TABLES

Table	Page
1. Physical and chemical characteristics of representative soil on research plots . . .	9
2. Meteorological conditions at Michigan State University tree research center during the 1970 growing season	10
3. Wind barrier effectiveness in reducing wind velocity.	24
4. Growth responses of 18-week-old black walnut seedlings in exposed and protected field plots.	35
5. Periodic height growth of black walnut seedlings in exposed and protected field plots .	39
6. Periodic diameter growth of black walnut seedlings in exposed and protected field plots.	41
7. Daily pattern of xylem sap tension of first-year black walnut seedlings in exposed and protected plots on September 2, 1970 . . .	46
8. Average xylem sap tension of black walnut seedlings on protected and exposed plots between 12:00 noon and 4:00 p.m. on September 2, 9, 10, and 11, 1970	47
9. Soil water distribution in containers at different soil moisture contents for 5 and 10-week-old black walnut seedlings	62
10. Growth response of 80-day-old black walnut in two wind velocities and two soil moisture regimes	68
11. Average transpiration rate of black walnut seedlings during 11 hour wind period at 12, 8, and 4 percent soil moisture content. . .	85

Table		Page
12.	Relative stomatal aperture of black walnut seedlings after 11 hours of wind at 12, 8, and 4 percent soil moisture content. . . .	85
13.	Comparative growth response of 18-week-old black walnut in exposed and protected field plots.	91
14.	Comparative growth response of 80-day-old black walnut in two wind velocities and two soil moisture regimes	94
15.	Foliar nutrient analysis of 18-week-old black walnut in field study	103
16.	Foliar nutrient analysis of 80-day-old black walnut in controlled environment study.	103
17.	Periodic average stem height of black walnut seedlings in controlled environment study. .	104
18.	Periodic average stem diameter at 1 cm height of black walnut seedlings in controlled environment study	104
19.	Periodic average leaf area of black walnut seedlings in controlled environment study. .	105
20.	Periodic average leaflet length of black walnut seedlings in controlled environment study.	105
21.	Periodic average leaflet width of black walnut seedlings in controlled environment study.	106
22.	Periodic average number of leaflets of black walnut seedlings in controlled environment study.	106

LIST OF FIGURES

Figure	Page
1. Field design examining the effects of wind protection on growth of black walnut seedlings: (A) plot design and (B) one field replication.	12
2. Pressure bomb used to determine xylem sap tensions of black walnut seedlings	17
3. Root excavation showing (A) trenching and (B) removal of root systems from the soil with water spray	21
4. Weekly averages of daily solar radiation in exposed and protected plots	24
5. Solar radiation received in exposed and protected plots on August 2, a clear day	26
6. Solar radiation received in exposed and protected plots on July 23, an overcast day . . .	26
7. Air temperature in exposed and protected plots on August 2, a clear day	28
8. Air temperature in exposed and protected plots on July 23, an overcast day	28
9. Weekly average maximum and minimum air temperatures in exposed and protected plots . .	31
10. Weekly average relative humidities in exposed and protected plots	31
11. Weekly average temperature of upper 15 cm of soil in exposed and protected plots. . . .	34
12. Weekly average moisture content (% by weight) of the upper 15 cm of soil in exposed and protected plots	34
13. Shoot development of 18-week-old black walnut in (A) protected plot and (B) exposed plot . .	36

Figure		Page
14.	Stem and root development of 18-week-old black walnut in (A) exposed plot and (B) protected plot.	42
15.	View of tunnels used to examine the effects of wind on black walnut seedlings: (A) low wind velocity tunnel and (B and C) side and end of high wind velocity tunnel.	53
16.	Soil moisture characteristic curve for composite samples of A _p and A ₂₁ horizons of Metea sandy loam soil	56
17.	Watering with hypodermic syringe to obtain uniform soil moisture distribution	60
18.	Microphotograph of cellulose acetate positive of lower leaf surface of black walnut seedling with stomatal apertures classified as 1 (bottom center), 2 (middle left), and 3 (upper right)	66
19.	Shoot development of 80-day-old black walnut in (A) low wind, high soil moisture regime, (B) low wind, low soil moisture regime, (C) high wind, high soil moisture regime, and (D) high wind, low soil moisture regime	69
20.	Stem and root development of 80-day-old black walnut in (A) low wind, high soil moisture regime, (B) low wind, low soil moisture regime, (C) high wind, high soil moisture regime, and (D) high wind, low soil moisture regime	71
21.	Stem height and diameter growth of black walnut seedlings in two wind velocities and two soil moisture regimes	74
22.	Foliar development of black walnut seedlings in two wind velocities and two soil moisture regimes	77

VITA

Randall Bruce Heiligmann

Candidate for the Degree of
Doctor of Philosophy

Final Examination: May 20, 1971

Guidance Committee:

Dr. G. Schneider (Chairman), Department of Forestry
Dr. J. Hanover, Department of Forestry
Dr. R. Kunze, Department of Crops and Soil Science
Dr. D. P. White, Department of Forestry

Dissertation: Effect of Wind and Wind Protection on the
Early Growth Response of Black Walnut (Juglans
Nigra)

Biographical Items:

Born December 14, 1942, Philadelphia, Pennsylvania
Married

Education:

Ohio State University, B.S., 1965
Michigan State University, M.S., 1968
Michigan State University, Ph.D., 1971

Professional Experience:

September, 1966 - March, 1971
Graduate Research Assistant, Department of
Forestry, Michigan State University
Summer, 1967
Forest Technician, Dunbar Experimental Forest,
Department of Forestry, Michigan State Uni-
versity
January - August, 1966
Graduate Research Assistant, Natural Resource
Institute, Ohio State University

Organizations:

Phi Kappa Phi
Sigma Xi
Xi Sigma Pi
Society of American Foresters
The American Forestry Association

CHAPTER I

INTRODUCTION

Black walnut, Juglans nigra, is a tree species native to most of the eastern United States. It occurs primarily as scattered individuals or small groups of trees throughout the mixed mesophytic forests (Fowells, 1965). About 87 percent of its total growing stock is located in the 10 states of Missouri, Kentucky, Ohio, West Virginia, Indiana, Tennessee, Virginia, Kansas, and Illinois (Quigley and Lindmark, 1966).

Because of its many desirable wood characteristics, the lumber and veneer of black walnut are in very high demand for furniture, paneling, gunstocks, and other products in both domestic and foreign markets. This demand has increased rapidly from an annual cut of approximately 62 million board feet in 1948 to about 97 million board feet in the mid-1960's. This is in contrast with an estimated annual growth of 132 million board feet in the mid-1960's. Approximately one-third of this annual cut, 31 million board feet in the mid-1960's is of veneer quality material, while the estimated annual growth of veneer quality material is 25 million board feet. It would appear that the rate of removal of

veneer quality walnut is currently exceeding its rates of growth and natural regeneration (Quigley and Lindmark, 1966; Randall, 1967).

Cliff (1966) suggested a twofold solution to this problem. First, accelerate the growth rate of existing walnut trees so as to reduce the time necessary to produce the size and quality required for market. Second, develop fast growing plantations that supplement the naturally regenerated walnut stock. To successfully establish and obtain maximum plant productivity will require the use of the best suited genetic material for the site and the development of intensive cultural techniques and management plans. The development of these techniques is based on a thorough understanding of just how black walnut responds to both the different environmental factors and the techniques used to modify them.

The effects of wind on tree growth have received relatively little attention in forestry. However, the experimental manipulation of wind velocities has led to dramatic increases in crop yields. Several studies have suggested that wind may be an important factor in the establishment and early development of black walnut (Khattak, 1968; Schneider et al., 1970).

This study was designed to examine the growth response of black walnut to (1) the influence of wind barriers on field planted seedlings and (2) the effects

of a controlled environment where wind velocity approximates that to which field grown black walnut seedlings are normally exposed.

CHAPTER II

THE EFFECTS OF WIND BARRIERS ON THE GROWTH OF FIRST-YEAR BLACK WALNUT

Introduction

Wind barriers of various designs and compositions have long been an important tool in the production of farm and horticultural crops. In the Great Plains regions of the United States where high velocity winds are frequent, shelterbelts of one or more rows of trees are commonly used to protect crops from the effects of wind (Read, 1964; Stoeckeler, 1962).

Read (1964) presents brief summaries of much of the research that has been done on the effects of these shelterbelts on plant growth indicating that the yields of a wide variety of crops are increased by being planted to the lee side of or between them.*

Similar shelterbelts have also been recommended in coastal regions to protect crops from land and sea winds. Metcalf (1936) reported that California lemon trees

*Crops whose yield has been shown to increase by being planted to the lee of or between shelterbelts include: alfalfa, apples, barley, beans, beets, cabbage, carrots, citrus, clover, corn, cotton, crabapples, cucumbers, flax, grass, oats, peas, potatoes, rice, rye, soybeans, strawberries, sugar beets, timothy, tobacco, tomatoes, and wheat.

protected from such winds by windbreaks were twice as large and bore five times as much fruit as those growing unprotected. As pointed out by both Read (1964) and Stoeckeler (1962), however, shelterbelts not only alter wind movement but have been reported to variously affect air and soil temperature, atmospheric humidity, soil moisture, snow distribution, and, over long periods of time, the physical and chemical properties of the soil.

The effects of small artificial wind barriers on crop growth and yield have been examined to a limited extent. Hogg (1965b) reported on two such experiments. In the first, plots were surrounded by 3-foot high screens composed of straw bales, wooden lath, or wire netting. The growth and/or yield of beans, potatoes, anemones, and tulips was increased over those grown in a surrounding area. In the second, the yield of lettuce was significantly greater when grown between barriers at four times the height spacing than between barriers at eight times the height spacing.

Winter (1965) examined the effects of "Manx-leg" shelters* on the growth of lettuce and cabbage. These one-foot high shelters were composed of woven one-inch strips of fiberglass and were 50 percent permeable. The

*"Manx-leg" shelters are wind barriers composed of three legs emanating from a central point, as the spokes of a wheel, with 120 degrees between the legs.

results of this experiment indicated that the plants in all sectors of the shelter were largest toward the center of the shelter where wind protection was greatest. Those plants in the sector most protected from the prevailing wind were the largest. Metcalf (1936) reported that lattice windbreaks provided suitable protection for young lemon trees but were less desirable than windbreaks composed of trees because of their high cost and tendency to damage in high winds.

Only a few studies have examined the effects of wind modification on forest tree growth. Rennie (1956) studied the establishment of Sitka spruce (Picea sitchensis) and sessile oak (Quercus petraea) on the Calluna moors of the British Isles. He observed less dieback and tree mortality where some wind protection was provided. This occurred in plowed strips in the natural vegetation or on the lee side of furrows rather than in trees planted on flat plowed ground. However, no micro-meteorological measurements were made during the study and some question remains as to whether the observed mortality and dieback might not have been caused by wind-borne ocean salt spray.

Fourt (1968) studied the effects of side shelters on Sitka spruce (Picea sitchensis) seedlings. The height but not the diameter growth of the seedlings progressively increased with increasing density of the shelters. He

attributed the reduced growth of the less protected seedlings to higher transpiration stress caused by the wind.

Two recent studies indicate that wind and its modification may be important in the establishment and early growth of black walnut. Schneider et al. (1970) reported that the growth of black walnut transplants was significantly greater in forest openings than in nearby open fields. They suggested that the probable cause of this was reduced air movement and modified air temperature conditions in the forest openings. Khattak (1968) examined the effects of wooden lath wind barriers on the shoot growth of black walnut transplants. He reported that by the middle of the second year after transplanting the shoot growth of the seedlings grown on the lee side of the barriers was significantly greater than that of the unprotected seedlings.

To further examine the effects of wind barriers on black walnut seedlings, this portion of the study was designed to (1) evaluate the effects of wooden lath wind barriers on the growth of first-year black walnut seedlings grown from seed and (2) characterize the effects of the wind barriers on the seedling's micro-environment.

Methods

The study was carried out at the Michigan State University Tree Research Center located in East Lansing, Michigan.

The soil at the study area, Metea sandy loam, is a well-drained Gray-Brown Podzol developed from sand or loamy sand material lying over material derived from loam or clay loam till (Table 1) (Anonymous, 1961). The thickness and structure of the soil horizons are extremely variable.

General meteorological information was collected from May to September, 1971 at a weather station located within 300 meters of the study plots (Table 2). Instrumentation included mercury-in-glass maximum-minimum thermometers, standard and recording precipitation gauges, and a standard evaporation pan. A comparison of this information with the past weather records from the Tree Research Center and the East Lansing, Michigan weather station indicates that the observed meteorological conditions during this period were not unusual for the area with the exception of precipitation. A total of 55.1 cm of rain fell during the study period. This is 46 percent more than the 37.8 cm average (Eaten and Eichmeier, 1951).

Experimental Design

The growth response of one-year-old black walnut in the presence of a wind barrier was evaluated using a randomized complete-block design with three replications. Each replication consisted of a protected plot of

TABLE 1.--Physical and chemical characteristics of representative soil on research plots.

Horizon	Thickness of Horizon -----cm-----	Texture	Structure	pH	Organic Matter (Loss on Ignition) -----%	P -----ppm	K -----ppm	Ca -----ppm	Mg -----ppm
Ap A21	15-40	sandy loam	granular	5.4	2.6	2	25	183	22
A ₂₂ -B ₁	35-60	sandy loam	weak subangular blocky	6.4	1.0	5	20	277	22
IIB ₂	25-50	clay loam	moderate-strong subangular blocky	6.3	---	3	48	1220	152

TABLE 2.--Meteorological conditions at Michigan State University tree research center during the 1970 growing season.

Month	Average Daily Air Temperature		Average Daily Solar Radiation (langleys)	Precipitation	Evaporation	Wind
	Maximum	Minimum		-----cm-----		km/day
May (15-31)	22.0 (28.9) ^a	10.6 (1.6) ^b	---	4.3	7.6	141.1
June	25.2 (31.6)	12.5 (2.8)	486	19.3	16.4	110.2
July	27.0 (33.4)	16.4 (8.4)	442	19.2	17.5	103.3
August	27.6 (31.6)	14.0 (8.4)	426	5.1	16.5	76.8
September (1-19)	23.6 (29.4)	11.4 (3.9)	504 ^c	7.2	6.5	105.0

^aMaximum temperature recorded in parentheses.

^bMinimum temperature recorded in parentheses.

^cObservation period September 1 to September 12.

thirty-six walnut trees planted in a row on the east side of a north-south oriented wind barrier and a paired exposed plot of thirty-six trees planted in a row in an adjacent exposed area (Figure 1).

Each L-shaped wind barrier consisted of a twenty-five meter long section oriented north-south and a 2.5 meter section extending eastward from the southern end of the north-south section. Each portion of the wind barrier was composed of three thicknesses of 1.2 meter high wooden lath snowfence. To the west of the north-south axis to a distance of 7.5 meters were six rows of small trees and a second row of three thicknesses of snowfence.

Seed

Black walnut seeds were collected in the Fall of 1969 from two trees in Cass County, Michigan. The seeds were immediately husked, cleaned, placed in string bags, and buried two feet below ground level. On April 27, 1970 the seeds were lifted, placed in wooden flats, and covered with three to four inches of soil. The flats remained out-of-doors and were kept moist until May 15. At that time seeds with radicles beginning to emerge were selected for planting.

Figure 1.--Field design examining the effects of wind protection on growth of black walnut seedlings: (A) plot design and (B) one field replication.



..... Trees
 ——— Snowfence Windbarrier

A

N →



B

Establishment

Germinating seeds were planted in three replications on May 16, 1970. The 36 trees behind the wind barrier were planted 61 cm apart in a row 61 cm to the east of the barrier. The trees in the exposed plot were planted 61 cm apart in a row directly in line with the trees behind the wind barrier (Figure 1). To facilitate planting and encourage early root development, the planting site was prepared by rototilling along the planting row to a depth of 12.5 cm. The seeds were planted at a depth of 3 to 5 cm, with the radicle tips pointing downward. Each seed received four gallons of water after planting. A second watering, equivalent to 2.5 cm of water, was applied to the soil surface by aerial irrigation on May 20.

