# EARLY RESPONSE OF PLANTED BLACK WALNUT TO SITE MODIFICATION

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This is to certify that the

thesis entitled

EARLY RESPONSE OF PLANTED BLACK WALNUT TO SITE MODIFICATION

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ABSTRACT

EARLY RESPONSE OF PLANTED BLACK WALNUT
TO SITE MODIFICATION

by Ghaus Mohammed Khattak

The effects of wind protection, mulching, irrigation, and fertilizer application were investigated during 1967 and 1968 on the early growth of field planted black walnut. The growth criteria used for assessing plant response were leaf area, height, and diameter. Foliar analyses were employed to indicate the nutritional status of the plants. Soil moisture was measured by neutron thermalization in 1967 and gypsum blocks in 1968.

Snow fencing provided wind protection and fresh hardwood chips, mulch. Fertilizer was applied in perforated plastic sacks. Irrigation comprised weekly surface application of 7.5 liters of water to each tree unless at least 2.5 cms. of natural precipitation had been received during the previous week.

Mulching as well as irrigation, separately maintained the 0-30 cms. soil layer at a significantly higher moisture content as compared to the control. None of the treatments applied had any effect on the soil moisture content at the 30-60 cms. depth.

During the first growing season (1967), mulching increased soil K at 15 cms.depth, and irrigation decreased it.

Irrigation increased foliar K from a level indicating deficiency to that characteristic of an intermediate level of nutrition. Fertilizer application increased foliar N but not sufficiently to bring the plants from the intermediate to the normal level of nutrition. Mulching increased leaf area. The response was greatest when wind protection and mulching were combined -- the two treatments together increasing leaf area by 70 per cent.

By the middle of the second growing season (July, 1968) mulching had increased foliar K concentration by 100 per cent, thereby effectively correcting its deficiency in the mulched trees. Fertilizer application increased foliar K of the unmulched trees, but only to an intermediate level of K nutrition. It also increased N foliar concentration further in the normal range. Both wind protection and mulching separately, increased leaf area, and height and diameter growth. The combined effect of the two treatments was greater than the sum of their separate effects.

Wind velocity up to 10 kilometers per hour did not affect leaf water tension as measured by the Scholander "pressure bomb." The mulching probably increased vegetative growth of black walnut at the site by correcting K deficiency. The ameliorative role of wind protection was probably due to increased temperatures in the shelter of the wind-breaks, and reduced mechanical injury to the leaves.

Ghaus Mohammed Khattak

Direct planting of container grown black walnut would appear to hold considerable promise in farm-forestry due to minimizing root disturbance in planting, prolonging of the first growing season by several weeks, and enabling the plants to effectively absorb soil applied fertilizer even during the first year of application.

# EARLY RESPONSE OF PLANTED BLACK WALNUT TO SITE MODIFICATION

By

Ghaus Mohammed Khattak

A THESIS

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# INTRODUCTION

Black walnut (Juglans nigra L.) timber is highly prized throughout the world. It has consistently been in demand within the United States since the Colonial times and its export to the European countries and to Japan has increased ten-fold in the past ten years (QUIGLEY and LINDMARK, 1966). Because of this heavy use of high-quality stock, its annual cut now exceeds growth by 6 million board feet (RANDALL, 1966). Though the current demand for quality walnut is high, dwindling supplies combined with increasing costs are likely to accelerate the pace of its replacement by substitute products - notably the photographic reproductions.

Can this be avoided? Given the current trend of increasing per capita income in the United States, and the human desire for the authentic, walnut can probably hold its own against substitutes in the foreseeable future provided it does not become so scarce as to lose its price advantage against its plausible substitutes. To insure the future of black walnut in the high-class wood-using industries, therefore, our aim should be to increase the available supplies of quality material as quickly as possible. According to Cliff (1966), supplies can be increased by stimulating

diameter growth of crop trees and by increased planting of genetically superior stock with the most intensive cultural practices feasible economically -- objective: rotation of 40 years for saw timber. Walnut occurs naturally as scattered trees, it can therefore be grown singly or in small groves by most farmers. With the high prices that the trees fetch, the surplus of farmland, and the Government incentives for non-farm land use, it should be economically feasible for a large number of small farmers to invest in intensive growing of walnut.

To produce quality material at short rotations, it is necessary to provide optimum growing conditions to the species. The approach has so far been to recommend walnut planting only on naturally fertile land. Being scarce, such land usually is under more intensive farm uses. The challenge for the silviculturist, therefore, is to devise measures for ameliorating the site conditions of below average farmland to create a more favorable environment for crops of black walnut, also to improve planting and post-planting techniques to insure survival and promote rapid early growth. This is the objective of the present study.

An attempt has been made in this study to investigate a number of practices which may increase the growth rate of walnut. These practices fall under the following categories:

1. improvement in the internal water balance of the plants by irrigation, wind-breaks, mulches, and control of competing vegetation.

2. improvement in the soil nutrient status by the use of fertilizers.

3. improvement in early growth and survival through the development of better container planting techniques.

# REVIEW OF LITERATURE

Since very little has been published on the effects of the treatments applied on black walnut specifically, this review will include the responses of all the plants studied so far to these treatments with the object of clarifying their mode of action on plant growth in general.

## Mulching

The major role of organic mulches is the conservation of soil moisture, though they may also alter the availability of certain nutrients to plants.

Mulches and Soil Moisture Conservation: Mulches conserve soil moisture by increasing the rate of infiltration and decreasing the evaporative losses from the soil surface. By keeping down weeds, they also decrease transpiration losses.

Organic mulches increase soil infiltration rates by offering protection against rain drop impact, improving soil aggregation, and decreasing the frequency of freezing of the surface soil during winter. Duley and Kelly (1939) found that straw and stubble mulches increased infiltration by preventing the formation of a compact

surface layer due to rain drop impact. By favoring the multiplication of fungi, bacteria, and actinomycetes, mulches induce greater aggregation of the surface soil which is conducive to higher infiltration (JACKS, BRIND, and SMITH, 1955). Infiltration is also favored because earthworms increase under organic mulches: their burrows facilitate infiltration directly and their castings increase it indirectly by improving soil aggregation (VON NEIROP and WHITE, 1958). Infiltration is prevented when surface soils freeze. Organic mulches reduce this incidence, thereby favoring infiltration. Kohnke and Werkhoven (1963) found the frequency of freezing at 2.5 cms. depth to be three times as great in bare soils as in the mulched.

The potentialities for decreasing evaporation losses from the soil have been analyzed by Lemon (1956). Mulches, according to him, significantly decrease evaporative losses from the soil only when the soil surface is wet. From field experiments, Russel (1939) concluded that mulches conserved soil moisture only when the rains were adequate and frequent. Depth of mulching, from 4 to 36 metric tons per hectare did not influence moisture conservation.

Mulches and the Availability of Nutrients: Decomposable mulches, in general, increase the availability of P and K. They may increase or decrease N levels depending on their C/N ratio. Studying the effect of organic mulches on coffee in Kenya, Robinson and Hosegood (1959) concluded that mulches reduced soil acidity; increased organic carbon,

Kjeldahl N, exchangeable K, and available P; and decreased exchangeable Ca and Mg. Tukey and Schoff (1963) obtained increases in available P and exchangeable K with decomposable mulches. But Ca, Mg, and soil pH were not affected.

Beneficial Effect on Black Walnut: Seidel (1946) reported a doubling in the height growth of black walnut under broomesedge (Andropogon virginicus L.), wheat straw, and old hardwood sawdust mulches, five years after planting of 3 year old black walnut stocks grafted with one year old grafts of nine horticultural varieties. No explanation was given for this effect.

## Wind Protection

Though winds up to about 3 kilometers per hour may increase assimilation by increasing $CO_2$ diffusion into plant leaves, higher wind velocities are detrimental to growth. Thus Martin and Clements (1935) observed a progressive decrease in leaf area, stem height, diameter, and dry weight of Helianthus annuus L. when wind velocity was increased from 8 to 24 kilometers per hour. Wind velocities up to 3 kilometers per hour increased transpiration rates by about 20 to 30%; at 26 kilometers per hour the increase was 50%. Similar decreases in growth were observed by Whitehead (1963) in corn (Zea mays L.) and Helianthus annuus L. when the wind velocity was increased from zero to 48 kilometers per hour.

The mechanism by which wind reduces plant growth is not known. Both Wadsworth (1959, 1960) and Whitehead (1963) inpute the characteristic effects of wind to increased internal water stress in the plant under high wind velocities - the former contending that the wind-induced decrease in growth was due both to decreased leaf area as well as decreased assimilation rate, the latter maintaining that decreased leaf area alone was responsible for decreased growth, except in extreme cases when the photosynthetic apparatus might also be affected.

Finnell, as early as 1928, reported considerable mechanical injury and deformation of potted marigolds exposed to high wind velocities, in addition to reduced height growth, increased time of maturity, reduced yield of dry matter, and increased number of side branches.

## Irrigation

Irrigation is the most direct means of augmenting soil moisture. Plant growth, however, is determined directly by plant water stress and only indirectly by the soil water status. The effect of irrigation on plant growth will therefore be conditioned by the entire complex of factors which determine the balance between water loss and absorption within the plant. After over 30 years of controversy over whether plant growth was retarded by a reduction in soil moisture content from field capacity to permanent wilting point, it is now generally agreed that

vegetative growth starts declining as soil water is decreased from somewhat below the field capacity (STANHILL, 1957).

Recent work e.g. Sands and Rutter (1959) with 1 and 3 season old potted Scotch pine (Pinus sylvestris L.); Jarvis and Jarvis (1963) with potted seedlings of birch (Betula verrucosa Ehrh), aspen (Populus tremula L.), Scotch pine and Norway spruce (Picea abies (L.) Karst); and Uriu (1964) with 8-10 year old peaches; indicates that an increase in soil tension above about .5 atmospheres is detrimental to growth. Khattak (1965) working with 6 year old "shisham" (Dalbergia sissoo Roxb.) growing on clay loam soil in the irrigated plantations of West Pakistan observed an almost linear increase of wood production with an increase in the depth of water delivered to the trees during the irrigation season (mid-April to mid-October). The volumes of wood produced under different depths of irrigation are given below:

| Depth of water delivered (meters) | Volume of wood produced per hectare (over bark, cu. meters solid) |
|---|---|
| 0.45 | 63 |
| 0.91 | 106 |
| 1.36 | 148 |
| 1.82 | 190 |
| 2.27 | 232 |

## Mineral Nutrient Elements

Certain mineral nutrient elements are essential for the optimum growth and reproduction of plants; the multiplicity of functions performed by them are illustrated in Table 1. Of these nutrient elements, N, K, and Mg are usually deficient for tree crops -- in particular for walnut. N is deficient most often and needs to be added in the largest amounts (REUTHER, EMBLETON, and JONES, 1958; PROEBSTING and SERR, 1966).

Assessing the Nutrition Status of Tree Crops: The considerable depth to which trees exploit the soil for mineral nutrients usually makes soil analysis a poor method for assessing their nutrient status, better correlation usually being obtained between tissue analysis and nutrient status. This is so in walnut (PROEBSTING and SERR, 1966). The plant tissues most often analyzed are the leaves, because they are present throughout the growing season, can easily be identified, and their removal does not harm the plant (KENWORTHY, 1967).

Basis for the Validity of Tissue Analysis: From sand and water culture experiments, and field experiments, it is possible to establish for each plant species the average content of a particular nutrient element associated with desirable growth characteristics. Such "standard values" have been shown to be remarkably constant for a particular

TABLE 1. Role of mineral nutrients in plants (After Evans and Sorger, 1966)

| Mineral Nutrient | Functions performed in plant processes |
|---|---|
| N | Essential component of proteins, amino acids, nucleic acids, and co-enzymes |
| P | Component of sugar phosphates, nucleic acids, nucleotides, co-enzymes, phospholipids, phytic acid, and other compounds; key role in energy transfer |
| K | Co-enzyme for a large number of enzymes |
| S | Component of cysteine, cystine, and methionine in proteins; constituent of lipoic acid, co-enzyme A, thiamine pyrophosphate, glutathione, biotin, adenosine-5-phosphosulfate, and 3-phosphoadenosine-5-phosphosulfate and other compounds |
| Ca | As calcium pectate, a constituent of the middle-lamellas of plant cell walls; co-factor for certain enzymes involved in the hydrolysis of ATP and phospholipids |
| Mg | Required non-specifically by a large number of enzymes; involved in phosphate transfer; constituent of the chlorophyll molecule |
| Fe | Constituent of cytochromes, and of non-heme iron proteins; involved in photosynehesis, nitrogen fixation, and respiratory-linked dehydrogenases |
| Mn | Activation of some dehydrogenases, decarboxylases, kinases, oxidases, peroxidases, and certain other enzymes |
| B | Probably involved in carbohydrate transport |
| Cu | Component of ascorbic acid oxidase, tyrosinase, laccase, monoamine oxidase, uricase, cytochrome oxidase, and galactose oxidase |
| Zn | Constituent of alcohol, glutamine, and lactic dehydrogenases; carbonic anhydrase, carboxypeptidase B, and other enzymes |
| Mo | Constituent of nitrate reductase and xanthine oxidase; necessary for nitrogen fixation |
| Cl | Required for photosynthetic reactions involved in oxygen evolution |
| Co | Essential for free-living and symbiotic nitrogen fixing micro-organisms |

plant species, being dependent mainly on nutrient status and affected by environmental conditions only to a minor degree. Therefore, whenever the observed value of a nutrient element in a tissue sample is much below the "standard value" characteristic of the species, a deficiency of that element can be assumed and a response expected when it is supplied; even though the plant may not be exhibiting any external symptom of the deficiency. "Standard values" have not so far been developed for black walnut but have been for California walnut (Juglans Californica, S. Wats.) and Finn (1966) has used them to indicate a possible deficiency of K in Iowa soils for the maximum growth of black walnut.

Mineral Nutrition of Black Walnut: Systematic studies on the mineral nutrition of black walnut have recently been started (FINN, 1966) but nothing conclusive appears to have been reported so far on the response of the species to fertilization during its early stages of growth.

## OBJECTIVES AND SCOPE

The study was designed to find out if early growth of black walnut could be increased when planted on abandoned farmland. The site ameliorative practices tested were wind protection, irrigation, mulching, and fertilizer application. In addition to measuring gross plant responses to the treatments applied, their effects on such environmental factors as wind velocity, soil moisture, soil and air temperature, were also evaluated. Foliar analyses and leaf water tension measurements were also conducted to gain a better insight into plant response.

Because chemical weed control, careful planting practices, and pruning are prerequisites to intensive silviculture, these were adopted as standard practices over the entire experiment.

Anticipating the growing popularity of container-stock planting in farm-forestry, a preliminary investigation was initiated to compare the growth rates of seedlings raised in "BR-8" wood pulp fibre blocks and papier-mache plantable containers, with 1-0 stock planted bare rooted and germinating nuts planted directly in soil.

## THE EXPERIMENTAL AREA

The field experiments were conducted at the Tree Research Center, in the southeast corner of the Michigan State University campus. Features of the experimental area, relevant to these investigations, are described below:

Meteorological Data: The meteorological data for the Station for 1967 and 1968 growing seasons are given in Table 2. Low temperatures on the 6th and 7th of May 1968 (minimum temperature recorded in the weather station of the Tree Research Center, -3 and -2°C, respectively, killed all the leaves which had just started to develop. A milder frost occurred on May 18 (minimum temperature recorded at the weather station, 0°C) and killed the young leaves of the plants not protected from wind.

Soil: Soil types: the soil types represented in the experimental area are: Kalamazoo sandy loam; well-drained soils with a sandy loam to loam plow layer; 25-64 cms. thick sandy clay loam to clay loam subsoil; pervious sand occurring at 61-107 cms. with bands of variable thickness which are either loamy sand or sandy loam in texture. Metea sandy loam; well to moderately well-

TABLE 2. Meteorological data for Michigan State University Tree Research Center, 1967 and 1968 (part) growing seasons

| Month | Total precipitation (cms.) | Total pan evaporation (cms.) | Relative humidity (%) | | Air temperature, °C | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Max. | Min. | Mean max. | Range of max. | Mean min. | Range of min. |
| | | | | 1967 | | | | |
| June | 15.7 | 14.5 | 90 | 51 | 24 | 16 - 29 | 13 | 5 - 22 |
| July | 2.0 | 16.0 | 90 | 49 | 27 | 20 - 32 | 14 | 9 - 21 |
| August | 8.4 | 18.8 | 92 | 47 | 26 | 17 - 31 | 11 | 4 - 17 |
| Sept. | 7.9 | 19.8 | 92 | 48 | 22 | 6 - 28 | 7 | 0 - 17 |
| | | | | 1968 | | | | |
| May | 11.2 | 9.1 | 89 | 48 | 19 | 11 - 28 | 2 | -3 - 16 |
| June | 20.5 | 2.4 | 80 | 56 | 24 | 18 - 33 | 11 | 8 - 21 |
| July | 5.9 | 10.3 | 83 | -- | 28 | 21 - 34 | 16 | 9 - 23 |

drained with 45 to 61 cms. of sandy loam over loam till, moisture conditions varying with the depth to the loam material.

Chemical Properties: The soils are acidic and of low fertility, deficient especially in K. The soil chemical properties of the site are characterized below:

| Ph | Loss on ignition | $NO_3$-N | Avail. P | Exch. K | Exch. Ca | Exch. Mg |
|---|---|---|---|---|---|---|
| | % | (ppm) | | (kilograms per hectare) | | |
| 5.6 | 2.1 | 16 | 26 | 136 | 895 | 73 |

Moisture Retaining Characteristics: The moisture retained by the soil at the 60 cms. and the 15 atmospheres tensions was determined for the 15, 30, and 45 cms. depths. Two of the 16 plots in each replication were picked out at random and duplicate disturbed and undisturbed samples taken from each of the three depths. The moisture content at 60 cms. tension was determined by saturating undisturbed soil cores for 48 hours and then placing them on a tension table at 60 cms. tension until no more water could be extracted out of them. This normally took about 24 hours. The cores were then oven-dried for 48 hours and the weight of water lost expressed as a per cent of the volume of the cores. These undisturbed cores were also used for the determination of bulk density.

The moisture content at 15 atms. tension was determined by the porous plate apparatus. The disturbed samples

were saturated on the porous plate for 24 hours and then subjected to a pressure of 15.5 kilograms per square cm. until no more water could be extracted from them. This normally took about 24 hours. The samples were then oven-dried and the per cent moisture content by weight converted to per cent moisture content by volume, by multiplying with the bulk density for the sampling point. A summary of the data is given in Table 3.

TABLE 3. Mean bulk densities and soil moisture content at 60 centimeters and 15 atmospheres tensions

| Depth (cms.) | Bulk density, grams per cubic centimeter | | Soil moisture content, per cent by volume | | | |
|---|---|---|---|---|---|---|
| | | | 60 centimeters tension | | 15 atmospheres tension | |
| | Mean | Range | Mean | Range | Mean | Range |
| 15 | 1.47 | 1.37-1.62 | 23.4 | 17.2-27.0 | 5.9 | 2.6-8.5 |
| 30 | 1.59 | 1.48-1.76 | 21.4 | 18.1-25.0 | 5.3 | 1.4-10.2 |
| 45 | 1.66 | 1.55-1.83 | 20.3 | 14.9-26.7 | 6.9 | 2.7-15.7 |

## AMELIORATION OF SITE CONDITIONS FOR PLANTED SEEDLINGS

The principal field study comprised an evaluation of the effects of wind protection, mulching, irrigation and fertilization on the growth of planted 1-0 black walnut seedlings. The importance of chemical weed control was so well known that it was applied uniformly rather than as a separate treatment.

Description of Treatments: Wind protection: wind protection, where prescribed, was provided by three thicknesses of 1.4 meters high snow fence. The rows of walnut were planted 1.5 meters to the leeward of the wind-break. The L-shaped wind-breaks were oriented with their long arms roughly north-south, across the predominant wind direction. Short cross arms, 5 meters in length, were provided at the southern ends of the wind-breaks to offer protection from the south-westerly winds.

Irrigation: due to the onset of a prolonged dry spell towards early spring, all the plants were irrigated about a week after planting to avoid heavy mortality. Subsequent irrigations were applied only to the plants for which the treatment was prescribed. Unless it had rained more than

2.5 cms. during the previous week, 7.5 liters of water were applied once every week to all the plants allotted to this treatment. The water was poured inside of retaining rings about 2.2 cms. in radius and 5 cms. high, made by encircling each plant with aluminum "lawn-stop" strips. The irrigations were applied on the 19-20 May; 2-3 June; 13, 21, 28 July; 2, 8, 17, 22 August. Beyond the 22nd of August, it was not considered necessary to irrigate as by then active growth had ceased and soil moisture generally remained adequate after this date.

Soil moisture was measured once every week with a Nuclear-Chicago Corporation model P 19 neutron depth moisture gauge equipped with model 2800 portable scaler, (Figure 1), positioning the probe with its center at 15 and 45 cms. below the soil surface.

Mulching: about 2.5 cms. thick layer of fresh hardwood chips was applied to 3 x 1.5 meter strips, with a group of three plants representing each treatment in the center of the strip; the mulch thus covered the soil for at least 75 cms. all around the plants.

Fertilizer application: a plastic sack[1] containing 56 grams of 16:8:16 soluble fertilizer (WHITE and ELLIS, 1965) was buried with each plant for which this treatment was indicated.

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[1]Obtained commercially from S & D Products, Inc., Prairie duChien, Wisc. Contain ammonium nitrate, ammonium phosphate and muriate of potash.

Figure 1. Measurement of soil moisture with Nuclear-Chicago depth neutron probe and portable scaler.

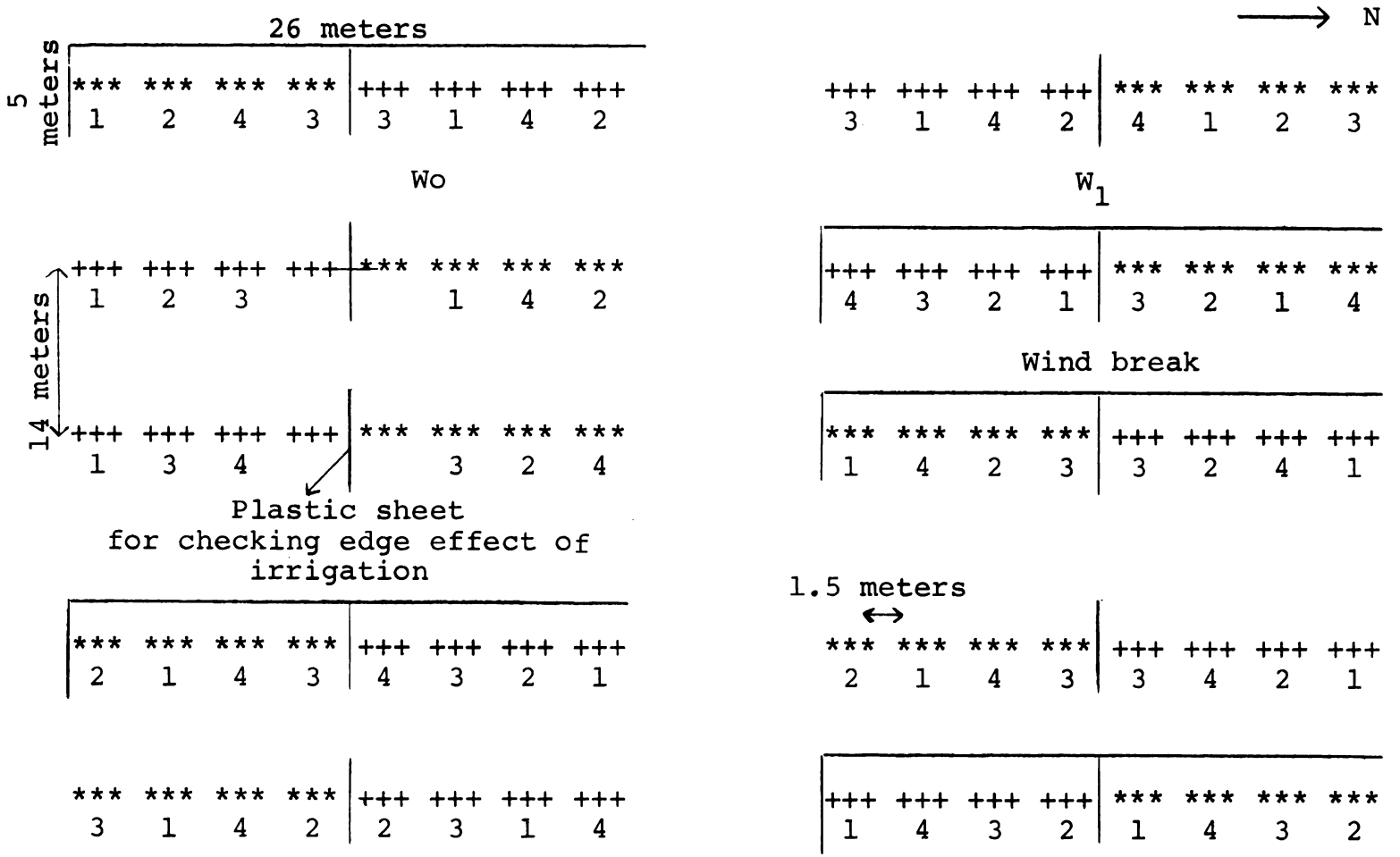
The sacks were placed about 15-23 cms. deep and 7 cms. to the side of the root. Four equally spaced holes 1.2 mm in diameter had been punched through the sacks to permit slow diffusion of nutrients into the soil.

Design of the Experiment: A split-split plot design was used with the treatments arranged as in Figure 2. This design was adopted for the following reasons:

1. The first main split was provided because it was considered advisable to keep the wind-breaks long enough to prevent wind whipping around the edges. Had 3-4 meter long individual barriers been provided to each treatment comprising three plants, the edge effect would probably have been considerable.
2. The second main split was provided because it was considered preferable to keep together all irrigated subplots to minimize the edge effect of irrigation on the unirrigated plots. As a further precaution against this, a plastic sheet of heavy gauge was buried to a depth of one meter between the irrigated and unirrigated second split main plots.

Operations Conducted: Planting: Black walnut 1-0 stock (seed source 0-3373, Kellogg Farm, Kalamazoo County) which had been root-pruned at 20 cms. depth the previous fall, was lifted from the nursery beds on May 1, 1967, and stored

Figure 2. Layout of black walnut plantation.



in the cold room at about 4°C. During the first week of May, soil pits about 30 cms. in depth and 15 cms. in diameter were excavated by a tractor operated post-hole digger. The seedlings ranged in height from 25-35 cms. and were graded into 2.5 cm. classes. While planting, on the 13-14 of May, the same height class was planted in each replication, starting with the largest from replication V and working towards replication I with the successively smaller. To further even out the effect of variation in size, the largest plants in each 2.5 cms. class were planted at the center of the group of three plants representing a treatment. Almost the entire root system of the stock planted comprised the 20 cms. long stub of tap root, with few fibrous roots. Cultural practices and protective measures adopted are given in Table 4.

## Subsidiary Measurements

Wind velocity measurements were taken over a period of about a month to assess the relative effectiveness of wind-breaks. Soil moisture was measured once every week from July 1 to October 3 in 1967 and soil moisture tension checked during June and July 1968 in conjunction with plant leaf water tension measurements.

Wind Velocity Measurements: Wind velocity measurements were carried out with calibrated and paired totalling cup anemometers; one pair of anemometers in the open and the other behind the wind-breaks. The individual anemometers of a pair were spaced about 9 meters from the ends of the protected or non-protected first split main plots, and the

TABLE 4. Cultural practices and protective measures adopted during the investigations

| Practice | Date applied | Comments |
|---|---|---|
| Pruning of multiple leaders and side branches | Nov. 15, 1967<br>June 15, 1968 | Subsequently, as required by individual plants |
| | Chemical weed control | |
| Amitrol - T | May 3, 1967 | 2.27 kilograms per hectare pre-planting foliar spray |
| | June 15, 1967 | 2.27 kilograms per hectare post-planting foliar spray, plants covered with empty cherry cans |
| Paraquat | Aug. 1, 1967 | 4.75 liters per hectare foliar spray, plants covered with empty cherry cans |
| Amitrol - T | May 1, 1968<br>June 15, 1968 | 2.27 kilogram per hectare foliar directed spray |
| | Insect and disease control | |
| Malathion | June 7, 1967<br>Aug. 2, 1967<br>June 3, 1968 | 10 milliliters of 57 per cent emulsion in 3.8 liters of water |
| Bordeaux mixture | July 20, 1967 | 2:1:50 spray, applied to wet the foliage thoroughly |

same distance apart from each other. The height of installation above ground was 45 cms.

The wind-breaks reduced wind velocity by about 50 per cent in most of the replications (Table 5). The reduction in Replication IV was only about 20 per cent probably because the wind protected half of the replication was on higher ground as compared to the unprotected half.

Soil Moisture Measurements: Measurement of soil moisture was confined to the unfertilized subplots assuming that the adjacent subplots with fertilizer treatment would be at the same moisture content.

Installation of soil moisture access tubes: 60 cms. long galvanized iron access tubes, with the inside diameter just large enough to permit passage of the neutron probe, were driven into slightly narrower augur holes to get a tight fit with the soil, leaving 5 cms. of the tubes above ground. The tubes were capped with rubber stoppers.

Field calibration of the neutron scattering soil moisture meter: field calibration was considered necessary for two reasons:

1. Since measurements were planned at 15 cms. (in addition to 45 cms.) depth, considerable escape of neutrons was anticipated. A correct estimation of moisture content would therefore only be possible if the probe counts at this depth were related to the actual moisture content.