A weed-free strip of 30 cm was maintained around each seedling throughout the growing season by hand weeding and monthly application of Amitrol-T (31 ml per liter of water). The surrounding area was kept closely mowed to prevent vegetation from interfering with wind movement.

On June 19 and August 13 the trees were sprayed with a mixture of 31 ml of Sevin and 8 ml of malathion per liter of water to protect them from defoliating insects.

Micrometeorological Measurements

Wind.--The effect of the wind barriers on wind velocity was determined by calibrating the barriers using pairs of 3-cup anemometers and rate meters. Anemometers were placed at 6.2, 12.5, and 18.8 meters from the end of each wind barrier while others were placed in comparable positions in the adjacent exposed plots. The anemometers were placed within the plant rows at a mid-cup height of 30 cm. Wind velocities were recorded simultaneously on the exposed plot and behind the barrier. Fifty readings were taken at each location at 30-second intervals at different periods of time throughout the summer.

Solar radiation.--Solar radiation was monitored with two pyrheliographs located in Replicate 2. One pyrheliograph sensor, at a height of 20 cm, was located 6.2 meters from the northern end of the wind barrier and the other in a comparable position in the adjacent exposed plot.

Air temperature--relative humidity.--Daily maximum-minimum temperatures were obtained from shielded mercury-in-glass maximum-minimum thermometers placed 18 cm above the soil surface at the center of each plot. A recording of daily temperatures and relative humidity

was also obtained on the exposed plot and behind the barrier from two hygrothermographs located in Replicate 1 and positioned within the rows in the same manner as the pyrliographs in Replicate 2.

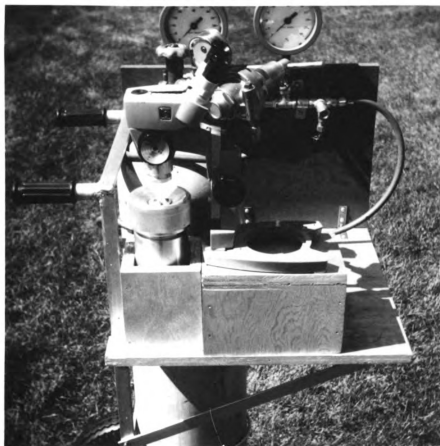
Soil temperature--soil moisture.--Daily temperatures and weekly moisture measurements were made for the upper 15 cm of soil between 8 and 10 a.m. Soil temperature was obtained from shielded mercury-in-glass thermometers inserted in the soil at the center of each plot. Soil moisture measurements were gravimetrically determined by obtaining a core sample from a randomly selected location in each plot.

Plant Measurements

Xylem sap tension.--Trees were randomly selected from each plot between 6:00 a.m. and 8:00 p.m. for xylem sap tension determinations with a pressure bomb on September 2, 9, 10, and 11 (Figure 2) (Scholander, et al., 1965; Waring and Cleary, 1967). Depending upon the magnitude of the xylem tensions, from 30 to 90 minutes were required to measure such internal water stresses for all replications.

Each tree was sampled by selecting a healthy compound leaf in the upper third of the crown and removing the distal 3 leaflets by cutting the rachis immediately

Figure 2.--Pressure bomb used to determine xylem sap tensions of black walnut seedlings.



above the fourth and fifth leaflets with a sharp razor blade. This portion of the leaf was placed in the pressure bomb with the rachis extending through the compression membrane and out the top of the bomb approximately 3 mm. The gas pressure in the bomb was then gradually increased 5 psi every 10 seconds until xylem sap first appeared at the cut surface of the rachis. The best estimate of xylem sap tension was interpreted as the pressure in the chamber when xylem sap first appeared at the cut surface of the rachis minus 2.5 psi.

When each tree was sampled for xylem sap tension, concurrent observations were made of air temperature, wind velocity, and relative humidity. Soil moisture content was determined on September 2 and September 10 and total daily solar radiation was determined for all four days.

Plant growth.--The total height and stem diameter at 2.5 cm above the ground were determined for all trees every 2 to 3 weeks during the study. Height was measured to the nearest millimeter with a metric ruler and diameter to the nearest 0.25 mm using a micrometer.

At the termination of the study, September 15 to 22, the following measurements were taken:

On all trees

1. Total height above ground (cm)
2. Total height above root collar (cm)

3. Diameter 2.5 cm above ground (cm)
4. Oven-dry weight of stem (g)
5. Oven-dry weight of foliage (g)

On a subsample of 9 trees randomly selected from each plot

1. Length and width of each leaflet on the tree (cm)
2. Depth of root penetration (cm)
3. Oven-dry weight of root (g)

Oven-dry weights were determined after plant material had been dried to a constant weight of 70°C. Foliar nutrient analyses of the seedlings in the protected and exposed plots were obtained at this time (Table 15).

The total leaf area of each of the 54 trees in the subsample was determined by solving the following regression equation ($R^2 = .99$) for each leaflet and summing the values obtained for all the leaflets on the tree:

$$\text{Leaflet Area} = .105 + .663 [\text{leaflet length (cm)}] [\text{leaflet width (cm)}]$$

Information on the root systems of the trees in the subsample was obtained by excavating the root systems. This was accomplished by first digging a trench 2 meters deep and 1 meter to the side of each row of trees and then removing the root systems by washing away the soil with water under pressure (Figure 3).

Figure 3.--Root excavation showing (A) trenching and (B) removal of root systems from the soil with water spray.

**B****A**

Results and Discussion of Micro-
meteorological Factors

Wind

The average velocity of prevailing winds at mid-crown height (25-30 cm) in the protected plots was 33 percent of that in the exposed plots (Table 3). Approximately 75 percent of this reduction in wind velocity by the barriers was attributable to the 3 layers of snowfence, 61 cm to the west of the plant row (Khattak, 1968).

Variations in the effectiveness of the barriers in reducing wind velocity were undoubtedly due to variations in the permeability* of the wind barrier. Some additional variation may have been introduced during calibration because of differences in the velocities of winds blowing against the barriers and in the exposed plots.

Wind reduction by the barrier appeared to apply uniformly to all winds less than 16 km/hour, the maximum wind velocity observed during the calibration period. Similar observations have been reported for wooden lath wind barriers by Gloyne (1965) and for moderately impermeable natural windbreaks by Read (1964).

*Permeability is the ratio of air space in a barrier to its total surface area (Hogg, 1965a).

TABLE 3.--Wind barrier effectiveness in reducing wind velocity.

Barrier	Relative Wind (%)*
Rep 1	31.5
Rep 2	27.5
Rep 3	38.9

*Relative Wind = $\frac{\text{Wind at sheltered site}}{\text{Unobstructed wind}} \times 100$ (Hogg, 1965a)

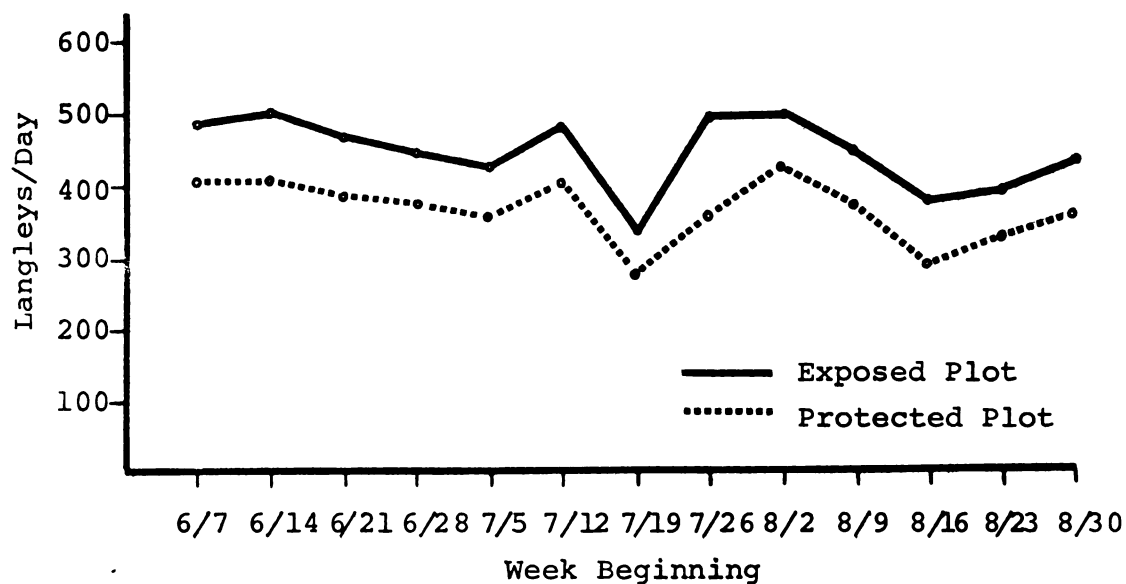


Figure 4.--Weekly averages of daily solar radiation in exposed and protected plots.

Solar Radiation

The average daily solar radiation received by the trees growing behind the wind barrier was 82 percent of that received by the trees growing in the exposed plot (Figure 4). Observations in a comparable position behind north-south shelterbelts near Vienna by Dirmhirn (1953) indicated reduced insolation of 72 to 84 percent. Reduction in solar radiation by the barrier on a given day, however, varied between 0 and 30 percent and appears related to conditions of cloud cover.

The reduction in the amount of solar radiation received by the trees behind the barrier was greatest on clear days when direct radiation was the larger proportion of total solar radiation. By shading the protected plot, the barrier intercepted much of the direct solar radiation when the sun was in the western sky. This is well illustrated in the pyrliographs recorded on August 2 (Figure 5). The trees growing in the protected plot received approximately 473 langleys of solar radiation while those growing in the exposed plot received 591 langleys. The abrupt drop in solar radiation behind the barrier occurred between 2:00 and 3:00 p.m.

On overcast days, however, direct radiation makes up a smaller proportion of the total solar radiation than it does on clear days. On overcast days barrier interception of radiation from the western aspect was less

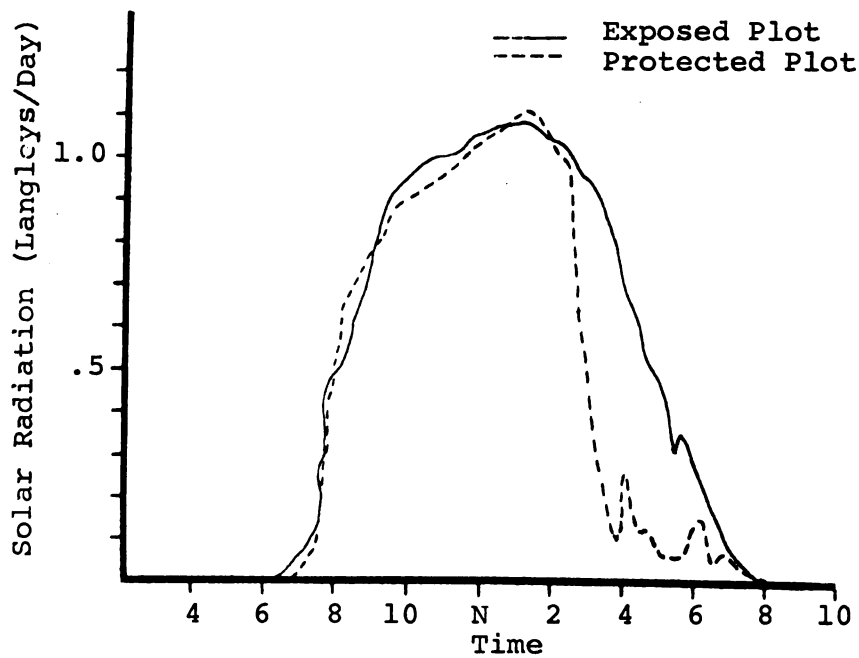


Figure 5.--Solar radiation received in exposed and protected plots on August 2, a clear day.

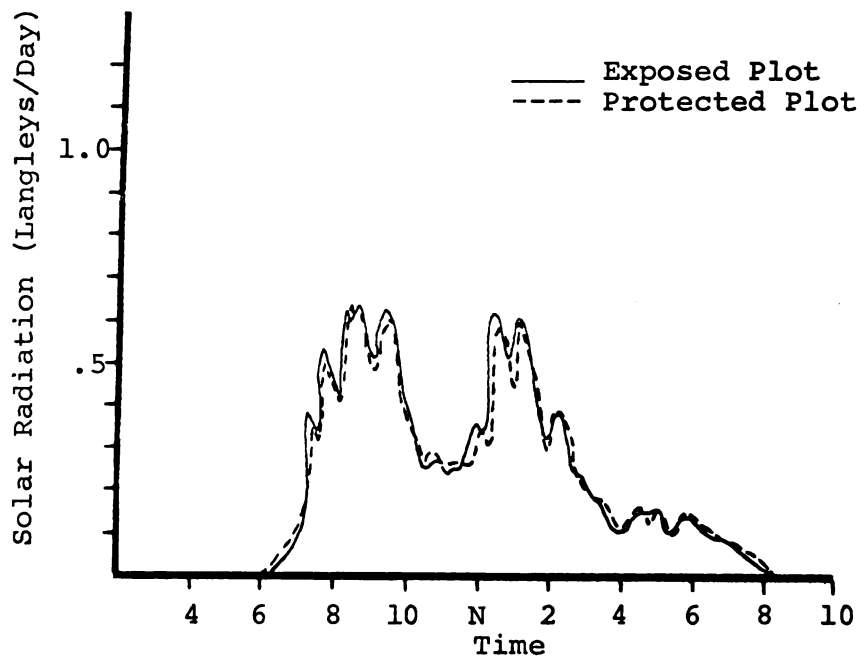


Figure 6.--Solar radiation received in exposed and protected plots on July 23, an overcast day.

effective in reducing the total solar radiation received by the trees in the protected plot than on clear days. Although diffuse radiation from the western direction was blocked by the barrier, this was apparently compensated for by diffuse radiation from the eastern sky striking the barrier and its subsequent reflection to the plot. This type of day was recorded by the pyrlieliograph on July 23 (Figure 6). Both exposed and protected plots received approximately 276 langleys of solar radiation.

Consequently on any particular day the percent of the total solar radiation received by the plants behind the wind barrier appears dependent on the amount of cloud cover during the afternoon of that day. The more clear the afternoon sky, the less the percentage of total solar radiation received by the trees behind the barriers. Similar observations have been made by Geiger (1966) in considering the local climate at the different edges of a forest stand. He notes that "the greater the proportion of diffuse radiation to direct sunshine, . . . as in cloudy weather . . . the less will be the difference between different edges."

Air Temperature

Typical temperature patterns for days of high and low solar radiation are shown in Figures 7 and 8. Two differences are apparent. First, air temperatures on cloudless days are considerably higher behind the barrier

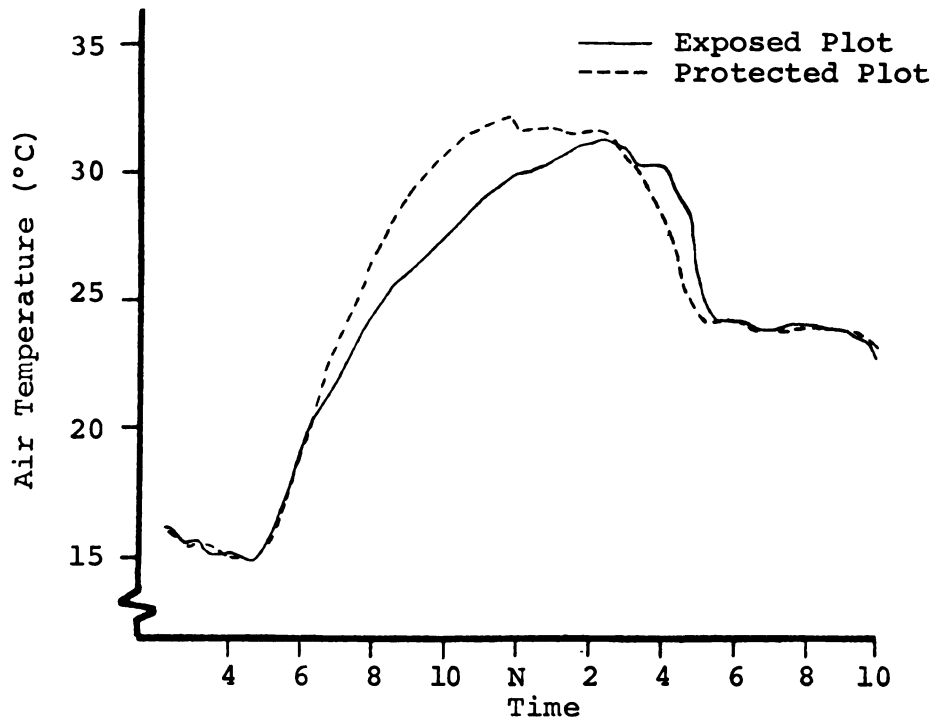


Figure 7.--Air temperature in exposed and protected plots on August 2, a clear day.

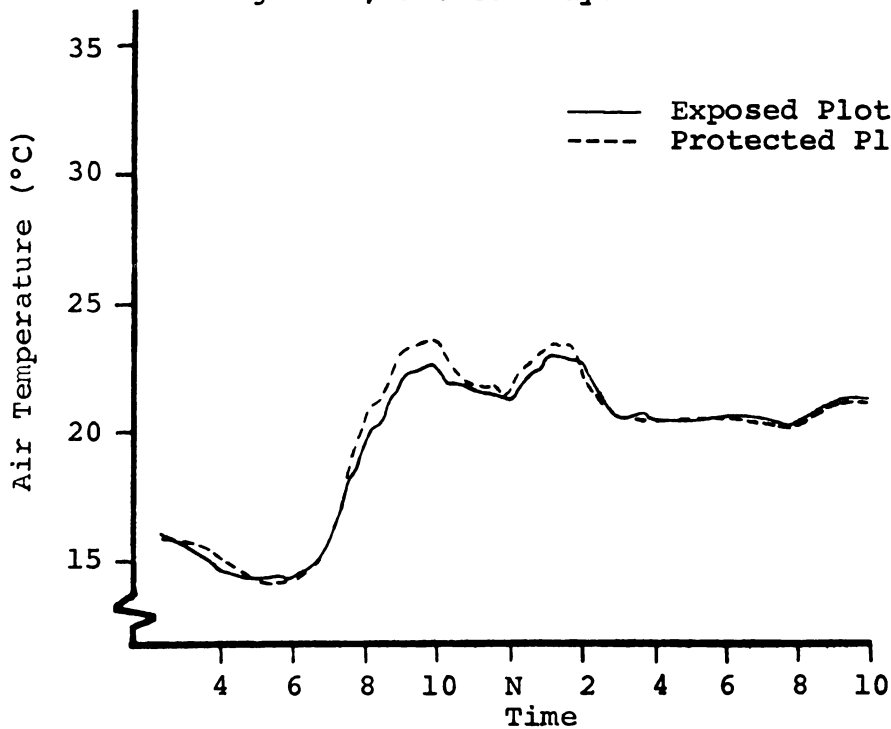


Figure 8.--Air temperature in exposed and protected plots on July 23, an overcast day.

than those in the exposed plots during the morning and early afternoon hours. This also occurs on overcast days but to a much lesser extent. An explanation is that in the morning solar radiation heats the soil surface to a temperature greater than that of the air. By conduction, the air layer overlying the soil surface is heated. On exposed plots the wind and convection currents rapidly mix this heated air with the air above it, reducing the development of a stagnant layer of warm air near the ground. Behind the wind barrier, where wind turbulence is greatly reduced, mixing occurs more slowly and a layer of warm air near the ground surface develops. Stoeckeler (1962) reported that increases in midday air temperatures to the leeward side of dense shelterbelts resulted from ". . . air stagnation and hence more heating out to about 3 H." (H = times height of shelterbelt.) This effect would be intensified on sunny days because the increased input of solar radiation produces higher soil surface temperatures and a greater heating of the overlying layer of air.

The second difference observed was that the air temperatures on sunny days were higher on the exposed plots than those behind the barriers during the middle and late afternoon hours but on overcast afternoons there was little temperature difference between the exposed and protected plots. Recalling the effect of the barrier

on solar radiation, the plots behind the barriers were shielded from much of the direct solar radiation during the middle and late afternoon on sunny days. This reduction in solar radiation would have two results: (1) a reduction in the radiant heating of the air in the shaded area and (2) a reduction in the radiant heating of the soil surface in the shaded area. The cooler soil and reduced wind velocities behind the barrier would result in a cooler layer of air overlying the ground surface behind the barrier than in the exposed plot. On overcast days, when the solar radiation received in the exposed and protected plots was nearly the same, there would be little difference in the radiant heating of the air and soil between the plots.

Maximum air temperatures in the protected plots were found to be significantly (5%) greater than those in the exposed plots. Throughout the summer, maximum air temperatures behind the barriers averaged 2.9°C higher than in the adjacent exposed plots (Figure 9). This difference was primarily the result of the increase in air temperature which occurred during the morning and early afternoons in the protected plots.

The final effect of the wind barriers on the air temperature in the protected plots was to significantly increase the minimum air temperatures. The minimum air temperatures in the protected plots averaged 1.6°C

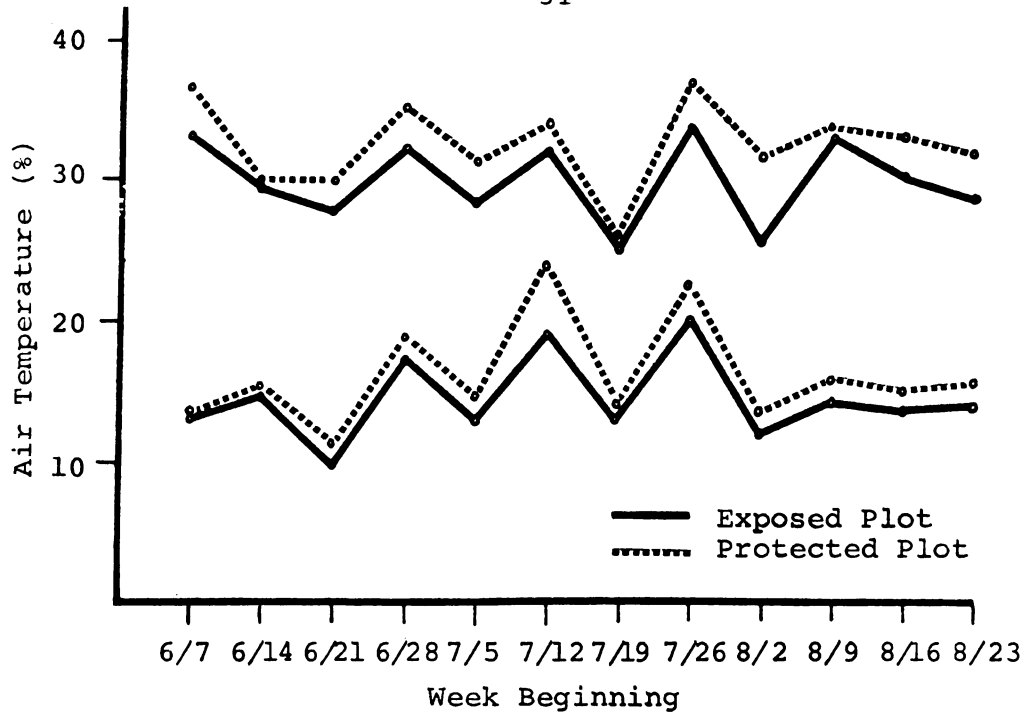


Figure 9.--Weekly average maximum and minimum air temperatures in exposed and protected plots.

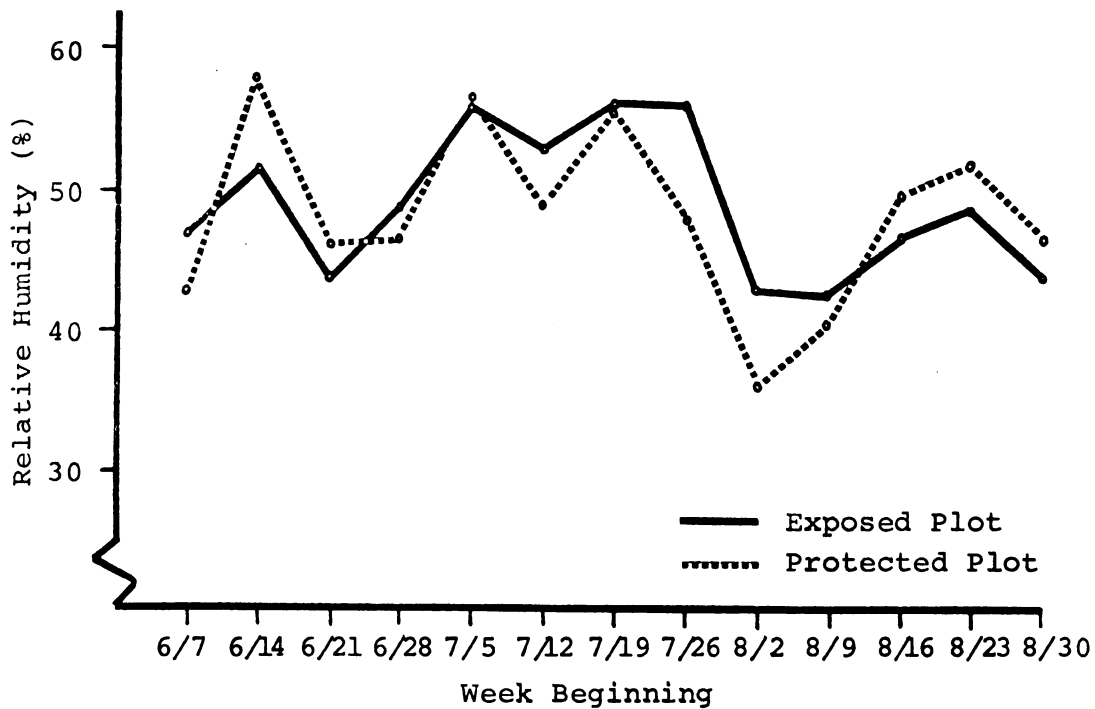


Figure 10.--Weekly average relative humidities in exposed and protected plots.

higher than those in the exposed plots (Figure 9). It should be noted that all minimum air temperatures occurred during the night, usually just prior to sunrise. At night the net long-wavelength radiation from the soil surface is usually outward resulting in the cooling of the ground surface. Lausher (1934) reported that the net long-wavelength radiation in the vicinity of a barrier was less than for a relatively flat ground surface. Therefore, a slower rate of cooling of the ground surface in the vicinity of the barrier results in a warmer soil surface behind the barrier at any given time during the night. The warmer soil surface behind the barrier and a reduced wind velocity would result in a higher minimum air temperature behind the barrier than in the exposed plot.

Relative Humidity

Daily maximum and minimum relative humidities on the protected plot were not significantly different from those recorded on the exposed plot. On both plots the maximum relative humidity reached 100 percent on 92 percent of the nights. On no night was the maximum relative humidity less than 85 percent. Weekly average minimum relative humidities for the protected and exposed plots are presented in Figure 10.

Soil Temperature

There was no significant difference between the temperatures of the upper 15 cm of soil recorded daily at 8:00 a.m. in the exposed and protected plots (Figure 11). On any particular day, differences between soil temperature in the exposed and protected plots of the same replication were seldom greater than 0.5°C.

Soil Moisture

There was no significant difference between the soil moisture content (percent by weight) of the upper 15 cm of soil in the protected plot and in the exposed plot (Figure 12). Working with similar wind barriers, Khattak (1968) reported the same results for the upper 30 cm of soil at a distance equal to the height of the barriers (1.2 meters) to the leeward side of the barriers.

Results and Discussion of Plant Measurements

Plant Growth

Shoot development.--The effects of wind barriers on the shoot growth of 18-week-old black walnut seedlings are presented in Table 4 and Figure 13. Stem height was increased by 15 percent, stem diameter by 13.5 percent, and stem oven-dry weight by 46 percent. The total leaf area per seedling and the total oven-dry weight of the foliage were increased by 85 percent and 158 percent respectively. This resulted from the trees on the

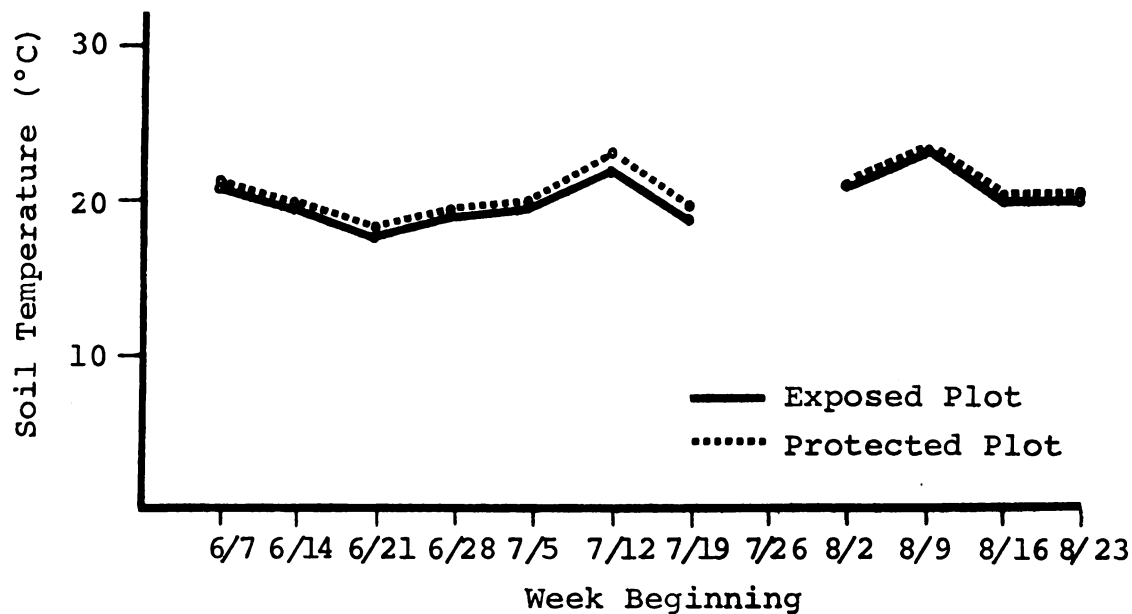


Figure 11.--Weekly average temperature of upper 15 cm of soil in exposed and protected plots.