TABLE 5. Effect of wind-breaks on wind velocity

| Replication number | Period of observation | Total wind recorded behind the wind-breaks (kilometers) | Total wind recorded in the open (kilometers) | Total wind recorded behind the wind-breaks as percent of that in the open |
|---|---|---|---|---|
| I | Aug. 28-31 | 194 | 429 | 45 |
| II | Aug. 25-28 | 588 | 1160 | 51 |
| III | Sept. 3-7 | 70 | 139 | 50 |
| IV | Sept. 10-13 | 284 | 357 | 80 |
| V | Sept. 17-22 | 300 | 618 | 49 |

2. Thickness as well as the material of the access tubes used were different from those used in factory calibration.

The data for the field calibration were obtained in the following manner:

1. The undisturbed core samples taken for the determination of the moisture content at 60 cms. tension were used to establish a relationship between the per cent moisture content by volume as determined gravimetrically and the ratio of counts per minute (cpm) soil over counts per minute in the shield of the neutron moisture meter. To enable this, two cores were taken with their centers at each of the 15, 30, and 45 cms. depths after neutron counts had been made with the probes centered at these depths.
2. Since none of the above measurements were taken at a high enough moisture content, supplementary measurements were taken with the Veihmeyer tube when the soil moisture content was high. For this purpose, an access tube was installed at the site of measurement and neutron counts recorded at 15, 30, and 45 cms. depths. Three soil samples were then withdrawn along different radii, at about 2.5 cms. from the access tube, from each of 0-15, 15-30, 30-45, and 45-60 cms. depths.

The per cent moisture content of the samples by volume was determined gravimetrically. The values for 0-15 and 15-30 cms. depths for each measuring site were averaged and considered to represent the average moisture content of the upper sphere of soil measured by the cpm soil/ cpm shield ratio of the neutron moisture meter with the probe positioned at 15 cms. from the soil surface. In the same manner, the moisture content of the samples withdrawn from the 30-45, and 45-60 cms. depths were considered to represent the soil moisture content of the lower sphere of soil corresponding to the moisture content indicated by the cpm soil/cpm shield ratio obtained with the probe at the 45 cms. depth.

From the data obtained in the above-mentioned manner, separate regression equations were worked out giving the relationship between neutron moisture meter ratios and the corresponding per cent soil moisture content by volume with the probe at 15 cms. ($Y = 0.6539 + 27.2211\ X$) and 45 cms. ($Y = 2.4512 + 22.3609\ X$) depth.

Measurement procedure: Before starting measurements at any replication, five successive one-minute counts were taken with the probe in the shield, and the average used as the denominator of the ratio cpm soil/cpm shield. While taking counts in the soil, the base of the shield of the probe was

rested on an 8 cms. long aluminum sleeve placed around the above-ground portion of the access tube. The probe was first lowered until its center was 15 cms. below the soil surface. A one-minute count was taken at this depth and then the probe lowered to the 45 cms. depth where another count of a similar duration was taken. The ratios cpm soil/cpm shield for both the depths were converted to per cent soil moisture by volume using Tables prepared from the relevant regression equations.

Soil-Water Tension Measurements: In June 1968, a Bouyoucos block (BOUYOUCOS, 1961) was embedded 30 cms. deep and 15 cms. to the side of the root of the middle plant in each unfertilized 3-tree plot. This reduced the number of blocks needed assuming that the moisture status of the fertilized and unfertilized plots would be about the same provided all other treatments were identical. The blocks were used to record soil moisture tension while measuring plant water tension.

Plant-Leaf Water Tension Measurements: Since walnut has a large root system, it is not possible to characterize the soil moisture status in its root zone by one or two measurements. Moreover, soil moisture is not the only factor determining the availability of water within the plant for various life processes and for the maintenance of turgor. Perhaps of greater importance are the various environmental factors which govern the steepness of the vapor pressure

gradient from the plant leaf to the atmosphere. The interplay of all these factors would be reflected in the tension with which water is held within the plant at any instance. Especially for deep rooted tree species, this tension would perhaps indicate more meaningfully than soil moisture alone can, the moisture stress to which the plant is subject at any time.

When a leaf is severed from an actively transpiring plant, the water in its xylem elements recedes a certain distance depending on the magnitude of the tension at which it was held within the plant. If the cut leaf is placed inside a "pressure bomb," with its petiole protruding through a rubber "compression gland" (Figures 3 and 4) and the pressure within the "bomb" increased, the water which had receded from the cut end would be forced back towards it until it starts bubbling out. The pressure at which this water just wets the cut end can be considered to equal the tension at which water was held in the xylem elements of the leaf just before it was cut (SCHOLANDER et al., 1965).

The "pressure bomb" was used to find out if any of the treatments, especially wind protection, influenced the tension at which water was held inside the leaf. A 15 cms. length of rachis was standardized as the suitable size of leaf to use for each measurement. About .25 cms. of the petiole was allowed to protrude out of the "bomb." Only mature leaves were used for the measurements. The leaf was placed inside the "bomb" within about half a minute of

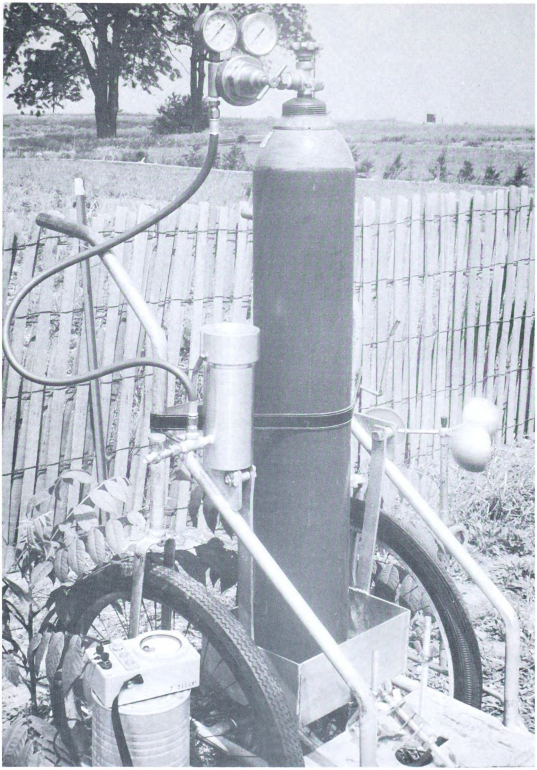


Figure 3. Measurement of walnut leaf water tension by Scholander "pressure bomb" and soil water tension by Bouyoucos blocks. View shows detail of wind break and position of totalizing anemometer.

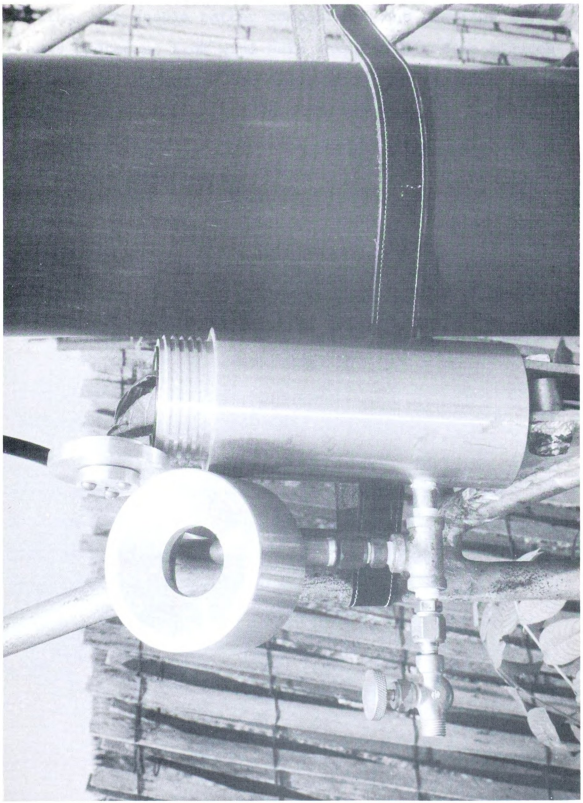


Figure 4. Leaf in the "bomb," with the rachis protruding through the rubber "compression gland" in the top.

cutting. To enable better comparison, the readings for plants protected from wind were taken within five minutes of those in the open. Air temperature was recorded at each tension measurement, wind velocity and relative humidity at 1-2 hour intervals, and soil water tension once during each day of measurement.

## Effects of Mulching and Irrigation on Soil Moisture

0-30 cms. Soil Layer: The moisture status of the 0-30 cms. soil layer during the 1967 growing season is depicted by Figure 5 and the complete data in Appendix I. Wind has not been taken into account in Figure 5 because neither its main effect nor its interaction with any treatment was significant statistically.

Of the treatments applied, both mulching and irrigation maintained the soil at a significantly higher (1% level) moisture content as compared to the control.

To follow the daily course of soil moisture after irrigation, the soil moisture content of the irrigated plots was measured 6 hours after the irrigation on August 8, and then on 9, 10, 11, 13, and 15. There was no rain during this interval. The results are given in Table 6 and Figure 6. The data suggest the following:

1. Out of the treatments applied, irrigation plus mulching maintains the highest moisture content in the 0-30 cms. soil layer throughout the week between successive irrigations.
2. Irrigation, unaccompanied by mulching, maintains a higher moisture content than the unirrigated

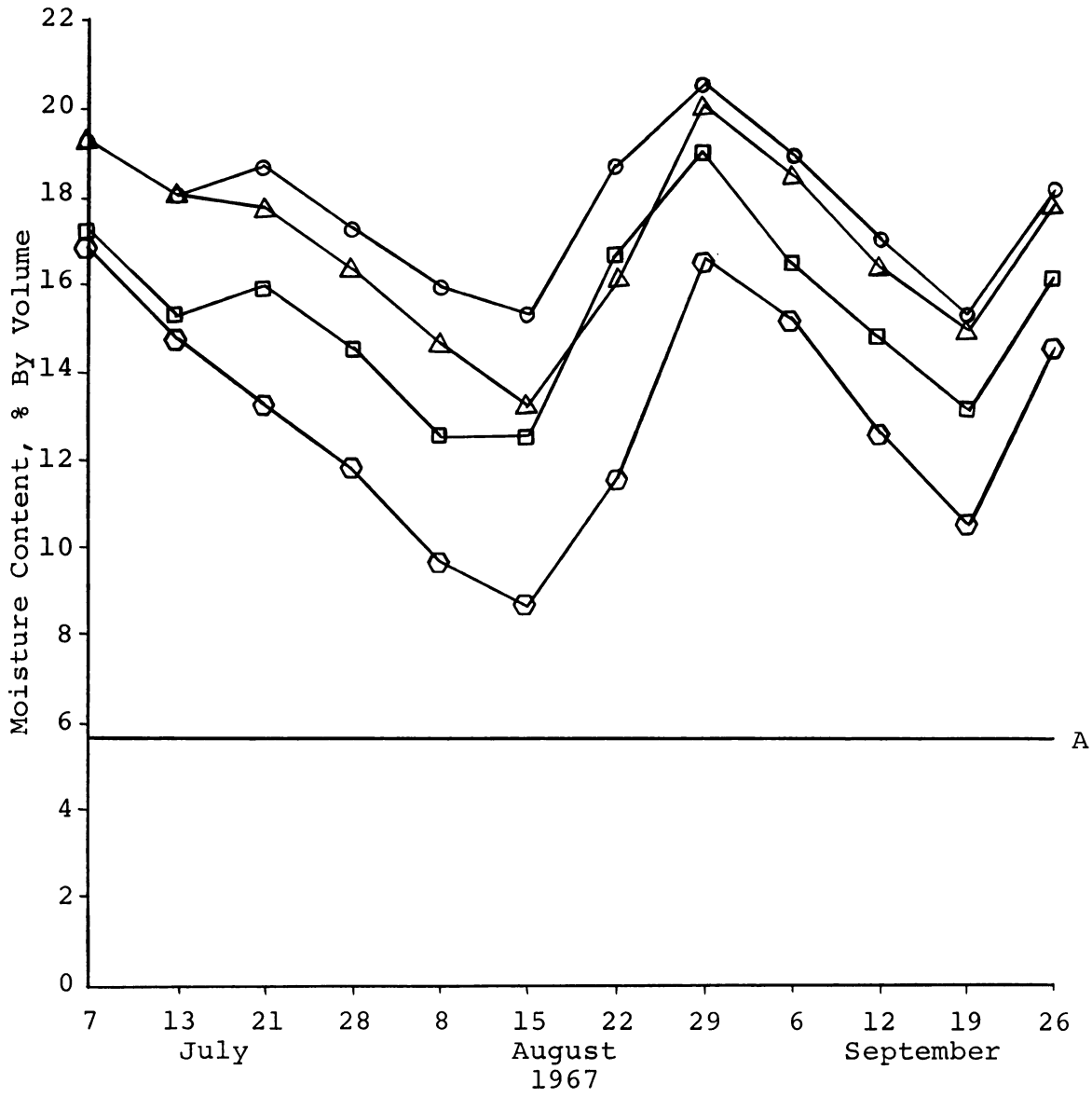



Figure 5. Moisture status of the 0-30 cms. soil layer under the treatments applied.

TABLE 6. Daily course of soil moisture following irrigation

| Treatment | August, 1967 | | | | | | |
|---|---|---|---|---|---|---|---|
| | 8[1] | 8[2] | 9 | 10 | 11 | 13 | 15 |
| | (Mean moisture content, per cent by volume)[3] | | | | | | |
| Irrigation plus mulching | 15.9 | 23.0 | 19.7 | 18.3 | 17.6 | 16.9 | 15.3 |
| Irrigation, no mulch | 12.6 | 19.9 | 17.6 | 15.7 | 14.8 | 13.5 | 12.6 |
| No irrigation, mulch | 14.7 | | | | | | 13.2 |
| No irrigation, no mulch | 9.7 | | | | | | 8.6 |

[1]Before irrigation

[2]6 hours after irrigation

[3]Mean moisture content at 60 cms. tension = 22.4%
Mean moisture content at 15 atmospheres tension = 5.6%