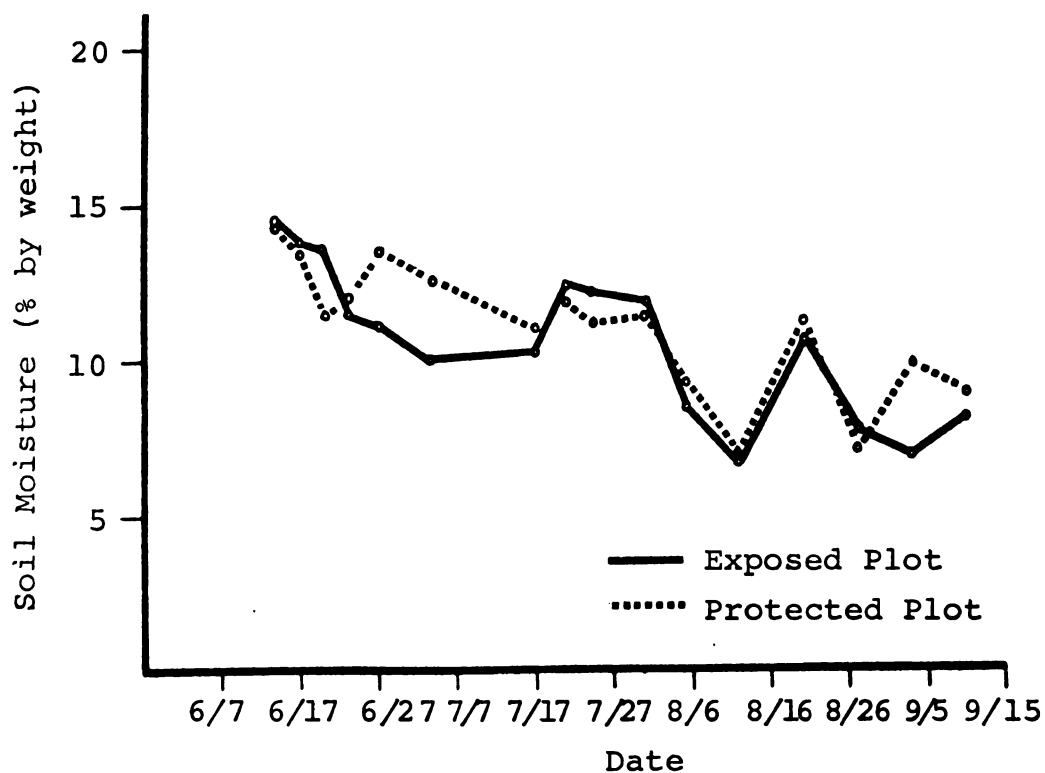


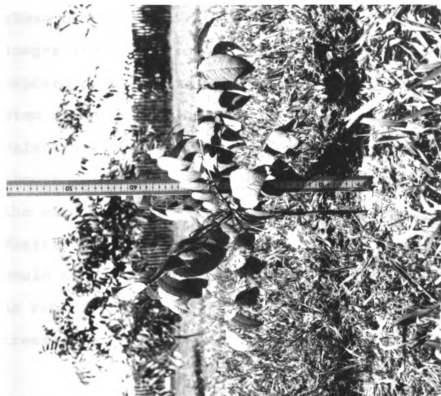
Figure 12.--Weekly average moisture content (% by weight) of the upper 15 cm of soil in exposed and protected plots.

TABLE 4.--Growth responses of 18-week-old black walnut seed-
in exposed and protected field plots.

Growth Parameter	Exposed Plots	Protected Plots	Level Significantly Different (%)
Stem Height (cm) ^a	21.6	24.7	2.1
Stem Diameter (cm)	0.66	0.75	9.2
Stem O.D. Weight (g)	3.7	5.4	4.7
Total Leaf Area (cm ²)	971.	1816.	4.5
Average Number Leaflets	63.	92.	8.7
Average Leaflet Length (cm)	6.4	7.2	4.0
Average Leaflet Width (cm)	3.3	3.6	2.9
Leaves O.D. Weight (g)	5.0	12.9	0.1
Shoot O.D. Weight (g)	8.7	18.3	0.2
Depth Root Penetration (cm) ^b	53.7	54.9	86.4
Root O.D. Weight (g) ^b	28.5	36.3	6.7
Root/Shoot (length) ^b	2.5	2.3	38.8
Root/Shoot (weight) ^b	2.7	2.1	4.8

^aMeasured from root collar.^bDetermined from subsample.

Figure 13.--Shoot development of 18-week-old black walnut in (A) protected plot and (B) exposed plot.

**B****A**

protected plots having (1) 46 percent more leaflets than those on the exposed plots and (2) leaflets 12 percent longer and 9 percent wider than those on the trees in the exposed plots. Similar effects of wind barriers on the stem diameter, stem height, and total leaf area of black walnut seedlings have been reported by Khattak (1968), though he did not observe significant differences until the middle of the second year after planting. However, Khattak planted 1/0 seedlings, the shoot growth of which would not be expected to respond to cultural treatments as rapidly during their first year after planting as trees planted from seed.

The difference in the stem height growth between the exposed and protected plots appears to have developed in two ways. Prior to August 3, the terminal growth rate in the protected plots was greater, though not significantly, than that in the exposed plots (Table 5). During this time the wind barriers appear to have been providing a more favorable environment for terminal growth than that which existed in the exposed plots. After August 3, the terminal growth in the exposed plots virtually ceased while that in the protected plots continued at a significantly greater rate. The wind barriers appear to have extended the period of terminal growth by several weeks.

The presence of wind barriers had little observable effect on stem diameter growth prior to August 3

TABLE 5.--Periodic height growth of black walnut seedlings in exposed and protected field plots.

Sampling Date	Total Growth			Growth Increment		
	Exposed Plots	Protected Plots	Level Sign. Different	Exposed Plots	Protected Plots	Level Sign. Different
	-----cm-----	-----cm-----	-----8-----	-----cm-----	-----cm-----	-----8-----
June 8	13.0	13.9	19.2	13.0	13.9	19.2
June 24	15.8	16.9	24.2	2.8	3.0	51.0
July 12	17.7	19.1	15.8	1.9	2.2	31.6
Aug. 3	19.0	20.6	14.6	1.3	1.4	62.5
Aug. 26	19.1	21.4	8.5	0.1	0.8	4.0
Sept. 18	19.2	21.8	6.3	0.0	0.4	7.4

(Table 6). The environmental modification by the barrier which appeared to favor increased stem height growth apparently did not affect stem diameter growth. After August 3, stem diameter growth in the protected plots was significantly greater than that in the exposed plots.

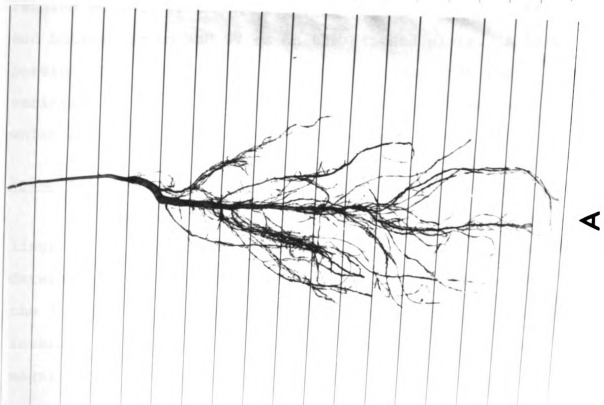
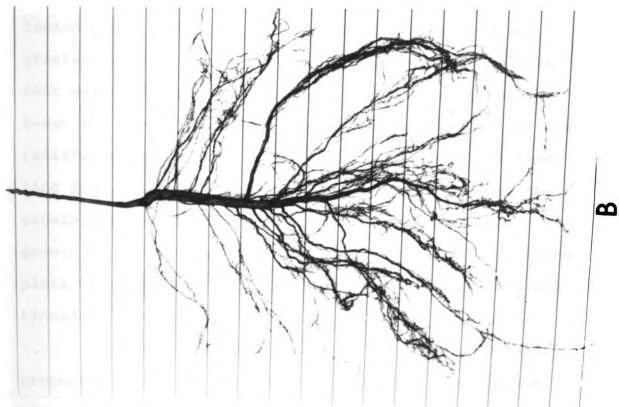
In addition to affecting the number and size of the leaflets of the seedlings, the wind barrier apparently affected the time of the onset of leaf senescence. By the latter part of August the discoloration that is typical of the senescing leaves of black walnut was evident in the seedlings in the exposed plots. Seedlings in the protected plots showed little evidence of senescence by mid-September. This early senescence of the leaves in the exposed plots may be related to the decline in growth rates observed in the exposed plots. Recent work by Carpenter (1971) indicates that toward the end of the growing season, when leaf senescence and abscission are occurring, rates of net photosynthesis are lower than earlier in the growing season.

Root development and root/shoot ratio.--The presence of the wind barriers significantly increased the root oven-dry weight by 27 percent and decreased the root/shoot weight ratio by 22 percent. The depth of root penetration and the root/shoot length ratio were not influenced by the wind barrier (Table 4, Figure 14). The

TABLE 6.--Periodic diameter growth of black walnut seedlings in exposed and protected field plots.

Sampling Date	Total Growth			Growth Increment		
	Exposed Plots -----cm-----	Protected Plots -----cm-----	Level Sign. Different -----§-----	Exposed Plots -----cm-----	Protected Plots -----cm-----	Level Sign. Different -----§-----
June 8	.32	.31	40.1	.32	.31	40.1
June 24	.41	.40	51.5	.09	.09	90.1
July 12	.48	.50	15.1	.08	.09	32.3
Aug. 3	.59	.59	86.8	.10	.09	57.3
Aug. 26	.64	.70	10.7	.05	.12	0.7
Sept. 18	.66	.75	9.2	.02	.05	8.2

Figure 14.--Stem and root development of 18-week-old black walnut in (A) exposed plot and (B) protected plot. (Scale: 5 cm grid.)



lower root/shoot weight ratio of the seedlings in the protected plots resulted from the wind barriers causing greater increases in shoot weight (110 percent) than in root weight (27 percent). This difference in growth between the shoots and roots may have resulted from (1) the redistribution in the protected plots of the total seedling productivity in favor of the shoots throughout the growing period or (2) the decline in seedling shoot growth in the exposed plots earlier than in the protected plots while the roots of the seedlings in both plots continued to grow.

Root penetration was highly variable on both the protected and exposed plots with depths of penetration ranging between 25 cm and 102 cm on the protected plots and between 22 cm and 97 cm on the exposed plots. A large portion of this variation may have resulted from the variation in the soil structure and horizon thickness which existed throughout the study area.

Xylem Sap Tension

The xylem sap tensions of the black walnut seedlings in the protected and exposed plots were examined to determine if the presence of the wind barriers affected the internal water status of the trees. Difference in the internal water status of the seedlings, if of sufficient magnitude, could result in observable differences in

seedling growth by affecting stomatal aperture and/or plant processes involved in growth.

The daily pattern for xylem sap tension in the seedlings in the exposed and protected plots for September 2 is presented in Table 7. The daily patterns in xylem tension for September 9, 10, and 11 were quite similar. Following sunrise the xylem tension rose rapidly until around midday when the rate of change in the tensions became relatively slow. This plateau was maintained until around 4:00 p.m., at which time the tensions began to decrease. Similar patterns in the daily course of relative water content in millet (Begg, et al., 1964), xylem sap tension in black walnut (Khattak, 1968), relative turgidity in cotton (Weatherly, 1950), and moisture content of sunflower and amaranthus (Wilson, et al., 1953) have been reported.

Because of the rapid changes in xylem tensions during the morning and late afternoon, only tension measurements taken during the "plateau period" were considered comparable. The average xylem sap tensions during the "plateau periods" of September 2, 9, 10, and 11 along with the concurrent environmental conditions are presented in Table 8. On these four days there were no significant differences between the xylem tensions of the seedlings in the exposed and protected plots during the "plateau periods." This result agrees with previous

TABLE 7.--Daily pattern of xylem sap tension of first-year black walnut seedlings in exposed and protected plots on September 2, 1970.

<u>Rep</u>	<u>Protected Plot</u>		<u>Exposed Plot</u>	
	<u>Time</u>	<u>Tension (atm)</u>	<u>Time</u>	<u>Tension (atm)</u>
1	6:32 a.m.	.2	6:40 a.m.	.5
2	6:47 a.m.	.5	6:55 a.m.	.9
3	7:04 a.m.	1.2	7:10 a.m.	2.2
1	9:43 a.m.	10.1	10:00 a.m.	11.9
2	10:25 a.m.	11.2	10:24 a.m.	13.6
3	11:15 a.m.	12.6	11:36 a.m.	12.8
1	1:15 p.m.	13.6	1:40 p.m.	16.0
2	2:45 p.m.	14.3	2:30 p.m.	14.0
3	3:20 p.m.	15.0	3:43 p.m.	16.0
1	5:36 p.m.	11.9	5:55 p.m.	13.3
2	6:53 p.m.	4.0	7:09 p.m.	5.3

TABLE 8.--Average xylem sap tension of black walnut seedlings on protected and exposed plots between 12:00 noon and 4:00 p.m. on September 2, 9, 10, and 11, 1970.

Date	Avg. Plot Tension (atm)		Max. Wind Velocity During Measurement (km/hr)	Avg. Soil Moisture (% wt.)		Air Temp. (°C)	Relative Humidity (%)	Total Daily Solar Radiation (langley's)
	Protected	Exposed		0-15 cm	15-30 cm			
9/2	14.4	15.4	8	8.1	7.5	27.8-30.0	40-50	369
9/9	15.5	15.3	6	---	---	26.6-28.9	40-50	407
9/10	14.0	14.2	13	8.8	7.8	20.0-22.2	40-50	315
9/11	13.9	13.8	3	---	---	24.4-26.6	30-40	354
All	14.4	14.7						

measurements made in the month of July on black walnut growing behind similar barriers (Khattak, 1968).

Several explanations that could be offered for the effect of the wind barriers on the xylem sap tension of black walnut seedlings observed are:

1. The presence of wind barriers does not affect xylem sap tensions of seedlings planted to their lee at any time.
2. During the period of maximum xylem tension, the "plateau period," the barriers do not affect the xylem sap tension but during periods of less tension the barriers do have an effect on tension.
3. Only under certain environmental conditions, different from those of September 2, 9, 10, and 11, do the barriers affect the xylem sap tension.
4. The barriers affect the xylem sap tension during part of the growing season but not during the period when the measurements were taken.

Additional study would be needed to determine if any of these hypotheses are correct. Furthermore, the technique used to determine xylem sap tension in this study was not entirely satisfactory. It is suggested that in any future work more than one pressure bomb be

used and simultaneous readings be made in all treatment combinations. Measurements taken at any time during the day would thus be comparable. In addition, the variation in tension due to the time of day of sampling could be removed from the analysis by the proper statistical technique. This would allow measurements to be taken over an entire day or several days and then analyzed together.

Some of the extraneous variation in the xylem sap tension could be further reduced by better control of the soil moisture in the vicinity of the trees. A more accurate evaluation of the effects of imposed treatments on the xylem sap tension could be obtained by growing the trees in containers in which soil moisture is controlled.

CHAPTER III

CONTROLLED ENVIRONMENTAL STUDY OF THE EFFECTS OF A MODERATE WIND VELOCITY ON FIRST-YEAR BLACK WALNUT SEEDLINGS

Introduction

It is difficult to modify wind in field studies without altering other environmental factors. There is also the potential risk of introducing unknown interactions between wind and other environmental factors. Therefore, the effects of wind on plants can best be studied under controlled environmental conditions. In comparison with other environmental factors, relatively few such controlled environmental studies have examined the effects of wind on plant growth.

Hill (1921) reported that a 5 m/sec wind for 24 hours a day reduced the germination and growth of cress and mustard growing on lamp-wicks.

Finnel (1928) observed that marigolds exposed to a 15 m.p.h. wind for 60 days were shorter, less mature, had less total dry weight, and had more deformed or destroyed foliage than control plants.

Martin and Clements (1935) reported that exposure of sunflower (Helianthus annuus) to increasingly higher

wind velocities of 0, 5, 10, and 15 m.p.h. for a period of 6 to 8 weeks caused progressively less growth in leaf area, stem height and diameter, and dry weight.

Rao (1938) reported that Italian millet (Setaria italica) plants grown in an 11 m.p.h. wind for one month were shorter and had thinner stems, narrower and shorter leaves, less shoot and root dry weight, and less root volume than the control plants.

Wadsworth (1959), working with rape (Brassica napus), observed that as these plants were subjected to progressively higher wind velocities their growth rates first increased and then decreased. He suggested that there is an optimum wind speed, which he estimated to be approximately 0.3 m/sec for rape under his experimental conditions, above and below which growth rate will be less than maximum.

Whitehead (1957, 1962, 1963) and Whitehead and Luti (1962) studied the effects of wind on the growth of corn (Zea Mays) and sunflower (H. annuus). Exposing corn plants to a 30 m.p.h. wind caused a decrease in height, weight of roots and shoots, and leaf length, and an increase in the leaf width and thickness, the root/shoot weight ratio, and the root length. With increasing wind velocities of 1, 9, 19, and 33 m.p.h. sunflower plants exhibited progressive decreases in leaf area, height

growth, root and shoot dry weight, and a progressive increase in the root/shoot weight ratio.

Satoo (1962) reported that exposure of black locust (Robina pseudoacacia) seedlings to a 3.6 m/sec wind for 4 weeks caused a decrease in stem height and diameter, shoot and root dry weight, number and length of leaflets, and length of root.

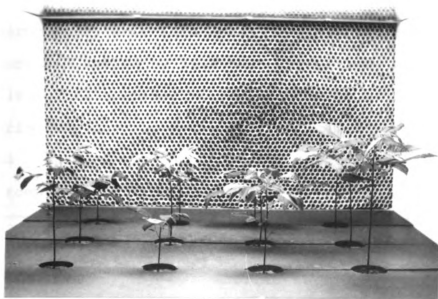
This portion of the study was designed to evaluate, under controlled environmental conditions, the effects on black walnut seedlings of a wind equal in velocity to the average wind at the field study site. Of primary interest was the growth response of the seedlings. In order to gain some insight into the physiological response of the seedlings, information was also obtained on the transpiration and stomatal responses to the wind and to the soil moisture levels maintained.

Methods

The growth responses of germinating black walnut seedlings were studied for 80 days under two different wind velocities and two different soil moisture regimes. The study was carried out in two wind tunnels located in an environment room which provided control of both ambient air temperature and relative humidity (Figure 15).

Wind velocities were maintained at either 2.8 m/sec or <0.1 m/sec for 11 hours a day, beginning one

Figure 15.--View of tunnels used to examine the effects of wind on black walnut seedlings: (A) low wind velocity tunnel and (B and C) side and end of high wind velocity tunnel.

**A****B****C**

hour after the lights came on and ending two hours before the lights went off. The lower velocity, or control, was maintained to prevent air stagnation in the tunnel. Within each wind tunnel the seedlings were randomly assigned to one of two soil moisture regimes.

Soil moisture was either allowed to fall to 8 percent* and then rewatered to 12 percent (the high soil moisture regime), or allowed to fall to 4 percent and then rewatered to 12 percent (the low soil moisture regime). These soil moisture levels, 12 percent, 8 percent, and 4 percent, correspond to soil water suctions of 0.20 atm., 0.75 atm., and 7.00 atm. respectively (Figure 16).

The seedlings received a 14 hour photoperiod provided by a bank of 6 Sylvania 40-watt cool-white fluorescent and 8 25-watt incandescent light bulbs. The average illumination in the seedling crowns was 1200 foot-candles. Air temperature was maintained at $20^{\circ}\text{C} \pm 1.5^{\circ}\text{C}$ at all times. Leaf temperatures, recorded with an infrared thermometer, were less than 1°C above ambient air temperature and varied by less than 1°C between the two tunnels. Soil temperature varied between a high of 21.6°C during the day and a low of 19.4°C at night. Both day and night relative humidity was maintained at 60 to 65 percent. The carbon dioxide level in the air of the

*All soil moisture percentages are expressed on a weight basis.

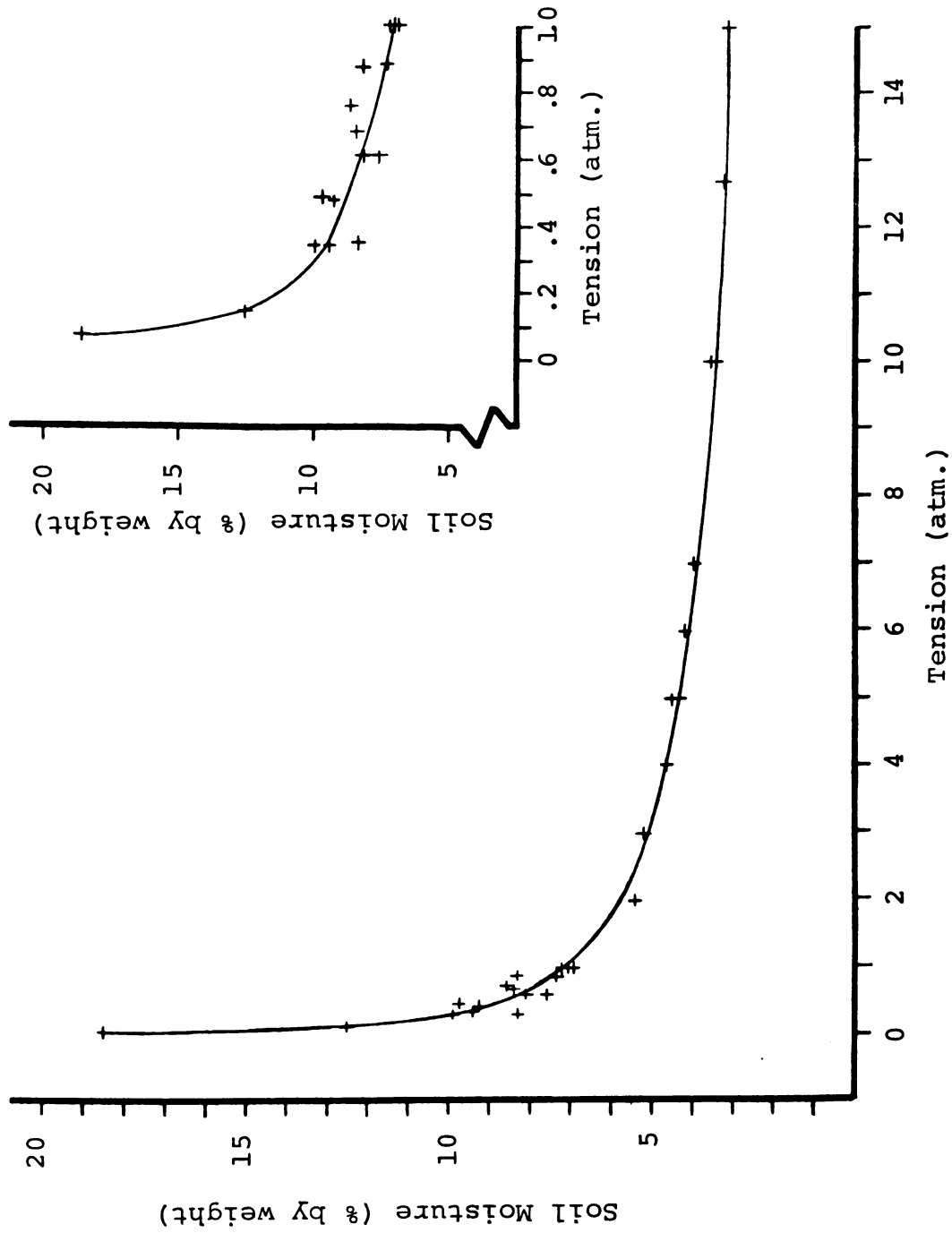


Figure 16.--Soil moisture characteristic curve for composite samples of A_p and A_{21} horizons of Metea sandy loam soil. Insert (upper right) details 0-1 atm tension.

tunnels, measured with an infrared gas analyzer, was approximately 300 ppm.

The experimental design was a split-plot factorial with two replications. Wind was analyzed as a whole plot treatment and soil moisture as a subplot treatment. Each replication consisted of 10 seedlings in each wind tunnel, half of which were randomly assigned to one soil moisture regime and half to the other.

Efforts to obtain sufficient seed of both uniform size and time of germination proved unsuccessful. It was, however, possible to obtain groups of 4 germinating seedlings which met these requirements. These were placed, one seedling per treatment combination, into the tunnels at one to three day intervals. This fact was taken into account by introducing into the analysis of variance a main effect, designated as TIME, which removed any variation in seedling response, caused by time, between the five four-tree groups. TIME was analyzed as a whole plot treatment which had the desirable effect of increasing the error degrees of freedom for testing the main effect of wind.

The black walnut seeds used in this part of the study were collected in the Fall of 1969 from a single tree in Cass County, Michigan. Seed treatment prior to the time of germination was identical to that of the field experiment described in Chapter II. When

germination began, approximately 600 seeds were placed in wooden flats, covered with moist soil, and put into a cold room at 4°C for 3 months for later use in the second replication. As germination proceeded, groups of 4 seedlings of comparable size and weight were selected and each seedling was planted in a 4-liter plastic container filled level with soil (approximately 5625 g of oven-dry soil). The soil used was collected from the A_p and A₂₁ horizons in the field study area described in Chapter II and passed through a 0.64 cm mesh sieve. The containers were watered to 12 percent soil moisture content, placed in the darkened controlled environment room for 12 hours, and then positioned in the wind tunnels at the beginning of the day cycle. To insure uniform wind exposure, the seedlings were rotated every other day during the first 60 days in the tunnel.

Watering of the seedlings was controlled by container weight. When the container weight, adjusted for seedling weight*, indicated a soil at either 8 percent or 4 percent moisture content, enough distilled water was added to the container to bring the soil moisture content up to 12 percent. Water was added with the aid of a hypodermic syringe. The needle was inserted into the

*Seedling weight was estimated by the following equation ($R^2 = .74$): Seedling Weight (g) = $-11.44 + 132.59$ (Stem Diameter in cm at 1 cm height).

top and sides of each container and the water was introduced at various depths in the soil (Figure 17).

To ascertain how effective this technique was in obtaining uniform soil water distribution, 9 walnut seedlings were grown for 5 and 10 weeks using this watering technique. Water distribution in the soil was then examined at different soil moisture contents (Table 9). Shortly after watering the distribution of water in the container is fairly uniform. However, as the time since watering increases, the distribution of water in the containers becomes less uniform, decreasing at the top more rapidly than at the bottom. This differential drying probably results from evaporation from the soil surface and from the absorption of water by the root. It should be noted that the seedling root systems did not fully occupy the soil mass.

A total of 450 g of RX-15* nutrient solution was applied to each seedling during its first week in the wind tunnel. This solution was applied in place of distilled water to replenish the soil moisture content.

At two week intervals the seedlings were sprayed with a 0.5 percent aqueous solution of zineb to minimize damage by walnut anthracnose, Gnomonia leptostyla (Jaynes, 1969).

*Manufactured by Garden Research Laboratories, Ltd., Toronto, Ontario, Canada.

Figure 17.--Watering with hypodermic syringe to obtain uniform soil moisture distribution.



TABLE 9.--Soil water distribution in containers at different soil moisture contents for 5 and 10-week-old black walnut seedlings.

Percent Moisture by Container Weight	Position of Sample in Container		
	Upper 1/3	Middle 1/3	Lower 1/3
<u>5 Weeks</u>			
11.0	11.5	10.4	13.4
11.0	11.6	11.6	11.0
11.0	9.8	9.9	12.8
5.2	3.8	4.6	5.3
5.5	4.5	5.1	5.8
5.3	4.1	4.8	5.6
4.6	2.8	4.6	5.5
5.0	3.8	5.8	6.3
5.0	3.2	5.0	5.8
 <u>10 Weeks</u>			
9.6	9.5	9.8	10.1
10.3	10.2	10.2	10.0
9.6	9.1	9.4	10.0
7.0	6.3	6.9	6.8
7.0	6.6	6.4	6.8
6.8	6.7	7.3	6.6
3.7	2.0	4.0	4.8
3.6	2.0	4.4	5.0
3.7	2.9	4.6	5.1

Both stem height and stem diameter, at 1 cm above the soil surface, were measured every 8 days. Height was measured to the nearest millimeter and diameter to the nearest 0.25 mm. The total leaf area of each seedling was determined every 8 days for the first 48 days and at the end of the study by measuring the length and width of each leaflet on the seedling and applying the procedure described in Chapter II. At the end of the study, the oven-dry weights (70°C) of the leaves, stem, and root of each seedling were determined. At this time foliar nutrient analyses of the seedlings in each treatment combination were obtained (Table 16).

Transpiration rates were calculated for each seedling during the last 20-day period in the wind tunnel. The night before the transpiration measurements were begun the soil moisture in the containers was brought up to 12 percent and the containers sealed in polyethelene bags to prevent the evaporation of water from the soil. The following morning the containers were weighed and placed in the tunnels for the 11 hour period. At the end of this time the containers were again weighed. The difference in the container's weight before and after the period in the wind tunnel was interpreted as the weight of the water transpired by that seedling during that 11 hour period.

Following these transpiration measurements, the polyethelene bags were removed and the trees returned to the wind tunnels. The soil moisture content in all of the containers was allowed to deplete over the next several days until it reached 8 percent, at which time the transpiration measurements were repeated. The soil moisture content in the containers of the seedlings subjected to the low soil moisture regime was allowed to further deplete to 4 percent and the transpiration measurements were once again repeated. The leaf areas used to calculate transpiration rate were the leaf areas of the seedlings at the end of the study adjusted for the areas of the leaflets lost between the transpiration measurements and the final leaf measurements.

Along with the transpiration measurements, silicon rubber impressions of the lower surface of one leaflet per seedling were taken to evaluate the response of stomata to wind and soil moisture levels. The impressions were taken in the tunnel during the 15 minute period before the wind ended and the final weighing occurred. The techniques of making the impressions and the transparent cellulose acetate positive replicas are described by Sampson (1961) and Zelitch (1961). General Electric RTV-11 liquid silicone rubber and Tenneco Nuocure 28 (2 drops per gram of silicone rubber) were used to make the

impressions and a 1:1 solution of clear fingernail polish and acetone to make the positive replicas.

To examine the stomatal apertures, the positive replicas were temporarily mounted on glass slides and examined with a compound light-microscope. Stomatal apertures were evaluated on a numerical scale from 1 to 4, with 1 indicating that the stomata were closed (Figure 18). A total of 25 stomata were examined on each leaflet along a line at right angles to the midrib through the center of the leaflet.

Results and Discussion

Plant Growth

The effects of the two wind velocities and two soil moisture regimes on the growth of 80-day-old black walnut seedlings are presented in Table 10 and Figures 19 and 20 (see Tables 17-22 for specific growth measurements).

Stem.--The higher wind velocity had no significant effect on the average stem height or diameter but significantly decreased the average oven-dry weight of the stem by 17 percent. The lower soil moisture regime significantly decreased the average stem height and diameter by 18 percent and the average oven-dry weight of the stem by 45 percent.

Figure 18.--Microphotograph of cellulose acetate positive
of lower leaf surface of black walnut seed-
ling with stomatal apertures classified as
1 (bottom center), 2 (middle left), and
3 (upper right).



TABLE 10.--Growth response of 80-day-old black walnut in two wind velocities and two soil moisture regimes.*

Growth Parameter	Wind Velocity <0.1 m/sec.		Wind Velocity 2.8 m/sec.	
	Low Soil Moisture Regime	High Soil Moisture Regime	Low Soil Moisture Regime	High Soil Moisture Regime
Stem Height (cm)	22.0 ^a	25.6 ^b	19.1 ^a	25.1 ^b
Stem Diameter at 1 cm Height (cm)	.46 ^a	.55 ^b	.45 ^a	.54 ^b
Stem Diameter at 2.5 cm Height (cm)	.40 ^a	.49 ^b	.38 ^a	.49 ^b
Stem Dry Weight (g)	1.39 ^a	2.34 ^b	1.05 ^c	2.05 ^d
Total Leaf Area (cm ²)	541 ^a	1133 ^b	459 ^a	968 ^b
Average Leaflet Length (cm)	5.2 ^a	7.3 ^b	4.6 ^c	6.6 ^d
Average Leaflet Width (cm)	2.6 ^a	3.5 ^b	2.3 ^c	3.3 ^d
Average Number Leaflets	44 ^a	49 ^b	40 ^a	50 ^b
Foliage Dry Weight (g)	2.27 ^a	4.62 ^b	1.75 ^c	3.53 ^d
Shoot Dry Weight (g)	3.66 ^a	6.96 ^b	2.81 ^c	5.58 ^d
Root Dry Weight (g)	5.34 ^a	11.84 ^b	3.99 ^c	9.46 ^d
Root/Shoot Weight Ratio	1.36 ^a	1.72 ^b	1.19 ^a	1.67 ^b

*Values with the same letter in the superscript are not significantly different at $\alpha = .05$.