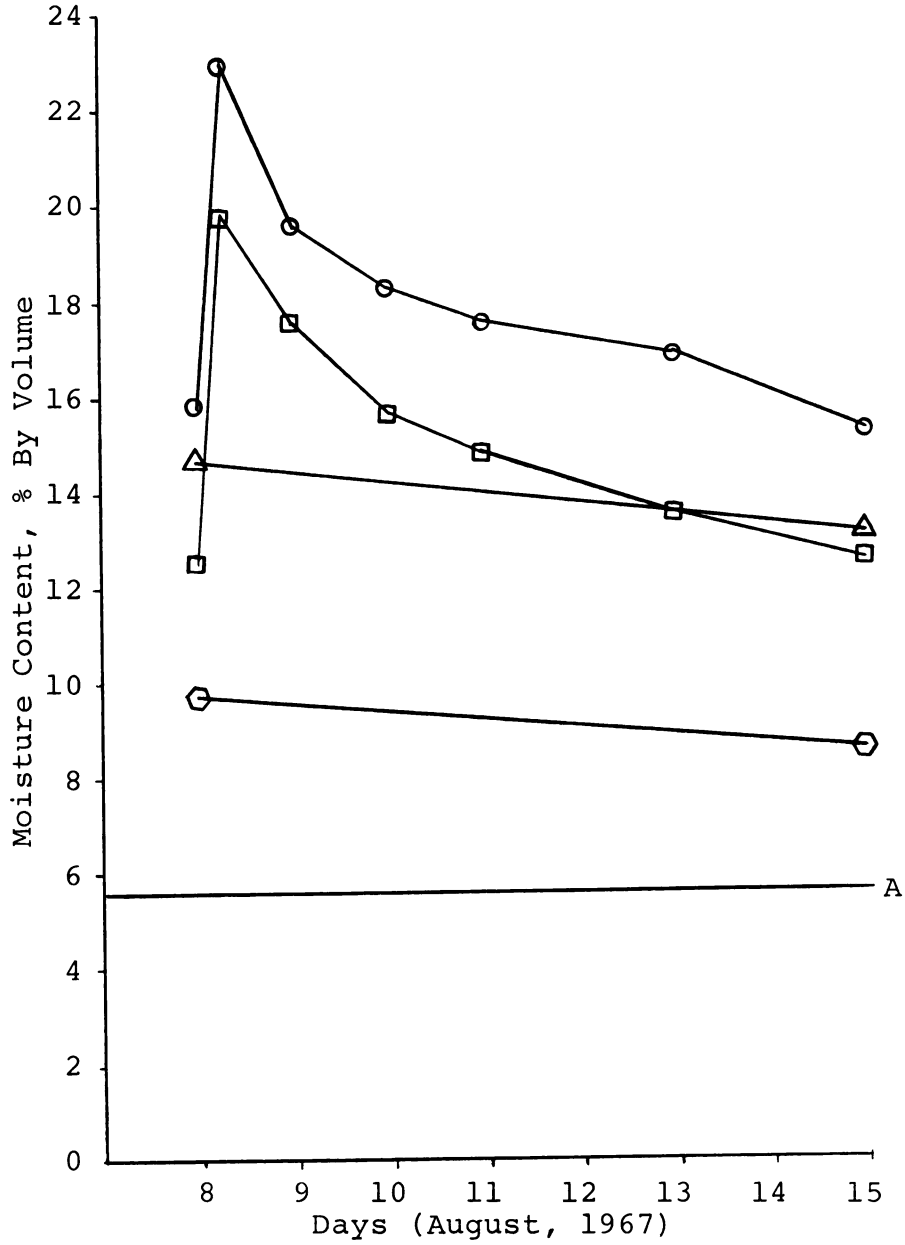



Figure 6. Daily course of soil moisture in the 0-30 cms. soil layer, following irrigation.

mulched plots only during the first half of the week.

30-60 cms. Soil Layer: None of the treatments applied, including irrigation, had any effect on the moisture content of the 30-60 cms. layer. The moisture status of the 30-60 cms. soil layer is depicted in Figure 7. Complete data are given in Appendix II.

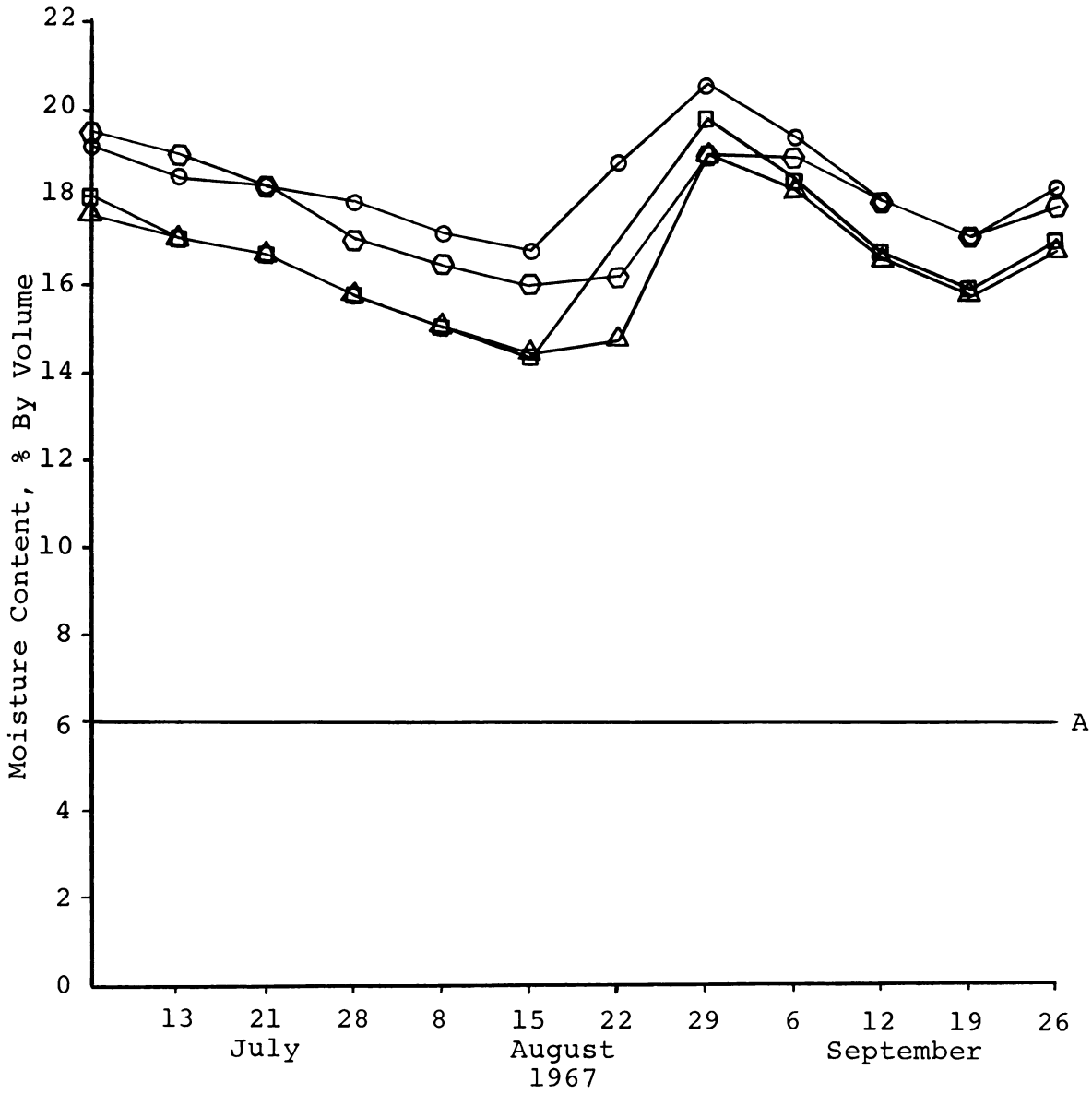



Figure 7. Seasonal moisture status of the 30-60 cms. soil layer under the treatments applied.

## Effect of Wind-Breaks on Temperature and Relative Humidity

Air temperature and relative humidity were recorded in the open and behind the wind-breaks on July 16 and 20 from sunrise to sunset and on July 21 from about 12 noon to 4:30 p.m. Air temperature was measured by mercury thermometers and relative humidity by sling type psychrometer. The measurements were carried out at the level of the plant crowns.

Air Temperature: Air temperature was 1 to 4°C higher behind the wind-breaks as compared to the open. This reflects their effect in reducing wind velocity. The greatest difference in temperatures occurred about 11:00 a.m. to about 4:00 p.m. The data for July 16, 1968 (Replication II) are representative of the general trend found during the latter part of July 1968 (p. 41).

Soil Temperature: Soil temperature was recorded at 7 cms. depth on July 28, 1968, in Replication V, in two mulched and two unmulched plots, in the open and behind the wind-break. The data are recorded on page 41.

| Time of observation | Air temperature (°C) | | Wind velocity (kilometers per hour) | |
|---|---|---|---|---|
| | Open | Wind-break | Open | Wind-break |
| 7:30 a.m. | 22 | 22 | 8.0 | 3.0 |
| 9:30 a.m. | 29 | 29 | 11.0 | 3.2 |
| 11:00 a.m. | 31 | 33 | 7.7 | 2.4 |
| 1:00 p.m. | 33 | 37 | 6.6 | 2.1 |
| 3.00 p.m. | 33 | 36 | 4.5 | 1.5 |
| 5:00 p.m. | 31 | 32 | 7.0 | 1.3 |
| 7:00 p.m. | 31 | 32 | 5.3 | 1.6 |
| 9:00 p.m. | 25 | 26 | 0.0 | 0.0 |

| Time of observation | Open | | Wind-break | |
|---|---|---|---|---|
| | Unmulched | Mulched | Unmulched | Mulched |
| | (mean soil temperature, °C) | | | |
| 10:00 a.m. | 19 | 20 | 21 | 21 |
| 10:30 a.m. | 20 | 20 | 22 | 22 |
| 11:00 a.m. | 21 | 21 | 23 | 22 |
| 11:30 a.m. | 22 | 21 | 24 | 23 |
| 12:00 noon | 23 | 22 | 25 | 23 |
| 1:00 p.m. | 23 | 22 | 26 | 24 |
| 2:00 p.m. | 24 | 23 | 27 | 24 |
| 3:00 p.m. | 24 | 23 | 28 | 25 |

Thus on the day of observation, wind-breaks increased soil temperature at 7 cms. depth in the unmulched plots by 4°C at 3 p.m. The increase was 2°C in the mulched plots. Mulching reduced soil temperature during the noon and afternoon hours by a maximum of 3°C in the plots protected from wind and 1°C in the plots in the open.

Relative Humidity: Relative humidity behind the wind-breaks remained virtually the same as in the open, as brought out by the following figures for July 20, 1968 (Replication III):

| Time of observation | Relative humidity (%) | |
|---|---|---|
| | Open | Wind-break |
| 7:00 a.m. | 97 | 97 |
| 8:00 a.m. | 77 | 77 |
| 10:00 a.m. | 69 | 70 |
| 11:00 a.m. | 63 | 63 |
| 12:00 noon | 56 | 54 |
| 1:00 p.m. | 51 | 51 |
| 2:00 p.m. | 43 | 44 |
| 3:00 p.m. | 40 | 45 |
| 5:00 p.m. | 47 | 47 |
| 7:00 p.m. | 44 | 44 |
| 8:30 p.m. | 66 | 66 |

During this period, the air temperature varied from 14 to 31°C in the open and from 15 to 32°C behind the wind-break; the wind velocity from zero to 6 kilometers per hour in the open, and zero to 2.5 kilometers per hour behind the wind-breaks. Though wind velocities up to 11 kilometers

per hour were recorded in the open (3 kilometers per hour behind the wind-break) on June 16, the relative humidity behind the wind-break remained about the same as in the open.

## Moisture Tension Inside the Leaf

Leaf water tension was measured on July 16 (Replication II) and July 20 (Replication III) from sunrise to sunset and on July 21 (all Replications) from about 12 noon to 4:30 p.m. Air temperature and exact time were recorded as soon as a leaf was cut. The solar radiation values at these points in time were obtained from the Michigan State University solar radiation record maintained by the Department of Agricultural Engineering. Wind velocity and relative humidity were recorded at the beginning and end of each set of observations and the two readings averaged to give the mean values for the duration of the set of tension measurements. To avoid diurnal variations in leaf water tension, the measurements on July 21 were taken between noon and 4:30 p.m. - a plateau for leaf water tension during the day, as established from observations on the 16th, and 20th of July. Air temperature during the observations varied from 30 to 33°C in the open and 31 to 35°C behind the windbreaks; wind velocity from 8 to 10 kilometers per hour in the open and 1.5 to 4 kilometers per hour behind the windbreaks; relative humidity from 47 to 52 per cent. There was no consistent pattern between wind protection and relative humidity. Solar radiation varied rapidly from 0.80

to 2.78 millivolts due to changing cloud pattern. The soil moisture tension under irrigation (both with and without mulch) was less than .25 atmospheres; without irrigation but with mulch it ranged from .25 to .5 atmospheres; and without both irrigation and mulch it varied from .25 to 1 atmosphere. One high ground plot recorded 6 atmospheres. Wind protection had no effect on soil moisture tension.

The mean leaf water tension values observed are given below:

| | No irrigation, no mulch | No irrigation, mulch | Irrigation, no mulch | Irrigation + mulch |
|---|---|---|---|---|
| No wind protection | 13.7 | 13.0 | 12.1 | 11.9 |
| Wind protection | 13.6 | 12.8 | 12.4 | 11.8 |

The data indicate that on the day of observation, wind velocities up to 10 kilometers per hour did not affect the leaf water tension. Though the mean tension in the unirrigated and unmulched plots was about 2 atmospheres higher as compared to the irrigated and mulched, the difference may well be within the normal range of variation.

Moreover, the significance of this magnitude of difference in leaf tension to the growth of black walnut in its third growing season is not known.

Diurnal Variation in Leaf Water Tension: During the initial stages of these preliminary investigations, considerable

variation was observed in the leaf water tension values during the day. To detect a pattern in this variation, observations were taken on the same plants at 2 hour intervals from 7:00 a.m. to 9:00 p.m. on July 16 (Replication II) and July 20 (Replication III). The average water tension in the leaves during the different time periods on July 16 are given below. Also shown are the average values for air temperature, relative humidity, and solar radiation.

| Time Interval | Leaf water tension (atmospheres) | Mean relative humidity (%) | Mean air temperature (°C) | Mean solar radiation (millivolts) |
|---|---|---|---|---|
| 7:00 to 7:38 a.m. | 0.4 | 90 | 22 | 0.41 |
| 9:35 to 10:21 a.m. | 10.1 | 69 | 30 | 1.54 |
| 11:10 to 11:45 a.m. | 11.2 | 65 | 32 | 2.04 |
| 1:22 to 2:00 p.m. | 12.4 | 54 | 34 | 2.00 |
| 3:08 to 3:39 p.m. | 12.4 | 50 | 33 | 1.29 |
| 5:09 to 5:40 p.m. | 10.4 | 54 | 31 | 0.80 |
| 7:11 to 7:43 p.m. | 7.0 | 65 | 31 | 0.11 |
| 8:43 to 8:58 p.m. | 2.4 | 79 | 27 | 0.00 |

There is a sharp increase in leaf water tension from about 7:30 a.m. to about 10:30 a.m. (Figure 8) along with an increase in solar radiation and air temperature, and a decrease in relative humidity. The highest tension is reached when solar radiation and air temperature are at their highest and relative humidity is lowest. Though solar radiation falls to about half the daily maximum after 3 p.m., leaf water tension still remains high, along with a high air temperature and a low relative humidity. It drops abruptly to 2.4 atmospheres around 9 p.m., when solar radiation is reduced to zero, air temperature to 27°C, and relative humidity rises to 79 per cent.

The above course of events would appear to indicate that though solar radiation may be the dominant factor determining leaf water tension in the morning and the evening due to its effect on the opening and closing of stomata, during the mid-day period leaf water tension is more responsive to changes in air temperature and relative humidity.

To speculate on the extent to which wind-breaks may decrease leaf water tension by reducing wind velocity, one must consider that wind-breaks also increase air temperature, and their effect on leaf water tension as reflecting plant water stress, would have to be a resultant of two forces: an increase due to increased air temperature and a decrease (assumed) due to a reduction in wind velocity.