Figure 19.--Shoot development of 80-day-old black walnut in (A) low wind, high soil moisture regime, (B) low wind, low soil moisture regime, (C) high wind, high soil moisture regime, and (D) high wind, low soil moisture regime (Scale: 5 cm grid).

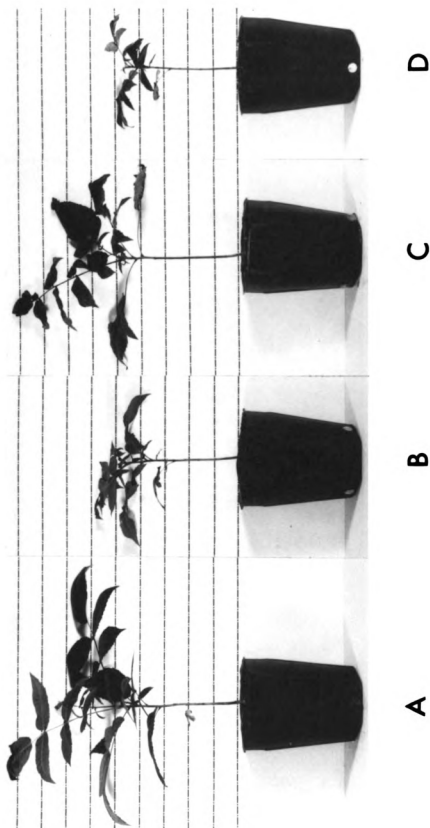
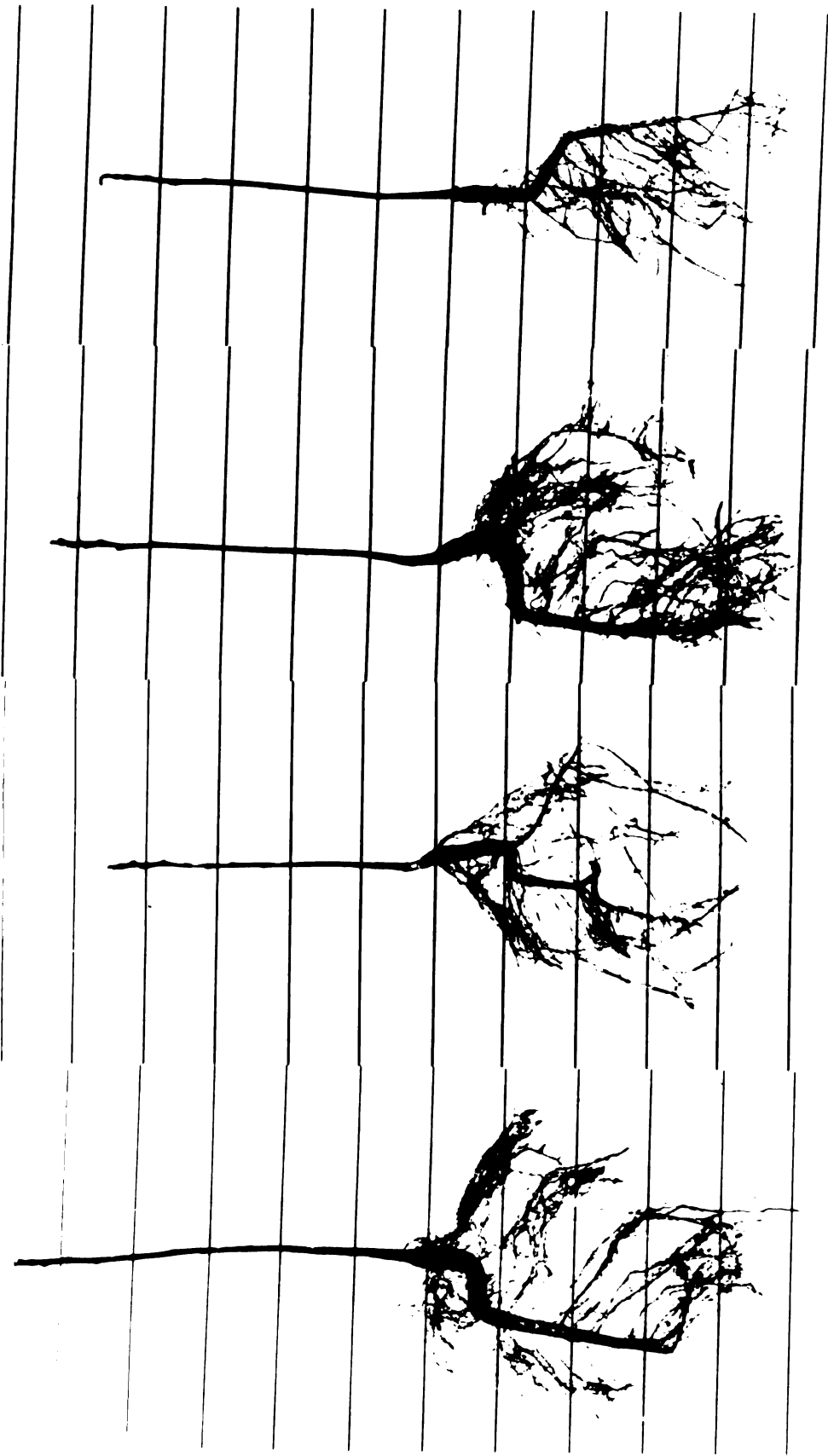


Figure 20.--Stem and root development of 80-day-old black walnut in (A) low wind, high soil moisture regime, (B) low wind, low soil moisture regime, (C) high wind, high soil moisture regime, and (D) high wind, low soil moisture regime (Scale: 5 cm grid).



A

B

C

D

The seedlings in all treatments achieved 90 percent of their height growth by the end of the first 16 days in the tunnels and by the 40th day height growth had virtually ceased (Figure 21). This rapid initial growth during the period when the seedlings had a relatively small amount of foliage was probably the result of the utilization of materials stored in the seed. During the first 40 days the average height of the trees growing in the two moisture regimes gradually diverged, becoming significantly different by the 16th day. The interaction between wind and soil moisture regime in seedling height was not significant.

Diameter, on the other hand, increased at a relatively steady rate throughout the entire 80 day period (Figure 21). The average diameter of the seedlings growing in the two moisture regimes became significantly different by the 24th day.

Foliage.--The higher wind velocity significantly decreased the average oven-dry weight of the foliage per seedling by 23 percent, the average leaf area per seedling by 15 percent ($\alpha = .10$), and the average length and width of individual leaflets by 11 percent and 7 percent respectively. The lower soil moisture regime significantly decreased the average oven-dry weight of the foliage per seedling and the average leaf area per

Figure 21.--Stem height and diameter growth of black walnut seedlings in two wind velocities and two soil moisture regimes.

- - - - Low Wind, Low Soil Moisture Regime
- Low Wind, High Soil Moisture Regime
- High Wind, Low Soil Moisture Regime
- - - High Wind, High Soil Moisture Regime

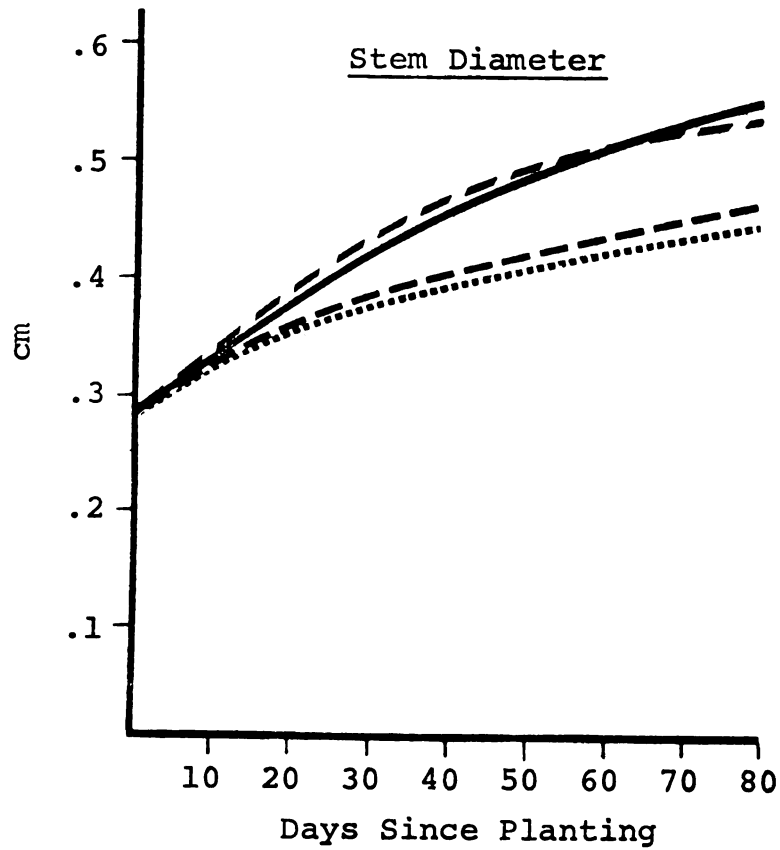
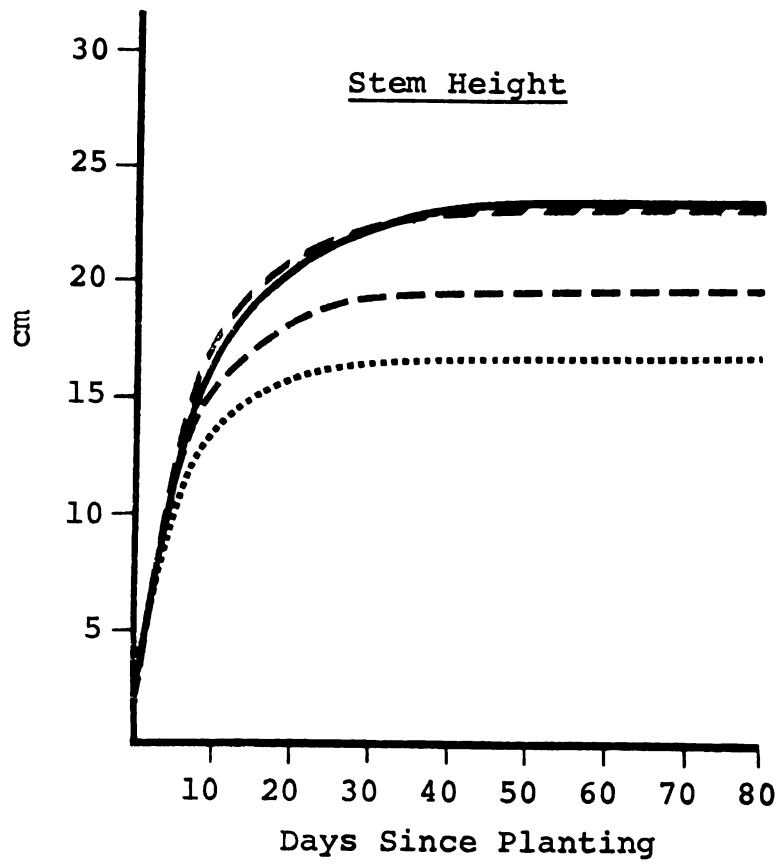
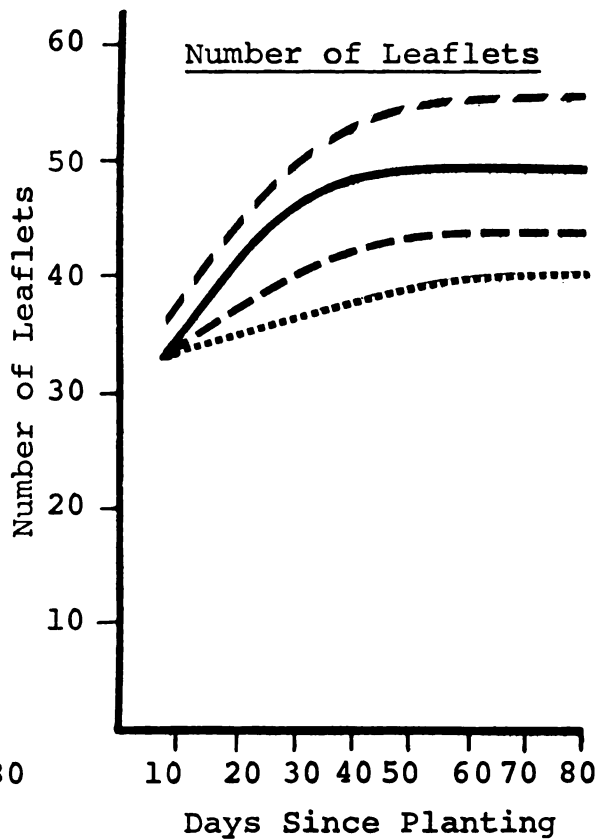
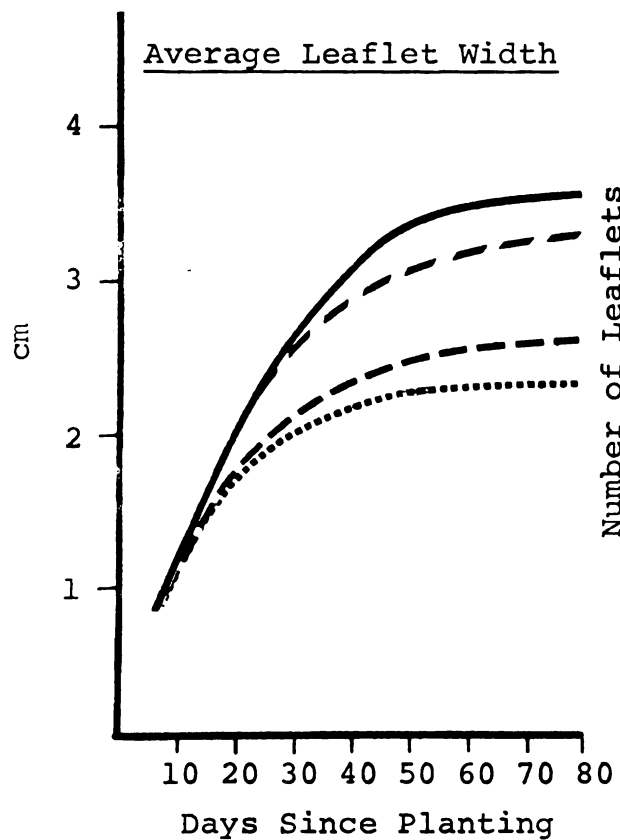
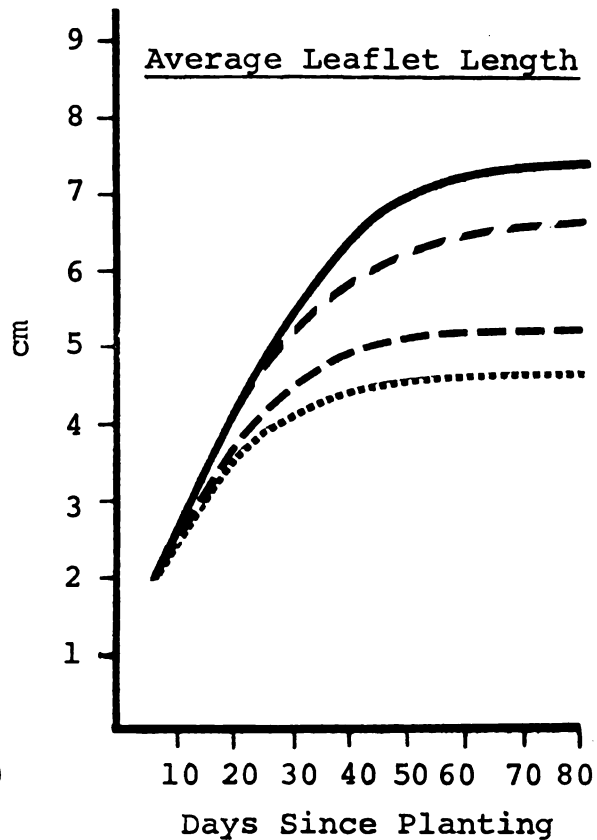
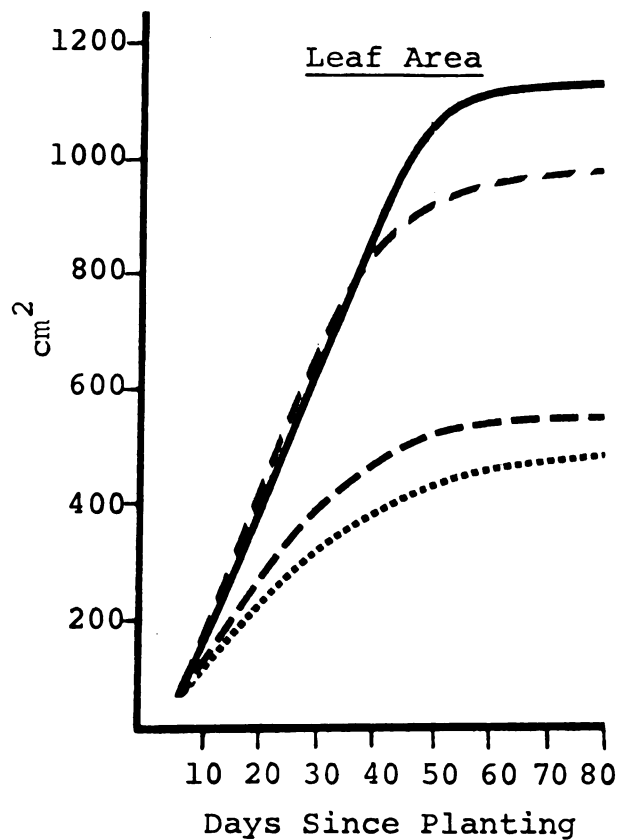


Figure 22.--Foliar development of black walnut seedlings in two wind velocities and two soil moisture regimes.

- Low Wind, Low Soil Moisture Regime
- ==== Low Wind, High Soil Moisture Regime
- High Wind, Low Soil Moisture Regime
- - - High Wind, High Soil Moisture Regime



decreasing 56 percent in the low soil moisture regime while the average oven-dry weight of the shoot decreased only 48 percent.

The tap root of every seedling exhibited the double bend seen in the seedlings in Figure 22. This deformation resulted from the germinating nuts being oriented in the soil in such a way that the radicle emerged from the side rather than the bottom of the nut. The emerging radicle grew horizontally for a short distance before turning downward.

In summary, the growth of first year black walnut seedlings was significantly decreased both by exposure to a constant 11-hour-per-day wind of 2.8 m/sec velocity and by being subjected to a soil moisture regime attaining approximately 7 atm. of soil water suction. The depressed growth of the walnut seedlings in wind agrees, in general, with the results obtained by Satoo (1962) for black locust seedlings Robinia pseudoacacia. The growth reductions in response to wind velocities averaging between 3.5 and 3.7 m/sec reported by Satoo were, however, much greater than those observed in this experiment and included a substantial reduction in height growth. Growth response differences in the two experiments may be due both to the differences in wind velocities maintained and/or to differences in the way the two species respond to wind.

Growth reduction in response to the lower soil moisture regime is in agreement with results demonstrating that plant growth can be significantly reduced by reductions in soil moisture content which are still within the range of "available soil water" (Glerum and Pierpoint, 1968; Jarvis and Jarvis, 1963a; Kaufmann, 1968; Miller, 1970; Miller, 1965; Sands and Ritter, 1959; Stanhill, 1957; Steinbrenner and Rediske, 1964; Stransky and Wilson, 1964). Such results disagree with the earlier view supported by Veihmeyer and Hendrickson (1950) that reductions in soil water content do not significantly reduce plant growth until the soil water content is reduced to very near the "permanent wilting percentage." One reason for this disagreement may be that Veihmeyer and Hendrickson's conclusion was based almost entirely on field experiments while the majority of the experiments referred to above were carried out with potted plants. The use of potted plants allows considerable control over and/or monitoring of the soil water status throughout the entire plant root system. In the field, on the other hand, determining the soil water status throughout the plant's root system is difficult because of spatial variations in the soil's water content and physical properties and problems in defining the extent of the plant's root system.

One point of difference between the results of this study and previous studies is the 25 percent decrease in the root/shoot ratio in the lower soil moisture regime. Previous work on jack pine (Miller, 1970), ponderose pine (Steinbrenner and Rediske, 1964), and sunflower (Whitehead, 1963) indicates that the root/shoot ratios of these species increases when they are grown at lower soil moisture levels. Despite the differences in rooting habit of walnut and these species, no explanation can be offered at the present time for this difference in response.

Transpiration and Stomatal Aperture

It is generally believed that wind affects trees primarily by causing mechanical injury and by affecting their transpiration rate (Satoo, 1962). Mechanical injury may lead to mutual shading of leaves due to crown deformation and/or a loss of photosynthetic surface due to the shredding or destruction of leaves (Schneider, et al., 1970). An increase in the transpiration rate could lead to a decrease in the tree's water potential sufficient to interfere with physiological processes or cause partial or complete stomatal closure. Closure of the stomata beyond a certain size would result in a decrease in photosynthesis due to a reduction in the rate of carbon dioxide diffusion into the leaf.

Little mechanical injury occurs at low wind velocities. The only evidence of mechanical effects observed in this study was a slight deflecting of the branches away from the direction from which the wind blew on the seedlings exposed to the higher wind velocity.

Transpiration from a plant may occur either through the cuticle or through the stomata. When the stomata are open there is generally less resistance to transpiration through the stomatal pathway than through the cuticular pathway and a high proportion of the transpiration occurs along that path (Slatyer, 1967). The "driving force" of stomatal transpiration is the vapor pressure gradient which exists between the air in the intercellular spaces of the leaf and that of the external air. The resistance to the diffusion of water vapor along this pathway is composed of (1) resistance within the leaf, composed of mesophyll resistance, intercellular space resistance, and stomatal pore resistance, and (2) resistance external to the leaf, which is the resistance to diffusion across the boundary layer of still air at the leaf's surface (Meidner and Mansfield, 1968; Slatyer, 1967).

Wind may initially affect the transpiration of a plant in two ways. First, it may decrease the thickness of the boundary layer thereby reducing the external resistance to diffusion. The result of this is to

increase transpiration. Second, it may decrease the temperature difference between the leaf and air which results in a less steep vapor pressure gradient between the leaf and air. This results in a decrease in the transpiration rate. The net effect on transpiration of these two effects of wind depends on the wind velocity, the relative importance of the leaf and external diffusion resistances, and the amount of radiant heating of the leaf occurring (Salisbury and Ross, 1969). In addition, if the wind initially causes increased transpiration, this may result in a decrease in the plant water potential sufficient to cause partial or complete stomatal closure resulting in reduced transpiration.

Soil water content also affects the internal water status of a plant--in general, the lower the soil water potential the lower the plant water potential. As observed above, a decrease in a plant's water potential may interfere with physiological processes and/or may cause a decrease in the stomatal apertures which could result in reduced carbon dioxide diffusion and photosynthesis. For a particular species, the soil water potential at which a particular plant potential results depends, in part, upon the aerial environmental conditions. An environment conducive to high rates of transpiration will cause lower plant water potentials to develop (in a given amount of time) at a particular

soil water potential than one which favors low transpiration rates.

The results of the transpiration and stomatal aperture measurements from this study are presented in Tables 11 and 12. Wind significantly increased the average transpiration rate at all soil moisture levels by an average of 50 percent but had no significant effect on the average stomatal aperture. There was no significant difference in the average transpiration rates or stomatal apertures between the 12 percent and 8 percent soil moisture levels. This corresponds to a 0.2 atm. and a 0.75 atm. soil water suction respectively. However at 4 percent soil moisture, 7 atm. soil water suction, the transpiration rate was, on the average, 70 percent less than that at soil moistures of 8 percent or 12 percent and the average stomatal aperture was significantly smaller.

The increase in average transpiration rate observed at the higher wind velocity agrees with previous reports (Martin and Clements, 1935; Rao, 1938; Satoo, 1962). However, Martin and Clements (1935), working with Helianthus annuus, and Satoo (1962), using Quercus acutissima, both observed considerable decrease in relative stomatal aperture in wind velocities of 2 m/sec to 3 m/sec. Recently, Caldwell (1970), working with Rhododendron ferrugineum and Pinus cembra, has shown

TABLE 11.--Average transpiration rate of black walnut seedlings during 11 hour wind period at 12, 8, and 4 percent soil moisture content.*

Wind Velocity	Soil Moisture Level		
	12	8	4
	-----g/dm ² /hr-----		
Low	.34 ^a	.34 ^a	.10 ^c
High	.52 ^b	.47 ^b	.16 ^d

*Values with the same letter in the superscript are not significantly different at $\alpha = .05$.

TABLE 12.--Relative stomatal aperture of black walnut seedlings after 11 hours of wind at 12, 8, and 4 percent soil moisture content.*

Wind Velocity	Soil Moisture Level		
	12	8	4
Low	2.55 ^a	2.55 ^a	2.36 ^b
High	2.57 ^a	2.52 ^a	2.31 ^b

*Values with the same letter in the superscript are not significantly different at $\alpha = .05$.

that the transpiration and stomatal response of different species to wind may be very different. Under the conditions prevailing in the wind tunnels, a wind velocity of 2.8 m/sec does not appear to be sufficient to cause a stomatal response in black walnut seedlings detectable after 11 hours.

The decreases in transpiration and stomatal aperture observed at 4 percent soil moisture content (7 atm. suction) agree with the general theory of the effects of decreasing soil water content on transpiration and stomatal aperture as briefly described above. At some soil moisture content, less than 8 percent (0.75 atm. suction) but greater than 4 percent (7 atm. suction), the stomata began to close and the transpiration rate began to decrease. It should be noted that these two events need not have occurred at the same soil moisture content or suction. Decreases in transpiration rate with decreasing soil water content or potential have been reported by several researchers (Cox and Boersma, 1967; Jarvis and Jarvis, 1963a; Jarvis and Jarvis, 1963b; Pessin, 1938; Slatyer, 1957). Decreases in stomatal aperture with decreasing soil water content or potential have been reported by Cox and Boersma (1967) in Trifolium repens and Satoo (1962) in Quercus acutissima.

Based on these results, the reduced growth of the black walnut seedlings exposed to the 2.8 m/sec wind

velocity cannot be explained by decreases in stomatal aperture resulting in a reduction in the rate of carbon dioxide diffusion and photosynthesis. Perhaps the increased transpiration rate of these plants resulted in the development of a lower plant water potential which, while not low enough to induce stomatal response, in some way affected one or more plant processes involved in growth. It is possible, however, that the reduced growth of the seedlings in the low soil moisture regime may have resulted, at least in part, from the decrease in stomatal aperture causing a reduction in the carbon dioxide diffusion rate and photosynthesis. In addition, it is also possible that the lower soil water potential caused lower plant water potentials to develop which affected one or more of the plant processes involved in growth.

CHAPTER IV

SUMMARY AND CONCLUSIONS

This study was designed to examine the growth response of black walnut to (1) the influence of wind barriers on field planted seedlings and (2) the effects of a controlled environment where wind velocity approximates that to which field grown black walnut seedlings are normally exposed.

The influence of wind barriers on first-year black walnut seedlings was examined by comparing the growth response and microenvironment of seedlings growing on the leeward side of wind barriers with that of seedlings growing in adjacent unprotected areas. The study was initiated on May 16, 1970, when the germinating walnut seed was planted, and ended during the week of September 15, 1970, when the seedlings were harvested. During this time various climatic and edaphic factors were monitored in both protected and exposed plots. Seedling stem height and diameter were measured every 2-3 weeks and, at the end of the study, the seedling stem height, stem diameter, total leaf area, oven-dry weight of stem, foliage, and root, and depth of root penetration were determined. On September 2, 9, 10, and 11 the

xylem sap tensions of the seedlings in both the exposed and protected plots were measured throughout the day with a pressure bomb to determine if the wind barriers had any effect on the seedling's internal water status.

The wind barriers considerably affected the microenvironment and growth of the black walnut seedlings. The wind velocities in the protected plots were reduced to 33 percent of those in the exposed plots. The total solar radiation received by the seedlings in the protected plots averaged 82 percent of that received in the exposed plots. This reduction in radiation did not occur equally on all days but was greater on relatively clear days than on overcast days. Maximum air temperatures averaged 2.9°C higher and minimum air temperatures 1.6°C higher in the protected plots. On clear days the air temperature in the protected plots was several degrees higher in the morning and early afternoon and lower in the middle and late afternoon than the temperature in the exposed plots. On overcast days the temperatures in the exposed and protected plots were quite similar throughout the day. There was no significant difference between the exposed and protected plots in the atmospheric relative humidity or the average temperature or moisture content of the upper 15 cm of soil. All of these effects can be explained by the effects of the barrier in reducing the wind movement in the protected plots and/or

shielding the protected plots from the greater proportion of the solar radiation from the western sky.

The presence of the wind barriers increased the size of the black walnut seedlings in all growth parameters measured except depth of root penetration (Table 13). The root/shoot weight ratio of the seedlings in the protected plots was 22 percent less than that of the seedlings in the exposed plots.

The increased seedling size in the protected plots was due, in part, to greater height growth on the protected plots throughout the growing season and a significantly greater height and diameter growth rate in the protected plots after August 3. Leaf senescence was evident on the seedlings in the exposed plots by the latter part of August while seedlings in the protected plots showed little evidence of senescence by mid September. This early senescence of the leaves in the exposed plots may be related to the decline in growth rates observed in the exposed plots.

Observation of the xylem sap tension of the seedlings during September indicated that in both the protected and exposed plots it rose rapidly following sunrise until around midday when the rate of change became relatively slow. This plateau was maintained until around 4:00 p.m. when the tension began to decrease. There was no significant difference in the xylem sap

TABLE 13.--Comparative growth response of 18-week-old black walnut in exposed and protected field plots.*

Growth Parameter	Growth Increase in Protected Plots %
Stem Height	15
Stem Diameter	14
Stem Dry Weight	46
Total Leaf Area	85
Average Leaflet Length	12
Average Leaflet Width	9
Average Number of Leaflets	46
Foliage Dry Weight	158
Shoot Dry Weight	110
Root Dry Weight	27
Total Dry Weight	47

*Significant at at least $\alpha = .10$.

tensions in the protected and exposed plots during the "plateau period" indicating that the wind barriers had no effect on the tensions during this time. Further study is needed to determine if this is true at all times of the day and growing season and under different environmental conditions.

The effects of wind under controlled environmental conditions were studied by examining the growth responses of germinating black walnut seedlings for 80 days under two wind velocities (<0.1 m/sec or 2.8 m/sec) and two soil moisture regimes (12 percent drying to 8 percent or 12 percent drying to 4 percent). All other environmental factors were maintained at levels within the range of natural conditions.

The growth response of the seedlings to the treatments was examined by periodically measuring the stem diameter, stem height, and the leaf area of each seedling and determining the oven-dry weights of the seedling leaves, stem, and roots at the conclusion of the study. The transpiration rates and average stomatal aperture were determined during the last 20 days of the study for each seedling at 12 percent, 8 percent, and 4 percent soil moisture after 11 hours of exposure to its wind treatment.

The effects of the two wind velocities and soil moisture regimes on the black walnut seedlings are

summarized in Table 14. Exposure to the higher wind velocity had no significant effect on seedling stem height, stem diameter, or number of leaflets but significantly reduced all other growth parameters measured. There was no significant difference between the root/shoot weight ratio in the two wind treatments. The low soil moisture regime caused a decrease in all observed growth parameters and significantly reduced the root/shoot weight ratio by 25 percent. The growth reductions caused by the lower soil moisture regime were greater in all parameters measured than those caused by the higher wind velocity.

No differences were observed in the height and diameter growth patterns between seedlings in the high and low wind velocities or between those in the high and low soil moisture regimes.