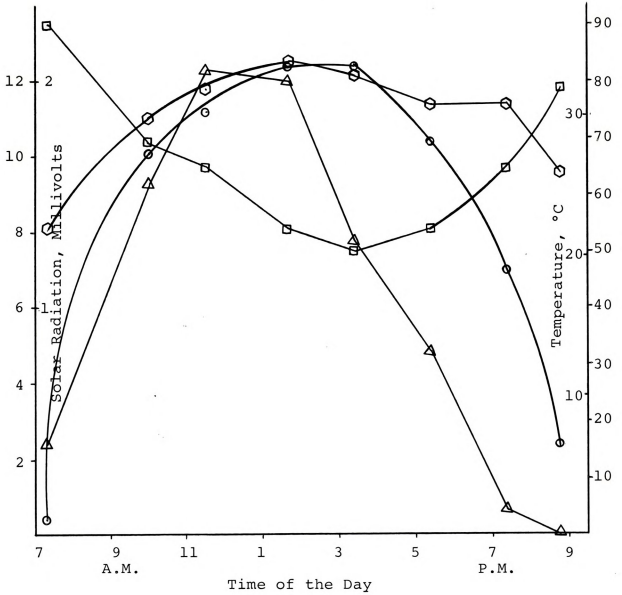



Figure 8. Diurnal variation in leaf water tension of black walnut in the second growing season after outplanting as 1-0, and in air temperature, relative humidity, and solar radiation. Measured July 16, 1968 at the Tree Research Center.

## Effects of the Treatments on Soil Mineral Nutrient Elements

Irrigation and mulching significantly affected the level of exchangeable K at the 15 cms. depth of soil. None of the treatments applied had any influence on the mineral nutrient status of the soil at the 30 cms. depth.

Irrigation: As indicated by the data given below, irrigation significantly decreased (1% level) exchangeable K at the 15 cms. depth (Appendix III):

| Replication | Mean exchangeable K (kilograms per hectare) | |
|---|---|---|
| | Unirrigated | Irrigated |
| I | 184 | 115 |
| II | 143 | 124 |
| III | 163 | 127 |
| IV | 237 | 197 |
| V | 181 | 136 |
| Mean | 182 | 140 |

The above means are based on unmulched plots only as mulching influenced exchangeable K. The data for wind and fertilizer treatments have been combined since these had no effect on exchangeable K. The decrease in K, with irrigation,

can be explained by increased leaching from the sandy soil of the experimental area.

Mulching: In conformity with previous findings (ROBINSON and HOSEGOOD, 1965; TUKEY and SCHOFF, 1963), mulching significantly increased exchangeable K at the 15 cms. depth (1% level). The fresh-wood mulch was probably the source of some of this potassium. The increase is evident from the following values of mean exchangeable K (kilograms per hectare) for the mulched and unmulched plots (Appendix IV):

| | Unmulched | Mulched |
|---|---|---|
| I | 170 | 235 |
| II | 127 | 167 |
| III | 97 | 192 |
| IV | 172 | 280 |
| V | 121 | 215 |
| Average | 137 | 218 |

The above means are based on combined date for fertilizer and wind treatments as neither of these treatments affected the K content of the soil.

This mulch-induced increase in exchangeable K was significantly reduced by irrigation (5% level) as indicated below:

| | Mean exchangeable K (kilograms per hectare) | |
|---|---|---|
| | Unmulched | Mulched |
| Unirrigated | 137 | 218 |
| Irrigated | 121 | 168 |

This effect would appear to follow from the separate effects of mulching and irrigation on exchangeable K described already: the former tending to increase it, the latter to scale it down.

Fertilizer Application in Plastic Sacks: Except for a greener foliage color on the fertilized plots, there did not appear to be much improvement in the fertility level as a result of fertilizer treatments. The following check was applied to find out how much fertilizer had been released from the plastic sacks at the end of the first growing season. The extent of nutrient leaching from the fertilizer packets was measured in an adjoining experiment with tulip poplar seedlings established at the same time. In November 1967 soil was carefully excavated to expose a column of soil, about 15 cms. in diameter, with the dead plant in its center. The fertilizer packets were thus exposed, wedged at the periphery of the soil columns. Soil samples were taken from the face of the column on which the fertilizer packet was found. The samples were taken in 7 cms. layers, starting from the top of the columns,

and going 7 cms. below the packet. The soil immediately in contact with the packet was marked as such. For each of the above points, an adjacent unfertilized planting point, identical in all the other treatments applied, was sampled in exactly the same manner as the fertilized planting point.

The results of soil analyses of these samples for P, K, and N, are given at Appendix V, VI, and VII, respectively. The data indicate that in only two of the five packets had some fertilizer been released from the packets during the first growing season. It was also observed that though the fertilizer inside the packets was moist, it had not lost its granular appearance and there was no evidence of a slurry being formed which could have escaped from the packets through the pin holes.

As an additional check, the packets were oven-dried for 24 hours, allowed to reach equilibrium with the atmosphere for four days, and then weighed. These weights were compared with the mean weight of the remaining 120 packets out of the lot used in the experiment. The results are given below:

Mean dry weight unused packets (gms) $56.4 \pm 1.3$

Weight (dry) of five packets buried in the soil for one growing season (gms.)

1. 53
2. 55
3. 58
4. 58
5. 55

These figures support a conclusion from soil analyses and visual observation of the packets: that there was only a small amount of nutrients released from the packets during the first growing season. Since, as shown in the next section, fertilization significantly increased foliar nutrient content, the lack of weight loss from gravimetric measurements may have been the result of water of hydration gain during field weathering.

## Effects of the Treatments on Foliar Mineral Nutrient Elements

Foliar analysis was employed during the first (1967) and second (1968) growing seasons to assess the mineral nutrition level of the plants subjected to the various treatments.

### First Growing Season Response

On August 20, 1967, two entire leaves were plucked from each plant and the collection bulked for the three trees comprising each treatment. The foliar samples were immediately placed in an oven at 70°C and dried for 24 hours, and then ground in a Wiley mill. The analyses were performed at the Michigan State University's Horticulture Department lab using the Kjeldahl method for N determination, flame photometer for K, and spectroscope of Na, Ca, Mg, Mn, Fe, Cu, B, Zn, and Al. The analyses indicated significant effects of irrigation and fertilizer application on the foliar mineral nutrient status of the plants.

Irrigation: The irrigated plants had significantly higher foliar concentrations of P, and K, and significantly lower foliar concentrations of Ca and Mg. The above observations are in conformity with the established views on the subject.

Thus Hibbard (1959) found that peaches and apples growing under moisture stress are unable to absorb P and K readily, and Cannell et al. (1959) observed higher concentrations of Ca and Mg in the leaves of celery subjected to moisture stress.

P foliar concentration: The following mean values for foliar P concentration (per cent) show its significant increase under irrigation (5% level) (Appendix VIII):

| Replication | Unirrigated | Irrigated |
|---|---|---|
| I | .183 | .212 |
| II | .165 | .212 |
| III | .195 | .190 |
| IV | .173 | .221 |
| V | .179 | .183 |
| Average | .179 | .203 |

The above means are for unmulched plots, combining the data for wind and fertilizer treatments. A similar increase occurred in mulched plots as well -- from .192 to .213 per cent.

K foliar concentration: Irrigation significantly increased K foliar concentration, as reflected in the data given below (1% level) (Appendix IX):

| Replication | K foliar concentration (%) | |
|---|---|---|
| | Unirrigated | Irrigated |
| I | .42 | .92 |
| II | .42 | .67 |
| III | .52 | .90 |
| IV | .76 | 1.06 |
| V | .72 | .54 |
| Average | .57 | .83 |

Since K foliar concentration is influenced by interactions involving almost all the treatments applied, the above means are based on combined data for wind treatments alone. Except for an unusually low value for the irrigated plots of Replication V, the comparisons all indicate considerable increases in the concentration of foliar K in response to irrigation.

Mg foliar concentration: Irrigation significantly decreased Mg foliar concentration (1% level). The effect was modified by the presence or absence of fertilizer (1% level); though irrigation reduced the foliar Mg concentration of both the fertilized as well as unfertilized plants, the reduction was much more pronounced for the fertilized plants (.49 to 37%) as compared to the unfertilized (.44 to .41). (Appendix X for complete data.)

Ca foliar concentration: Irrigation significantly decreased Ca foliar concentration (5% level), the mean of irrigated plants being 1.69 per cent as against 1.82 per cent for the unirrigated (Appendix XI for complete data).

Fertilizer application: Fertilizer application significantly increased N foliar concentration (1% level) as evident from the data given below (Appendix XII):

| Replication | Mean foliar N (%) | |
|---|---|---|
| | Unfertilized | Fertilized |
| I | 2.29 | 2.59 |
| II | 2.41 | 2.54 |
| III | 2.25 | 2.54 |
| IV | 2.36 | 2.54 |
| V | 2.46 | 2.22 |
| Average | 2.35 | 2.49 |

The above means are based on plots afforded wind treatments; the irrigated and mulched plots have not been included due to the significant interactions of these treatments with fertilizer application.

The fertilizer-induced increase in N foliar concentration appeared to be enhanced when irrigation was combined with fertilizer application (5% level). Fertilizer application increased the mean foliar concentration of unirrigated plants from 2.35 to 2.49 per cent and the increase for the irrigated plants was much higher -- from 2.16 to

2.56 per cent. These means are based on combined data for plots under wind protection and no wind protection treatments.

The increase in mean per cent foliar N concentration appeared to occur only in the unmulched plots: (interaction mulching x fertilizer application significant at 1% level): whereas the mean foliar concentration of the irrigated unmulched plots increased from 2.16 to 2.56 per cent with fertilization, there was no increase in the case of the irrigated mulched plots (2.33 for unfertilized, 2.37 for fertilized).

Practical significance: Interesting though these statistical significances may be, it is possible that the only one which had practical significance on the nutritional status of black walnut in the first growing season was the irrigation-induced increase in K foliar concentration, taking the plants out of the deficiency range almost to the verge of the intermediate range, according to the standard values for California walnut (Appendix XIII). The P and Mg levels remain in the normal range in spite of the slight responses to the applied treatments, the N level stays in the intermediate range even after the slight increase from the slow-release packets.

### Second Growing Season Response

On July 17, 1968, leaflets were collected from the three trees comprising each treatment and the collection

for each treatment bulked. Foliar samples were placed in an oven at 70°C, and after drying and grinding, the samples were analyzed for N and K in the same manner as in 1967.

K foliar concentration: Mulching almost doubled the K foliar concentration, taking the plants out of the deficiency range into the normal range for K nutrition. The magnitude of increase is brought out below (Appendix XIV for complete data):

| Replication | Mean foliar K concentration (%) | |
|---|---|---|
| | Unmulched | Mulched |
| I | 0.63 | 1.27 |
| II | 0.55 | 1.06 |
| III | 0.58 | 1.20 |
| IV | 0.82 | 1.36 |
| V | 0.62 | 1.12 |
| Average | 0.64 | 1.20 |

The above means are for unirrigated and unfertilized plants, combining the data for wind treatments. A similar, although smaller, increase occurred in the irrigated plants as well -- from 0.82 to 1.16 per cent.

As indicated below, fertilizer application significantly increased the foliar K concentration of the unmulched plants but not that of the mulched. (Interaction mulching x fertilizer application significant at 1% level):

| | Mean foliar K concentration (%) | |
|---|---|---|
| | Unfertilized | Fertilized |
| Unmulched | 0.64 | 0.87 |
| Mulched | 1.20 | 1.15 |

The above means are for unirrigated plants, combining the data for the wind treatments.

N Foliar Concentration: Fertilizer application significantly increased N foliar concentration (1% level). The magnitude of increase is brought out below (for complete data see Appendix XV):

| Replication | Mean foliar concentration (%) | |
|---|---|---|
| | Unfertilized | Fertilized |
| I | 3.10 | 3.35 |
| II | 2.85 | 3.10 |
| III | 2.57 | 3.10 |
| IV | 2.87 | 3.12 |
| V | 2.59 | 2.91 |
| Average | 2.80 | 3.12 |

Since no other treatment significantly influenced N foliar concentration, the above means are based on the combined data for all the treatments.

## First Growing Season's Growth Responses to the Treatments Applied

### Leaf Area

Leaf area was measured in the first growing season by systematically collecting a 10 percent random sample of leaflets and then applying a previously determined regression of dry weight to leaf area. Details of the two procedures are as follows:

A leaflet was plucked from the middle of the rachis of every alternate leaf of the plant in the center of the group of three plants representing each treatment. The leaflets were traced on paper and their leaf areas measured with a planimeter. Their oven-dry weight was then determined after drying for 24 hours at 70°C. (Appendix XVI.) The regression of leaf area on oven-dry weight was significant (1% level) with 99.7 percent of the variation in leaf area ascribable to variation in oven-dry weight.

A 10 percent random sample of the leaflets was taken from each plant in the following manner:

The total number of leaves and leaflets were counted on each plant. All the leaves on a plant were given serial numbers, starting from below, and lots were drawn from these numbers. As a particular number came up,

one leaflet was plucked from this leaf. The position of this leaflet on the rachis was determined by drawing lots from another set of numbers which represented the total number of leaflets on this particular rachis. As a number came up from this set, the leaflet to be plucked was spotted by counting from the lowermost leaflet, in counter-clockwise direction.

The collection from the group of three plants representing a treatment was bulked and its oven-dry weight determined. The oven-dry weight was converted to leaf area using the regression equation already developed (Y = 0.5535 + 171.8765 X). This value was then converted to leaf area of the group of three plants by multiplying it with the factor: total number of leaflets on the plants/number of leaflets plucked from them.

The treatment-wise mean leaf areas per plant are given in Appendix XVII. Of the treatments applied, only mulching increased leaf area significantly (1% level) during the first growing season. Owing to significant interactions with irrigation and wind protection, the data on page 63 have been taken only from unirrigated plots, not protected from wind. The data from fertilized and unfertilized plots have been combined as neither the main effect of fertilizer application nor its interaction influenced leaf area significantly.

| Replication | Mean leaf area per plant, $cm^2$ | |
|---|---|---|
| | Unmulched | Mulched |
| I | 1368 | 1502 |
| II | 2208 | 1988 |
| III | 1532 | 2114 |
| IV | 2120 | 2725 |
| V | 1595 | 2436 |
| Average | 1765 | 2153 |

The following figures would appear to indicate that though both mulching and irrigation, separately, increased leaf area, irrigating the mulched plots did not increase the leaf area further (interaction mulching x irrigation significant at 1% level).

| | Mean leaf area per plant, $cm^2$ | | | |
|---|---|---|---|---|
| | Wind protection | | No wind protection | |
| | Unmulched | Mulched | Unmulched | Mulched |
| Unirrigated | 1843 | 2947 | 1765 | 2153 |
| Irrigated | 2510 | 2519 | 2370 | 2236 |

The above means represent combined data for fertilized and unfertilized plots.

The effect of mulching in increasing leaf area was considerably enhanced when wind protection was also provided. This mulching x wind protection interaction (significant at 5% level) is brought out below:

| | Mean leaf area per plant, $cm^2$ | |
|---|---|---|
| | Unmulched | Mulched |
| No wind protection | 1765 | 2153 |
| Wind protection | 1843 | 2947 |

The above means are based on the unirrigated fertilized and unfertilized plots. Though wind protection, without mulching, did not increase leaf area, and mulching alone increased it by only 22 percent, mulching combined with wind protection raised it by 67 percent.

## Second Year's Growth Responses to the Treatments Applied

### Leaf Area

During 1968, leaf area was measured in a somewhat less tedious manner as follows:

A leaflet was plucked from the middle of the rachis of the leaf in the center of the crown of the best plant out of the three comprising each treatment. Its leaf area was measured (by planimeter); as were its length (L), and maximum width (W). The length and maximum width were multiplied to give the value L X W. The regression of leaf area on the value L X W was significant (1% level), with 95.7 percent of the variation in leaf area ascribable to variation in the value L X W.

The total number of leaflets were counted on the best of the three trees in each treatment. Four of the entire leaves from each of these plants were picked out at random by drawing lots and the central 3 to 5 leaflets on one side of the rachis of each of these leaves measured for length, and maximum width, making up a 10 percent sample of the leaflets so measured. From these measurements, the length and maximum width were worked out for the mean leaflet of the tree representing each treatment. The product L X W for the mean leaflet was converted to the area of the mean leaflet representing each treatment using the regression equation developed already ($Y = 1.237 + .6502\ X$).

The area of the mean leaflet for each tree was multiplied by the total number of leaflets on the tree to give its total leaf area (Appendix XVIII).

Wind protection (Figure 9) and mulching significantly increased leaf area (1% level), as indicated by the following means based on the combined data for the fertilizer and irrigation treatments:

| Replication | Mean leaf area of the best plant in the treatment, $cm^2$ | | | |
|---|---|---|---|---|
| | No mulch no wind protection | Mulch, no wind protection | No mulch, wind protection | Mulch + wind protection |
| I | 1686 | 1944 | 2576 | 3094 |
| II | 2419 | 2301 | 3359 | 4155 |
| III | 2048 | 2481 | 3960 | 5944 |
| IV | 2367 | 2612 | 4356 | 5602 |
| V | 3134 | 2904 | 4038 | 4949 |
| Average | 2331 | 2448 | 3658 | 4749 |

The interaction of wind protection x mulching was significant (1% level), and is evident from the data given above: whereas mulching alone increased leaf area only by 5 percent, and wind protection alone by 57 percent, both combined more than doubled it--from 2331 to 4749$cm^2$.

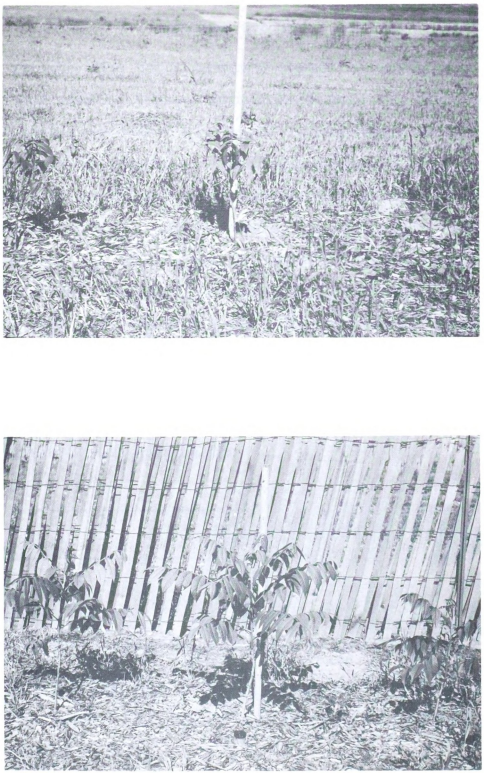


Figure 9. Field planted walnuts in second growing season without wind protection (top) and in the shelter of wind breaks (bottom). Wind protection significantly increased leaf area, height, and diameter.

## Height Growth

Total height: The total terminal height at the middle of the second growing season (measured on July 22, 1968) was significantly increased (1% level) by mulching, as well as wind protection (Figure 9); the interactions of wind protection with mulching and irrigation with mulching were also significant (1% and 5% levels, respectively). These observations are brought out in Table 7. When mulching and wind protection are applied alone, in the absence of irrigation, each caused a 7 percent increase in total terminal height. But when applied together, the combined effect is reflected in a 30 percent increase.

The interaction of mulching with irrigation is illustrated by the data below:

| | Mean total terminal height, cms | |
|---|---|---|
| | Unmulched | Mulched |
| Unirrigated | 47 | 61 |
| Irrigated | 54 | 57 |

Both irrigation as well as mulching increased total terminal height but irrigating the mulched plots did not increase their height further.

Table 7. Effect of wind protection, mulching, and the interactions of mulching with wind protection on the total terminal height of black walnut during the middle of the second growing season following outplanting (Measured July 22, 1968) (See Appendix XIX for complete data)

| Replication | Mean[1] total terminal height, cms | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | No wind protection | | | | Wind protection | | | |
| | Unirrigated | | Irrigated | | Unirrigated | | Irrigated | |
| | No mulch | Mulch | No mulch | Mulch | No mulch | Mulch | No mulch | Mulch |
| I | 40 | 42 | 35 | 44 | 49 | 56 | 57 | 60 |
| II | 44 | 45 | 50 | 50 | 48 | 57 | 47 | 55 |
| III | 43 | 45 | 39 | 44 | 43 | 59 | 50 | 60 |
| IV | 47 | 48 | 54 | 48 | 47 | 57 | 69 | 67 |
| V | 48 | 55 | 49 | 42 | 50 | 75 | 47 | 46 |
| Average | 44 | 47 | 45 | 46 | 47 | 61 | 54 | 57 |

[1]Means based on combined data for fertilized and unfertilized plots

Current year's terminal height growth: The response of the current years' (1968) terminal growth to the applied treatments was similar to that of total height growth. Significant effects were obtained with wind protection and mulching (1% level). The interaction irrigation x mulching was significant (1% level) and that of mulching x wind protection on the border of significance (5% level) (Table 8).

The interaction mulching x irrigation is illustrated by the following data for the wind protected plots, combining the data for the fertilizer treatments:

| | Mean current year's terminal height growth, cms | |
|---|---|---|
| | Unmulched | Mulched |
| Unirrigated | 22 | 37 |
| Irrigated | 28 | 31 |

As observed for total height growth, current year's height growth of the mulched plots does not seem to increase when irrigation was combined with mulching.

## Diameter Growth

Diameter at 2.5 cms. above ground level: As measured on July 22, 1968, during the middle of the second growing season after outplanting, diameter at 2.5 cms. above ground level was significantly increased by mulching, and wind

Table 8. Effect of wind protection, mulching, and the interaction of irrigation and mulching on the current year's (1968) terminal height growth during the second growing season after planting black walnut (measured July 22, 1968) (See Appendix XX for complete data)

| Replication | Mean[1] current year's terminal height growth, cms | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | No wind protection | | | | Wind protection | | | |
| | Unirrigated | | Irrigated | | Unirrigated | | Irrigated | |
| | No mulch | Mulch | No mulch | Mulch | No mulch | Mulch | No mulch | Mulch |
| I | 16 | 16 | 12 | 22 | 25 | 32 | 33 | 38 |
| II | 14 | 21 | 25 | 26 | 21 | 33 | 20 | 26 |
| III | 13 | 20 | 14 | 22 | 14 | 35 | 31 | 33 |
| IV | 19 | 26 | 36 | 29 | 23 | 36 | 38 | 37 |
| V | 14 | 29 | 18 | 17 | 26 | 47 | 20 | 19 |
| Average | 15 | 22 | 21 | 23 | 22 | 37 | 28 | 31 |

[1]Means based on combined data for fertilized and unfertilized plots

protection (1% level), their combination being synergistic (1% level) (Table 9). Though irrigation and mulching, separately, appeared to increase diameter growth, irrigating the mulched plots did not further increase the diameter growth. (Interaction of mulching and irrigation significant at 5% level.)

Diameter at the Base of the Current Year's (1968) Terminal Shoot: Diameter at the base of the current year's terminal shoot (Appendix XXII) is significantly increased by mulching, wind protection, and fertilizer application (1% level), the increase in mean diameter is about 1.0 mm in all cases.

A similar irrigation x mulching interaction as for diameter growth at 2.5 cms. above ground level, was also noticed. As evident from the following figures, though mulching and irrigation, separately, increased diameter, no further increase occurred when mulching was combined with irrigation:

| | Mean diameter at the base of the current year's shoot, cms | |
|---|---|---|
| | Unmulched | Mulched |
| Unirrigated | 0.76 | 0.98 |
| Irrigated | 0.84 | 0.92 |

Table 9. Effect of wind protection, mulching, and interaction of irrigation and mulching on diameter at 2.5 cms. above ground level; black walnut, in its second growing season after outplanting (measured July 22, 1968) (See Appendix XXI for complete data)

| Replication | Mean[1] diameter at 2.5 cms. above ground level, cms | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | No wind protection | | | | Wind protection | | | |
| | Unirrigated | | Irrigated | | Unirrigated | | Irrigated | |
| | No mulch | Mulch | No mulch | Mulch | No mulch | Mulch | No mulch | Mulch |
| I | 0.90 | 0.90 | 0.90 | 1.00 | 1.00 | 1.15 | 1.05 | 1.15 |
| II | 1.00 | 0.95 | 1.00 | 1.00 | 1.05 | 1.20 | 1.05 | 1.15 |
| III | 0.95 | 1.00 | 0.95 | 1.00 | 0.95 | 1.20 | 1.10 | 1.35 |
| IV | 1.05 | 1.05 | 1.20 | 1.10 | 0.90 | 1.20 | 1.30 | 1.30 |
| V | 0.95 | 1.10 | 1.10 | 1.00 | 1.05 | 1.40 | 1.10 | 1.00 |
| Average | 0.97 | 1.00 | 1.03 | 1.02 | 0.99 | 1.23 | 1.12 | 1.19 |

[1]Means based on combined data for fertilized and unfertilized plots

## PLANTING CONTAINER-RAISED BLACK WALNUT

Silvicultural experience in the planting of hardwoods has generally shown a direct correlation between intensive planting care and the initial success of plantations. This is particularly true with tap rooted species such as oak and walnut. There is also limited research data to show that initial black walnut plantation success is directly related to a minimum disturbance to the root system (SEIDEL, 1961).

Walnut develops a deep, fleshy tap root during the first growing season (Figure 10). This tap root is surrounded by a dense fibrous root system which occupies a rather considerable mass of soil the first season and may extend 45 cms. below the surface. When stock is raised in the nursery as 1-0, it already has a root system particularly unadapted to the bare-rooted lifting and planting methods which characterize standard forestry practice. General recommendations for planting nut-seeds have favored direct seeding, particularly because of the advantage of not having to disturb the root system. Current recommendations for black walnut planting (ERDMANN, 1966) mention that direct seeding may be successful if the several site

Figure 10. Root system of 3-month old black walnut raised in soil mix in cardboard milk containers.

and biological limitations to this approach, i.e., rodents, frost, poor germination, etc. could be controlled.

At the beginning of this study we thought that a method of container planting, such as has been successfully used for landscape and horticultural plants should be well suited to this species. The obvious increased cost of this approach is not a serious problem. The long term objective of walnut planting is to produce single high quality trees in 40-60 years which may have a stumpage value in excess of $500 each. Looking at the planting problem in this light, it would be better for a farmer to grow 25 carefully tended trees to maturity than to grow 25 acres of low grade walnut firewood in the same rotation--which incidentally is the future of many field planted walnut groves which have had no cultural care since planting.

The research and development of a "best" planting container was not an objective of this research. However, we settled on two types of planting containers which showed promise in the hope that by getting a head start with container grown trees growing in research plots we might further the establishment of potentially valuable trees.

The types of containers we used are:

1. BR-8 blocks (supplied by American Can Company, Neenah, Wisc.) made of wood pulp fibres with certain additives to prevent rot (Figure 11). The blocks were rectangular - about 20 cms.

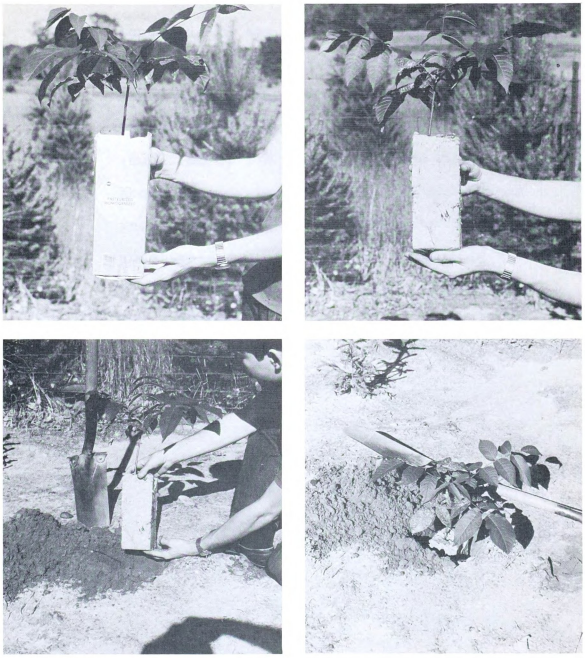


Figure 11. Field planting of greenhouse raised black walnut, six weeks from seed, in BR-8 blocks. Top left: BR-8 blocks inside cardboard milk container. Top right: container removed preparatory to planting, note vigorous roots coming right down to the bottom. Bottom left: BR-8 block being carefully planted to prevent any disturbance to the root system. Bottom right: Final stage in planting. Soil from sides of hole will be carefully packed around block using tiling spade. Top soil will be packed to cover the top of container.

long and 9x9 cms. at the top and bottom ends--and were inserted into 1/2 gallon waxed cardboard milk containers.

2. Papier-mache plantable containers (Figure 12). (supplied by Pullen Pot Co., New Iberia, La.) about 25 cms. long and with top and bottom inside diameters of about 9 and 6 cms., respectively. The pots were filled with a soil mix containing peat, Turface, and loam in a 1:1:1 ratio.

Figure 12. Three-week old black walnut raised in soil mix in papier-mache plantable pots (left). Plant removed to show the root system (right).

## Germination

A pre-requisite for successful container planting is prompt seed germination during the first week of April so that the stock in containers is about three-six weeks old and ready for planting when all danger of frost is over. Experience during 1967 had suggested that stratification at constant temperature in a cold room resulted in delayed germination which continued till October. Needed was a method which could accelerate germination, concentrating it in the first few days of April.

With this end in view, the following germination test was conducted:

Nuts were collected from a single tree in Kellogg Forest in October 1967. Half of them were husked and half left unhusked. Each of the two lots were further subdivided into two: One was stratified in moist vermiculite in the cold room at about 4°C, and the other stratified outdoors in a nursery bed, covering with about 10 cms. of the sandy soil.

On May 1, 1968, all the nuts were removed from stratification and planted immediately in the greenhouse in vermiculite after subjecting each of the above mentioned categories to the following treatments:

$T_1$ - Control

$T_2$ - Gibberellic acid 200 p.p.m. soak for 12 hours

$T_3$ - Thiourea .5% soak for 12 hours

$T_4$ - Thiourea 1% soak for 12 hours

The experiment was thus conducted in the split-split plot design, with husking and not husking as the first main split; field and room stratification as the second main split; and GA and thiourea soaking as subplot treatments in the second main split. Four replications were provided and eight nuts were allotted to each subplot treatment.