Exposure to the higher wind velocity significantly increased the average transpiration rate at all soil moisture levels by an average of 50 percent but had no significant effect on the stomatal aperture. The transpiration rates and stomatal apertures at 12 percent and 8 percent soil moisture content were not significantly different. However, at 4 percent soil moisture content the transpiration rate was 70 percent less than that at 8 percent or 12 percent and the average stomatal aperture was significantly smaller.

TABLE 14.--Comparative growth response of 80-day-old black walnut in two wind velocities and two soil moisture regimes.*

Growth Parameter	Growth Decrease (High Wind Velocity)	Growth Decrease (Low Soil Moisture Regime)
	-----g-----	-----
Stem Height	n.s.	18
Stem Diameter	n.s.	18
Stem Dry Weight	17	45
Total Leaf Area	15	52
Average Leaflet Length	11	30
Average Leaflet Width	7	30
Average Number of Leaflets	n.s.	18
Foliage Dry Weight	23	52
Shoot Dry Weight	21	48
Root Dry Weight	22	56
Total Dry Weight	21	53

*Differences significant at $\alpha = .05$.

Based on the transpiration and stomatal aperture data, the reduced growth of the black walnut seedlings exposed to the 2.8 m/sec wind velocity cannot be explained by decreases in stomatal aperture causing a reduction in the rate of carbon dioxide diffusion and photosynthesis. Perhaps the increased transpiration rate of these plants resulted in the development of a lower plant water potential which, while not low enough to induce stomatal response, affected one or more of the plant growth processes. It is possible, however, that the reduced growth of the seedlings in the low soil moisture regime may have resulted, at least in part, from the decrease in stomatal aperture. It is also possible that the lower soil water potential caused lower plant water potentials to develop which influenced one or more of the plant growth processes.

In summary, the results of these two studies indicated (1) that a constant wind velocity, approximating the average wind velocity that naturally growing black walnut seedlings are normally exposed to, can cause significant decreases in the seedling's growth and (2) the use of wind barriers to reduce the force of wind striking black walnut seedlings will result in significant increases in the seedling's growth. In addition to reducing wind movement, the barriers also affect solar radiation, air temperature, and, undoubtedly, soil surface temperature.

LITERATURE CITED

LITERATURE CITED

- Anonymous. 1961. Metea soil series description. National Cooperative Soil Survey, U.S.A. 2 pp.
- Baten, W. D. and A. H. Eichmeier. 1951. A summary of weather conditions at East Lansing, Michigan prior to 1950. Mich. St. Col., Agric. Exp. Sta. 63 pp.
- Begg, J. E., J. F. Bierhuizen, E. R. Lemon, D. K. Misra, R. O. Slatyer, and W. R. Stern. 1964. Diurnal energy and water exchanges in bulrush millet in an area of high solar radiation. Agric. Met. 1: 294-312.
- Caldwell, M. 1970. Plant gas exchange at high wind speeds. Plant Physiol. 46: 535-537.
- Carpenter, Stanley B. 1971. Developmental changes in assimilation and translocation of photosynthate in black walnut (*Juglans nigra* L.) and honeylocust (*Gleditsia triacanthos* L.) seedlings. PhD. dissertation, Mich. St. Univ.
- Cliff, E. P. 1966. The increasing challenge of decreasing quality. pp. 1-3. In Black walnut culture. N. Cent. For. Exp. Sta., St. Paul, Minn. No series. 94 pp.
- Cox, L. M. and L. Boersma. 1967. Transpiration, soil temperature, and water stress. Plant Physiol. 42: 550-556.
- Dirmhirn, I. 1953. Zur Strahlungsminderung an Windschutzstreifen. Wetter und Leben 5: 208-213.
- Finnel, H. H. 1928. Effect of wind on plant growth. J. Amer. Soc. Agron. 20: 1206-1210.
- Fourt, D. F. 1968. Sitka spruce, shelter and moisture. Res. Developm. Pap. For. Comm., Lond., No. 72. 8 pp. (Forestry Abs. 30: 430. No. 3647).
- Fowells, H. A. 1965. Silvics of forest trees of the United States. U.S.D.A. Handbook No. 271: 203-207.

- Geiger, R. 1966. The climate near the ground. Harvard Univ. Press, Cambridge, Mass.
- Glerum, C. and G. Pierpoint. 1968. The influence of soil moisture deficits on seedling growth of three coniferous species. For. Chron. 44: 26-29.
- Gloyne, R. W. 1965. Some characteristics of the natural wind and their modification by natural and artificial obstructions. Sci. Hort. 17: 7-19.
- Hill, L. 1921. The growth of seedlings in wind. Royal Society Proc., B, 92: 28-31.
- Hogg, W. H. 1965a. Measurement of the shelter effect of land forms and other topographical features and of artificial windbreaks. Sci. Hort. 17: 20-30.
- _____. 1965b. Report on work at experimental horticulture stations with shelter screens. Sci. Hort. 17: 61-66.
- Jarvis, P. G. and M. S. Jarvis. 1963a. The water relations of tree seedlings. I. Growth and water use in relation to soil water potential. Physiol. Plant. 16: 215-235.
- _____. 1963b. The water relations of tree seedlings. II. Transpiration in relation to soil water potential. Physiol. Plant. 16: 236-253.
- Jaynes, R. A. 1969. Handbook of North American nut trees. W. F. Humphrey Press, Inc., Geneva, New York.
- Kaufmann, M. R. 1968. Water relations of pine seedlings in relation to root and shoot growth. Plant Physiol. 43: 281-288.
- Khattak, G. M. 1968. Early response of planted black walnut to site modification. Ph. D. Dissertation, Mich. St. Univ.
- Lausher, F. 1934. Warmeausstrahlung u. Horizonteinengung. Sitz-B Wien. Akad. 143: 503-519. (Cited by Geiger, R. 1966. The climate near the ground. Harvard Univ. Press, Cambridge, Mass.).
- Martin, E. V. and F. E. Clements. 1935. Studies of the effect of artificial wind on growth and transpiration in Helianthus annuus. Plant Physiol. 10: 613-636.

- Meidner, H. and T. A. Mansfield. 1968. Physiology of stomata. McGraw-Hill Book Comp., New York.
- Metcalf, W. 1936. The influence of windbreaks in protecting citrus orchards. J. For. 34: 571-580.
- Miller, Elwood L. 1970. Studies of environmental factors affecting jack pine (Pinus banksiana Lamb.) regeneration. Ph.D. Dissertation, Mich. St. Univ.
- Miller, L. N. 1965. Changes in radiosensitivity of pine seedlings subjected to water stress during chronic gamma irradiation. Health Phy. 11: 1653-1662.
- Pessin, L. J. 1938. Effect of soil moisture on the rate of growth of longleaf and slash pine seedlings. Plant Physiol. 13: 179-189.
- Quigley, K. L. and R. D. Lindmark. 1966. Timber resources. pp. 6-12. In Black walnut culture. N. Cent. For. Exp. Sta., St. Paul, Minn. No series. 94 pp.
- Randall, C. E. 1967. Black walnut, our vanishing money tree. Amer. For. 73(10): 14-17, 38-40.
- Rao, V. P. 1938. Effect of artificial wind on growth and transpiration in the Italian millet, Setaria italica. Bull. Torrey Bot. Cl. 65: 229-232.
- Read, R. A. 1964. Tree windbreaks for the central Great Plains. U.S.D.A. Agri. Handbook No. 250. 68 pp.
- Rennie, P. J. 1956. The importance of shelter to early tree growth on upland moors. Forestry 29: 147-153.
- Sampson, Joan. 1961. A method of replicating dry or moist surfaces for examination by light microscopy. Nature 191: 932-933.
- Salisbury, F. B. and Cleon Ross. 1969. Plant physiology. Wadsworth Publ. Comp., Inc., Belmont, Calif.
- Sands, K. and A. J. Rutter. 1959. Studies in the growth of young plants of Pinus sylvestris L. II. The relation of growth to soil moisture tension. Ann. Bot. (NS) 23: 269-284.
- Satoo, T. 1962. Wind, transpiration, and tree growth. pp. 299-310. In Tree growth (Ed. T. T. Kozlowski). The Ronald Press Comp., New York.

4

- Schneider, G., G. Khattak, and J. N. Bright. 1970. Modifying sites for the establishment of black walnut. pp. 155-169. In Proceedings of the Third North American Forest Soils Conference. (Editors C. T. Youngberg and C. Davy). Oregon St. Univ. Press, Corvallis, Oregon.
- Scholander, P. F., H. T. Hammer, E. D. Bradstreet, and E. A. Hemmingsen. 1956. Sap pressure in vascular plants. *Science* 148: 339-346.
- Slatyer, R. O. 1957. The influence of progressive increases in total soil moisture stress on transpiration, growth, and internal water relations of plants. *Aust. J. Biol. Sci.* 10: 320-336.
- _____. 1967. Plant-water relationships. Academic Press, New York.
- Stanhill, G. 1957. The effect of differences in soil-moisture status on plant growth: a review and analysis of soil moisture regime experiments. *Soil Sci.* 84: 205-214.
- Steinbrenner, E. C. and J. H. Rediske. 1964. Growth of ponderosa pine and Douglas-fir in a controlled environment. *Weyerhaeuser For. Pap. No. 1*. Centralia, Wash. 31 pp.
- Stoeckeler, J. H. 1962. Shelterbelt influence on Great Plains field environment and crops. U.S.D.A. Production Research Report No. 62. 26 pp.
- Stransky, J. J. and D. R. Wilson. 1964. Terminal elongation of loblolly and shortleaf pine seedlings under soil moisture stress. *Proc. Soil Sci. Soc. Amer.* 28: 439-440.
- Veihmeyer, F. J. and A. H. Hendrickson. 1950. Soil moisture in relation to plant growth. *Ann. Rev. Plant Physiol.* 1: 285-304.
- Wadsworth, R. M. 1959. An optimum wind speed for plant growth. *Annals Bot. (NS)* 23: 195-199.
- Waring, R. H. and B. D. Cleary. 1967. Plant moisture stress: evaluation by pressure bomb. *Science* 155: 1248-1254.
- Weatherly, P. E. 1950. Studies in the water relations of the cotton plant. II. Diurnal and seasonal variations in relative turgidity and environmental factors. *New Phytol.* 50: 36-51.

- Whitehead, F. H. 1957. Wind as a factor in plant growth. pp. 84-95. In Control of the plant environment. (Ed. J. P. Hudson). Acad. Press, Inc. New York.
- _____. 1962. Experimental studies of the effect of wind on plant growth and anatomy. II. Helianthus annuus. New Phytol. 61: 59-62.
- _____. 1963. Experimental studies of the effect of wind on plant growth and anatomy. IV. Growth substances and adaptative anatomical and morphological changes. New Phytol. 62: 86-90.
- Whitehead, F. H. and R. Luti. 1962. Experimental studies of the effect of wind on plant growth and anatomy. I. Zea Mays. New Phytol. 61: 56-58.
- Wilson, C. C., W. R. Boggess, and P. J. Kramer. 1953. Diurnal fluctuations in the moisture content of some herbaceous plants. Am. J. Bot. 40: 97-100.
- Winter, E. J. 1965. Some effects of wind upon vegetable crop plants. Sci. Hort. 17: 53-60.
- Zelitch, I. 1961. Biochemical control of stomatal opening in leaves. Proc. Natl. Acad. Sci. 47: 1423-1433.

APPENDIX

TABLE 15.--Foliar nutrient analysis of 18-week-old black walnut in field study.

Treatment	Nutrient											
	N	P	K	Mg	Na	Ca	Mn	Fe	Cu	B	Zn	Al
	-----g				-----ppm							
Protected Plot	2.39	.24	.85	.28	334	1.59	229	159	11.2	56.1	25	501
Exposed Plot	2.23	.21	.83	.23	231	1.46	289	185	8.8	61.9	21	560

TABLE 16.--Foliar nutrient analysis of 80-day-old black walnut in controlled environment study.

Treatment	Nutrient											
	N	P	K	Mg	Na	Ca	Mn	Fe	Cu	B	Zn	Al
	-----g			-----			-----ppm					
Low Wind, Low Moisture	3.59	.18	1.14	.29	248	1.69	465	76	9.2	45	160	70
Low Wind, High Moisture	3.36	.16	1.31	.23	238	1.53	405	74	10.7	44	154	63
High Wind, Low Moisture	3.60	.16	1.29	.24	306	1.50	401	82	10.4	45	158	80
High Wind, High Moisture	3.45	.18	1.29	.26	272	1.61	360	88	14.9	57	138	88

TABLE 17.--Periodic average stem height of black walnut seedlings in controlled environment study.

Treatment	Days Since Planting									
	0	8	16	24	32	40	48	56	64	80
Low Wind, Low Soil Moisture	3.3	14.8	17.9	18.9	19.1	19.3	19.3	19.5	19.5	19.5
Low Wind, High Soil Moisture	3.3	15.3	19.6	21.2	22.4	22.7	22.9	23.0	23.0	23.0
High Wind, Low Soil Moisture	3.5	13.4	15.5	15.8	16.3	16.4	16.6	16.6	16.6	16.6
High Wind, High Soil Moisture	3.5	16.3	20.4	21.4	22.4	22.7	22.8	22.8	22.8	22.8

TABLE 18.--Periodic average stem diameter at 1 cm height of black walnut seedlings in controlled environment study.

Treatment	Days Since Planting									
	0	8	16	24	32	40	48	56	64	80
Low Wind, Low Soil Moisture	.28	.32	.35	.37	.38	.40	.41	.43	.43	.46
Low Wind, High Soil Moisture	.28	.32	.35	.39	.42	.45	.48	.50	.52	.55
High Wind, Low Soil Moisture	.28	.33	.34	.36	.37	.39	.40	.41	.42	.45
High Wind, High Soil Moisture	.28	.33	.37	.40	.44	.46	.49	.50	.51	.54

TABLE 19.--Periodic average leaf area of black walnut seedlings in controlled environment study.

Treatment	Days Since Planting						
	8	16	24	32	40	48	80
	-----cm ² -----						
Low Wind, Low Soil Moisture	54.5	205.1	305.3	384.9	464.9	511.7	541.0
Low Wind, High Soil Moisture	53.1	240.8	465.1	684.7	911.1	1045.4	1133.3
High Wind, Low Soil Moisture	52.5	180.8	244.8	325.1	387.1	412.1	478.7
High Wind, High Soil Moisture	59.8	280.6	488.0	671.5	836.8	924.9	968.1

TABLE 20.--Periodic average leaflet length of black walnut seedlings in controlled environment study.

Treatment	Days Since Planting						
	8	16	24	32	40	48	80
	-----cm-----						
Low Wind, Low Soil Moisture	1.93	3.37	3.95	4.70	4.92	4.96	5.24
Low Wind, High Soil Moisture	1.90	3.49	4.63	5.46	6.45	6.91	7.33
High Wind, Low Soil Moisture	1.84	3.19	3.71	4.18	4.40	4.45	4.64
High Wind, High Soil Moisture	1.86	3.65	4.67	5.36	5.87	6.10	6.60

TABLE 21.--Periodic average leaflet width of black walnut seedlings in controlled environment study.

Treatment	Days Since Planting						
	8	16	24	32	40	48	80
	-----Cm-----						
Low Wind, Low Soil Moisture	.82	1.54	1.86	2.23	2.37	2.42	2.56
Low Wind, High Soil Moisture	.81	1.60	2.18	2.55	3.07	3.32	3.53
High Wind, Low Soil Moisture	.82	1.52	1.80	2.04	2.17	2.23	2.32
High Wind, High Soil Moisture	.82	1.74	2.23	2.57	2.85	3.00	3.26

TABLE 22.--Periodic average number of leaflets of black walnut seedlings in controlled environment study.

Treatment	Days Since Planting						
	8	16	24	32	40	48	80
	-----#-----						
Low Wind, Low Soil Moisture	33	38	40	40	41	44	44
Low Wind, High Soil Moisture	32	39	44	49	49	49	49
High Wind, Low Soil Moisture	33	35	35	36	38	39	40
High Wind, High Soil Moisture	36	42	47	51	53	55	55

MICHIGAN STATE UNIV. LIBRARIES



31293008091393