The progress of germination is given in Table 10. Thus room stratification proved to be the most inferior method and field stratification of husked nuts better than that of unhusked, with the subplot treatments making no difference to germination.

Similar results were also obtained by Chase (1947) who concluded that the germination of black walnut nuts stratified at controlled temperature (in sand) was significantly lower than that of the nuts planted in fall or stratified outdoors. It may be that some inhibitor leaks out of the nuts during field stratification, or that alternating temperature outdoors has a stimulating effect on germination. The better germination with husk removal would seem to point to the possible role of an inhibitor.

The above trial suggests the following time table of operations for container stock planting in Michigan:

Table 10. Progress of black walnut germination under various treatments

| Replication | Date (1968) | Husked | | | | | | | | Unhusked | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Field stratified | | | | Room stratified | | | | Field stratified | | | | Room stratified | | | |
| | | $T_1$[1] | $T_2$[2] | $T_3$[3] | $T_4$[4] | $T_1$ | $T_2$ | $T_3$ | $T_4$ | $T_1$ | $T_2$ | $T_3$ | $T_4$ | $T_1$ | $T_2$ | $T_3$ | $T_4$ |
| | | (number of nuts germinated out of 8 planted) | | | | | | | | | | | | | | | |
| I | May 4 | 3 | 3 | 4 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| | May 12 | 2 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 3 | 1 | 0 | 3 | 0 | 0 | 0 | 0 |
| | Total | 5 | 3 | 5 | 1 | 1 | 0 | 0 | 0 | 4 | 1 | 1 | 3 | 0 | 0 | 0 | 0 |
| II | May 4 | 2 | 3 | 4 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 0 | 0 | 0 | 0 |
| | May 12 | 1 | 2 | 2 | 3 | 0 | 0 | 2 | 0 | 2 | 3 | 3 | 2 | 0 | 0 | 0 | 0 |
| | Total | 3 | 5 | 6 | 5 | 0 | 0 | 2 | 0 | 2 | 4 | 4 | 4 | 0 | 0 | 0 | 0 |
| III | May 4 | 5 | 4 | 5 | 3 | 0 | 1 | 0 | 0 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| | May 12 | 1 | 2 | 0 | 0 | 1 | 0 | 1 | 1 | 3 | 2 | 1 | 1 | 0 | 0 | 0 | 0 |
| | Total | 6 | 6 | 5 | 3 | 1 | 1 | 1 | 1 | 5 | 3 | 2 | 1 | 0 | 0 | 0 | 0 |
| III | May 4 | 5 | 3 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 |
| | May 12 | 0 | 2 | 2 | 1 | 2 | 1 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 0 |
| | Total | 5 | 5 | 5 | 5 | 2 | 1 | 0 | 0 | 0 | 1 | 2 | 2 | 1 | 0 | 0 | 0 |

[1]Control

[2]Gibberellic acid 200 p.p.m. soak for 12 hours

[3]Thiourea .5% soak for 12 hours

[4]Thiourea 1% soak for 12 hours

1. Collect nuts as soon as ripe (about mid-October)
2. Husk and stratify outdoors, immediately, covering with 10-15 cms. of sand
3. Remove seed from stratification on April 1 and plant in green house in soil, sand, or vermiculite
4. Pot as the seedlings emerge.

Comparison of Planting Container Stock, 1-0 Nursery Stock, and Germinating Nuts

On April 10, fifty germinating nuts which had just split (seed source 5748, Kellogg Forest) were planted in each of the 2 types of containers. An equal number were held in the cold room for direct seeding. For use with the BR-8 blocks, the nuts had to be just split, without the radical protruding so that it could work itself into the block material, otherwise we encountered difficulty in getting an adequate contact between the root and the pulp. A depression was made in the blocks, just large enough to accommodate the nut which was then covered with vermiculite. The containers were kept in the greenhouse and watered as necessary to keep the planting medium continuously moist. From May 10 until outplanting, the stock was exposed to full sun on every sunny day in the shelter of the greenhouse building.

The stock was outplanted on May 21 in moist soil. Preplanting weed control (amitrol T foliar spray) had been applied to the planting site on May 1. Wind protection was provided by parallel wind-breaks of snow fencing erected 10 feet apart against the predominant wind direction. The comparison was laid out in the randomized complete block

design with 6 replications and eight trees spaced 60 x 60 cms. allotted to each of the four treatments: papier-mache containers, BR-8 blocks, 1-0 nursery stock, and germinating nuts planted directly in the soil. No irrigation has been necessary since planting because of regular rains. A post-planting amitrol T spray was applied on June 15. All plants were protected with covering pails during the spraying operation. 28 grams of 8:4:8 NPK liquid fertilizer was applied to each tree in 800 c.c. of water on June 15 and August 8.

Present status: It is too early yet to make a detailed comparison of the methods tried. A visual rating of tree vigor about 3 months after planting would be:

1. Direct seeding
2. BR-8 blocks
3. Papier-mache containers
4. 1-0 stock

Direct planting of germinating nuts have produced plants which appear to be the most vigorous probably because their root systems are in a better position to absorb the added fertilizer. The same would appear to hold for the stock in BR-8 blocks. Even though the plants in papier-mache containers have a well developed root system, it emerges from the container 25 cms. below the soil surface and is thus not able to utilize the applied fertilizer most efficiently.

The 1-0 stock has probably not yet developed an extensive root system capable of absorbing the applied fertilizer efficiently.

## SUMMARY AND CONCLUSIONS

Wind protection and mulching significantly increased the early growth of black walnut. The treatments were synergistic when applied together. A positive response to these treatments was first detected in leaf area measured at the close of the first growing season after outplanting of 1-0 stock. On July 22, 1968, towards the middle of the second growing season, the response could also be detected in total height growth, current year's terminal height growth, diameter at 2.5 cms. above the ground level, and diameter at the base of the current year's shoot.

During the second growing season, wind protection combined with mulching, increased leaf area by 100 percent, total height by 31 percent, height of the current year's terminal shoot by 85 percent, diameter at 2.5 cms. from the ground level by 20 percent, and diameter at the base of the current year's terminal shoot by 25 percent.

Though the main effect of irrigation did not significantly influence any of the growth parameters measured, its interaction with mulching was invariably significant for each of them. It appears that irrigation and mulching separately, increased growth as reflected in the parameters measured; in combination, however, the increase did not

exceed that with mulching alone. The reason for not detecting the significance of the main effect of irrigation may be the design of the experiment adopted, with irrigation as a second split main plot treatment instead of a subplot treatment.

The only visible growth response to fertilizer application was its significant increase of the mean stem diameter at the base of the second growing season's terminal shoot from 0.8 to 0.9 cms. and a marked improvement in foliage color. Fertilizer uptake from the sacks in any quantity, however, only started during the second growing season and it can be expected that the effects of better nutrition will be even more pronounced in the following growing season.

Of the possible mechanisms by which mulching could increase vegetative growth, the one that stands out most prominently is its effect on the K nutritional status of the plants. The plants in the experimental area were deficient in K and mulching apparently corrected this deficiency, as shown by the doubling of foliar K concentration with mulching. Irrigation also increased foliar K concentration but brought the plants only up to the verge of the intermediate range, for K nutrition.

Mulching also maintained the 0-30 cms. soil layer at a slightly higher moisture content (12-21 percent by volume during the 1967 growing season as compared to the

control (11-19 percent for most of the growing season, dropping to 8 to 9 percent for only two weeks in August). It seems unlikely that soil moisture ever became limiting to the growth of black walnut even in the 0-30 cms. layer. Moreover, the roots must have reached the 30-60 cms. layer of soil within a short time after planting, and soil moisture in this soil layer was not influenced by any of the treatments applied. The above reasoning would appear to lead to the suggestion that the beneficial response with mulching is probably not primarily due to its effect on soil moisture conservation. Mulching decreased soil temperature at 7 cms. depth during the heat of the day. But high summer soil temperatures are not a factor limiting plant growth in Michigan.

The beneficial role of wind protection in increasing growth is more difficult to explain. Wind protection not only considerably increased growth by itself, but increased the beneficial response to mulching. In the absence of wind protection, the response to mulching was barely detectable, but the two combined acted synergistically under the conditions of this experiment.

In this experiment, wind could conceivably increase vegetative growth through the following mechanisms:

1. Both air and surface soil temperatures were higher in the shelter of the wind-breaks for most of the day as compared to the open.

Besides increasing plant growth throughout the growing season, this effect on temperature has considerable bearing on the incidence of early spring frost. Following a frost on May 18, 1968, for example, the plants in the shelter of the wind-breaks were not affected whereas all the leaves on the plants in the open were killed and the trees were set back in growth by two weeks.

2. Considerable mechanical injury to the foliage (Figure 13) is a conspicuous effect of wind on the study site, especially during June and early July, when it is hard to find a single undamaged leaf on unprotected small trees. This could adversely affect leaf area thereby reducing vegetative growth in general.

3. Even though no soil moisture stress seems to have developed for black walnut during the period of this study, it is possible that plant water stress did develop due to higher transpiration demand under high wind velocities. It could thus be argued that wind-breaks may have increased vegetative growth by reducing plant water stress during such periods due to their effect in reducing wind velocity. But in addition to decreasing wind velocity, wind-

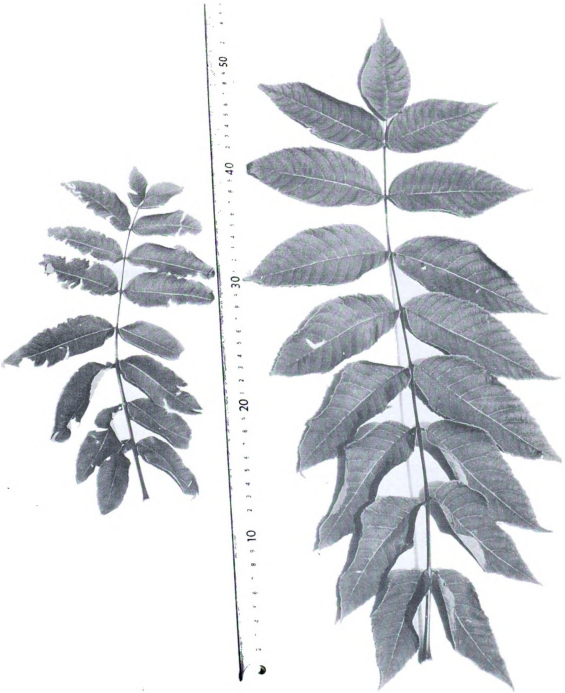


Figure 13. Walnut leaves from open grown trees (left) and in the shelter of wind break (right). Unprotected leaf shows serve mechanical injury.

> breaks also increased temperature in their shelter, which would tend to increase plant water stress. So the net effect of wind-breaks on plant water stress at any time would depend upon the balance between the reduction in plant water stress due to decreased wind velocity, and its increase due to the higher temperatures behind the wind-breaks as compared to the open. It was found that wind velocities up to 10 kilometers per hour did not increase plant water tension under the conditions of the investigation.

The above reasoning would appear to suggest that wind protection increased vegetative growth due to its effect in increasing temperature, decreasing wind-caused mechanical injury, and probably also by reducing plant water stress on hot, dry, windy days.

Though the main effect of irrigation was not significant, its interaction with mulching indicates that by itself it did increase leaf area, height, and diameter. These increases could also be caused by an irrigation-induced improvement in the K nutrition of the plants. Since irrigation combined with mulching did not improve the K status of the plants over mulching alone, the plant growth response to irrigation + mulching was not greater than to mulching alone.

In summary, the principle site improvement recommendations for field planted black walnut are:

1. Wind protection is essential for the vigorous early growth of black walnut on level, open field sites.
2. Where plants are deficient in K, favorable growth responses can be expected to the application of wood-chip mulch.
3. Wind protection and mulching are synergistic in their effect on plant growth and should be combined.
4. Some practical way should be found to insure adequate nutrition and correction of any nutrient deficiencies during the first growing season. Perhaps some modification in the slow-release fertilizer packet may achieve this, or the periodic application of foliar or liquid fertilizer may be the answer.

Though the investigations on planting stock raised in containers have not been pursued long enough to yield any definite conclusions, indications are that planting 3 to 6-week old stock with containers, immediately at the start of the frost-free period, is likely to increase growth due to the elimination of any damage whatsoever to the root system, an increase of the growing period by 3 to 6 weeks, and a better ability of the root system to absorb soil applied fertilizer during the first growing season after planting.

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## LITERATURE CITED


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# APPENDICES

## APPENDIX I

Mean Moisture Content of the 0-30 cms. Soil Layer of the Site During July-September, 1967, as Determined by Neutron Probe.

| | $W_0I_0M_0$ [1] | $W_0I_0M_1$ | $W_0I_1M_0$ | $W_0I_1M_1$ | $W_1I_0M_0$ | $W_1I_0M_1$ | $W_1I_1M_0$ | $W_1I_1M_1$ [2] |
|---|---|---|---|---|---|---|---|---|
| Date | Mean moisture content, o/o by volume | | | | | | | |
| July 1 | 19.3 | 20.1 | 19.1 | 20.3 | 18.7 | 20.8 | 18.7 | 20.2 |
| July 7 | 17.5 | 19.1 | 18.0 | 19.6 | 16.5 | 19.8 | 16.4 | 19.2 |
| July 13 | 15.1 | 18.1 | 16.3 | 17.7 | 14.1 | 18.3 | 14.1 | 17.6 |
| July 21 | 13.6 | 17.3 | 17.0 | 19.0 | 12.9 | 18.3 | 15.5 | 18.4 |
| July 28 | 11.9 | 16.1 | 15.4 | 17.2 | 12.5 | 16.8 | 14.2 | 17.0 |
| Aug. 8 | 9.6 | 14.2 | 13.5 | 15.4 | 9.2 | 14.4 | 11.7 | 16.1 |
| Aug. 15 | 8.7 | 12.4 | 13.2 | 14.8 | 8.0 | 12.7 | 11.8 | 15.4 |
| Aug. 22 | 11.5 | 15.7 | 17.5 | 18.5 | 10.8 | 15.9 | 16.2 | 18.7 |
| Aug. 29 | 16.0 | 20.1 | 20.1 | 20.8 | 16.6 | 20.3 | 18.8 | 20.3 |
| Sept. 6 | 15.7 | 18.2 | 18.7 | 18.9 | 14.8 | 18.2 | 16.5 | 19.1 |
| Sept. 12 | 12.6 | 16.7 | 15.7 | 17.5 | 12.7 | 16.3 | 14.1 | 17.0 |
| Sept. 19 | 10.3 | 14.5 | 14.5 | 15.2 | 10.8 | 14.7 | 12.5 | 15.7 |
| Sept. 26 | 14.5 | 17.5 | 16.9 | 18.3 | 14.5 | 18.5 | 15.8 | 18.4 |
| Oct. 3 | 18.7 | 20.1 | 20.0 | 20.5 | 17.9 | 20.7 | 19.2 | 20.3 |

[1] $W_0$ No wind protection, $I_0$ No irrigation, $M_0$ No mulching

[2] $W_1$ Wind protection, $I_1$ Irrigation, $M_1$ Mulched

## APPENDIX II

Mean Moisture Content of the 30-60 cms. Soil Layer of the Site During July-Septmeber 1967, as Determined by Neutron Probe.

| | $W_0I_0M_0$ | $W_0I_0M_1$ | $W_0I_1M_0$ | $W_0I_1M_1$ | $W_1I_0M_0$ | $W_1I_0M_1$ | $W_1I_1M_0$ | $W_1I_1M_1$ |
|---|---|---|---|---|---|---|---|---|
| Date | Mean moisture content, percent by volume | | | | | | | |
| July 1 | 21.2 | 18.3 | 19.8 | 19.7 | 19.4 | 18.9 | 20.4 | 19.7 |
| July 7 | 21.3 | 16.7 | 17.2 | 19.3 | 18.1 | 17.7 | 19.3 | 18.8 |
| July 13 | 20.9 | 16.1 | 16.2 | 18.7 | 16.1 | 17.3 | 18.3 | 18.1 |
| July 24 | 19.9 | 15.8 | 15.9 | 18.5 | 16.2 | 17.1 | 17.9 | 17.6 |
| July 28 | 18.0 | 14.3 | 14.9 | 17.7 | 16.6 | 16.6 | 17.3 | 17.7 |
| Aug. 8 | 18.8 | 13.3 | 14.0 | 16.9 | 14.7 | 15.7 | 16.6 | 16.8 |
| Aug. 15 | 18.0 | 12.9 | 13.5 | 16.8 | 14.4 | 14.9 | 16.8 | 16.2 |
| Aug. 22 | 18.1 | 13.2 | 16.0 | 18.7 | 14.5 | 15.2 | 18.5 | 18.2 |
| Aug. 29 | 20.2 | 18.2 | 19.4 | 20.8 | 18.3 | 19.3 | 20.7 | 19.9 |
| Sept. 6 | 20.0 | 17.1 | 17.6 | 19.5 | 17.9 | 18.1 | 19.5 | 18.8 |
| Sept. 12 | 19.3 | 15.5 | 15.7 | 17.8 | 16.7 | 17.1 | 18.4 | 17.5 |
| Sept. 19 | 19.0 | 14.5 | 14.9 | 17.2 | 15.8 | 16.2 | 17.7 | 16.5 |
| Sept. 26 | 19.4 | 15.4 | 15.9 | 18.1 | 16.7 | 17.2 | 18.4 | 18.0 |
| Oct. 3 | 20.7 | 17.2 | 18.1 | 20.1 | 18.9 | 18.8 | 20.1 | 19.3 |

## APPENDIX III

Effect of Irrigation on Exchangeable K[1] at the 15 cms. Soil Depth.

| Replication No. | Irrigation Status | Exchangeable K (kilogram per hectare) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Wind protection | | | | No wind protection | | | |
| | | $F_0M_0$[2] | $F_0M_1$ | $F_1M_0$[3] | $F_1M_1$ | $F_0M_0$ | $F_0M_1$ | $F_1M_0$ | $F_1M_1$ |
| I | Unirrigated | 110 | 220 | 205 | 233 | 188 | 161 | 233 | 265 |
| | Irrigated | 110 | 170 | 125 | 197 | 116 | 110 | 110 | 188 |
| II | Unirrigated | 72 | 125 | 170 | 214 | 133 | 179 | 197 | 80 |
| | Irrigated | 110 | 63 | 152 | 110 | 89 | 125 | 143 | 179 |
| III | Unirrigated | 80 | 72 | 205 | 161 | 125 | 110 | 241 | 161 |
| | Irrigated | 116 | 116 | 133 | 133 | 98 | 110 | 161 | 170 |
| IV | Unirrigated | 197 | 180 | 341 | 251 | 133 | 179 | 278 | 251 |
| | Irrigated | 116 | 116 | 214 | 179 | 234 | 179 | 223 | 260 |
| V | Unirrigated | 170 | 98 | 233 | 223 | 116 | 98 | 205 | 197 |
| | Irrigated | 110 | 125 | 161 | 161 | 110 | 89 | 161 | 197 |
| Average | Unirrigated | 126 | 139 | 231 | 216 | 139 | 145 | 231 | 191 |
| | Irrigated | 192 | 121 | 157 | 156 | 129 | 123 | 160 | 199 |

[1] Extracted with 1.0 N ammonium acetate

[2] $F_0$ Not fertilized

[3] $F_1$ Fertilized

APPENDIX IV

Effect of Mulching on Exchangeable K at the 15 cms. Soil Depth.

| Replication No. | Mulching Status | Exchangeable K (kilogram per hectare) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Wind protection | | | | No wind protection | | | |
| | | Irrigation | | No irrigation | | Irrigation | | No irrigation | |
| | | $F_0$ | $F_1$ | $F_0$ | $F_1$ | $F_0$ | $F_1$ | $F_0$ | $F_1$ |
| I | Not mulched | 110 | 170 | 110 | 220 | 116 | 110 | 188 | 161 |
| | Mulched | 125 | 197 | 205 | 233 | 110 | 188 | 233 | 269 |
| II | Not mulched | 110 | 63 | 72 | 125 | 89 | 125 | 133 | 179 |
| | Mulched | 152 | 110 | 170 | 220 | 143 | 179 | 197 | 80 |
| III | Not mulched | 116 | 133 | 80 | 72 | 98 | 110 | 125 | 110 |
| | Mulched | 116 | 133 | 205 | 161 | 161 | 170 | 241 | 161 |
| IV | Not mulched | 116 | 116 | 197 | 179 | 241 | 179 | 133 | 179 |
| | Mulched | 220 | 179 | 341 | 251 | 223 | 260 | 278 | 251 |
| V | Not mulched | 110 | 125 | 170 | 98 | 110 | 89 | 116 | 98 |
| | Mulched | 161 | 161 | 233 | 223 | 161 | 197 | 205 | 197 |
| Average | Not mulched | 112 | 121 | 126 | 139 | 131 | 123 | 139 | 145 |
| | Mulched | 155 | 156 | 231 | 218 | 160 | 199 | 231 | 192 |

APPENDIX VI

Soil Exchangeable K, Above and Below the Perforated Plastic Fertilizer Sacks, One Growing Season After Placement.

| Treatment \ Depth (cms.) | Exchangeable K (p.p.m.) | | | | |
|---|---|---|---|---|---|
| | 0-7.5 | 7.5-15.0 | 15.0-22.5 | 22.5-30.0 | 30.0-37.5 |
| (1) | | | | | |
| $F_1M_0I_0$ | 275 | 70 | 70* | 70 | |
| $F_0M_0I_0$ | 173 | 70 | 78 | 78 | |
| (2) | | | | | |
| $F_1M_1I_1$ | 220 | 125 | 110 | 117* | 141 |
| $F_0M_1I_1$ | 165 | 102 | 102 | 102 | 78 |
| (3) | | | | | |
| $F_1M_0I_0$ | 133 | 78 | 70 | 196* | 347 |
| $F_0M_0I_0$ | 102 | 110 | 102 | 102 | 78 |
| (4) | | | | | |
| $F_1M_1I_0$ | 259 | 78 | 70* | 70 | |
| $F_0M_1I_0$ | 307 | 102 | 78 | 63 | |
| (5) | | | | | |
| $F_1M_0I_0$ | 117 | 86 | 110 | 86* | 110 |
| $F_0M_0I_0$ | 220 | 63 | 63 | 70 | 73 |

* Depth of placement of fertilizer sack.

APPENDIX VII

$NO_3$-N Content of Soil Above and Below the Perforated Plastic Fertilizer Sacks, One Gorwing Season After Placement.

| Treatment \ Depth (cms.) | $NO_3$ - N (p.p.m.) 0-7.5 | 7.5-15.0 | 15.0-22.5 | 22.5-30.0 | 30.0-37.5 |
|---|---|---|---|---|---|
| (1) | | | | | |
| $F_1M_0I_0$ | 4.8 | 0.8 | 0.8* | 3.2 | |
| $F_0M_0I_0$ | 2.4 | 6.4 | 1.6 | 3.2 | |
| (2) | | | | | |
| $F_1M_1I_1$ | 1.6 | 0.0 | 0.0 | 8.8* | 16.0 |
| $F_0M_1I_1$ | 0.0 | 1.2 | 0.0 | 1.2 | 0.0 |
| (3) | | | | | |
| $F_1M_0I_0$ | 0.0 | 0.0 | 3.2 | 37.6* | 95.2 |
| $F_0M_0I_0$ | 0.0 | 4.0 | 19.2 | 24.0 | 0.0 |
| (4) | | | | | |
| $F_1M_1I_0$ | 0.8 | 3.2 | 4.0* | 13.2 | |
| $F_0M_1I_0$ | 4.0 | 18.0 | 19.2 | 15.2 | |
| (5) | | | | | |
| $F_1M_0I_0$ | 10.8 | 6.4 | 3.2 | 21.6* | 5.6 |
| $F_0M_0I_0$ | 1.6 | 3.2 | 4.8 | 14.4 | 0.8 |

* Depth of placement of fertilizer sack.

APPENDIX VIII

Effect of Irrigation on P Foliar Concentration, 1-0 Black Walnut, One Growing Season Following Outplanting, August 20, 1967.

| Replication No. | Irrigation Status | P foliar concentration % | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | No Wind protection | | | | Wind protection | | | |
| | | $F_0M_0$ | $F_1M_0$ | $F_0M_1$ | $F_1M_1$ | $F_0M_0$ | $F_1M_0$ | $F_0M_1$ | $F_1M_1$ |
| I | Unirrigated | .183 | .206 | .210 | .197 | .161 | .183 | .192 | .174 |
| | Irrigated | .223 | .201 | .206 | .223 | .210 | .214 | .232 | .223 |
| II | Unirrigated | .174 | .174 | .188 | .219 | .147 | .165 | .192 | .210 |
| | Irrigated | .197 | .210 | .237 | .188 | .268 | .174 | .192 | .210 |
| III | Unirrigated | .210 | .188 | .192 | .192 | .206 | .174 | .201 | .201 |
| | Irrigated | .250 | .210 | .255 | .183 | .188 | .210 | .210 | .188 |
| IV | Unirrigated | .197 | .170 | .206 | .161 | .170 | .156 | .188 | .161 |
| | Irrigated | .255 | .250 | .290 | .264 | .192 | .188 | .192 | .179 |
| V | Unirrigated | .174 | .174 | .192 | .237 | .188 | .179 | .165 | .174 |
| | Irrigated | .165 | .156 | .183 | .223 | .197 | .214 | .183 | .206 |
| Average | Unirrigated | .188 | .182 | .198 | .201 | .174 | .171 | .188 | .184 |
| | Irrigated | .218 | .205 | .234 | .216 | .211 | .200 | .202 | .201 |

APPENDIX IX

Effect of Irrigation on K Foliar Concentration, 1-0 Black Walnut, One Growing Season Following Outplantings, August 20, 1967.

| Replication No. | Irrigation Status | K foliar concentration | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | No wind protection | | | | Wind protection | | | |
| | | $F_0M_0$ | $F_1M_0$ | $F_0M_1$ | $F_1M_1$ | $F_0M_0$ | $F_1M_0$ | $F_0M_1$ | $F_1M_1$ |
| I | Unirrigated | 0.35 | 0.82 | 0.92 | 0.48 | 0.48 | 0.72 | 1.02 | 0.68 |
| | Irrigated | 0.86 | 0.88 | 0.74 | 1.00 | 1.06 | 1.30 | 0.90 | 1.28 |
| II | Unirrigated | 0.41 | 0.54 | 0.62 | 0.76 | 0.42 | 0.44 | 0.76 | 0.78 |
| | Irrigated | 0.88 | 0.92 | 1.06 | 1.08 | 0.46 | 0.98 | 0.96 | 0.76 |
| III | Unirrigated | 0.62 | 0.43 | 0.76 | 0.66 | 0.41 | 0.43 | 0.90 | 0.74 |
| | Irrigated | 0.86 | 0.90 | 1.04 | 0.96 | 0.94 | 0.96 | 1.12 | 1.04 |
| IV | Unirrigated | 0.76 | 0.84 | 1.02 | 0.92 | 0.76 | 0.82 | 1.00 | 0.52 |
| | Irrigated | 1.28 | 1.14 | 1.10 | 1.26 | 0.84 | 0.80 | 0.70 | 0.76 |
| V | Unirrigated | 0.72 | 0.44 | 0.47 | 0.34 | 0.72 | 0.35 | 0.66 | 0.42 |
| | Irrigated | 0.32 | 0.80 | 0.68 | 0.54 | 0.76 | 0.90 | 0.78 | 0.62 |
| Average | Unirrigated | 0.57 | 0.61 | 0.76 | 0.63 | 0.56 | 0.55 | 0.87 | 0.63 |
| | Irrigated | 0.84 | 0.93 | 0.92 | 0.97 | 0.81 | 0.99 | 0.89 | 0.89 |

APPENDIX X

Effect of Irrigation on Mg Foliar Concentration, 1-0 Black Walnut, One Growing Season Following Outplanting, August 20, 1967.

| Replication No. | Irrigation Status | Mg foliar concentration (%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | No wind protection | | | | Wind protection | | | |
| | | $F_0M_0$ | $F_1M_0$ | $F_0M_1$ | $F_1M_1$ | $F_0M_0$ | $F_1M_0$ | $F_0M_1$ | $F_1M_1$ |
| I | Unirrigated | .47 | .43 | .37 | .62 | .43 | .55 | .29 | .43 |
| | Irrigated | .48 | .42 | .48 | .40 | .23 | .28 | .33 | .24 |
| II | Unirrigated | .57 | .41 | .46 | .46 | .56 | .48 | .34 | .36 |
| | Irrigated | .34 | .32 | .30 | .26 | .37 | .45 | .36 | .53 |
| III | Unirrigated | .50 | .53 | .45 | .47 | .49 | .45 | .31 | .38 |
| | Irrigated | .36 | .36 | .41 | .27 | .29 | .25 | .31 | .27 |
| IV | Unirrigated | .36 | .45 | .34 | .36 | .43 | .42 | .38 | .49 |
| | Irrigated | .30 | .38 | .39 | .33 | .48 | .36 | .48 | .50 |
| V | Unirrigated | .50 | .62 | .59 | .61 | .51 | .70 | .48 | .62 |
| | Irrigated | .75 | .42 | .47 | .56 | .51 | .46 | .50 | .40 |
| Average | Unirrigated | 0.48 | .49 | .44 | .50 | .48 | .52 | .36 | .46 |
| | Irrigated | 0.45 | .38 | .41 | .36 | .38 | .36 | .40 | .39 |

APPENDIX XI

Effect of Irrigation on Ca Foliar Concentration, 1-0 Black Walnut, One Growing Season Following Outplanting, August 20, 1967.

| Replication No. | Irrigation Status | Ca foliar concentration (%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Wind protection | | | | No wind protection | | | |
| | | $F_0M_0$ | $F_1M_0$ | $F_0M_1$ | $F_1M_1$ | $F_0M_0$ | $F_1M_0$ | $F_0M_1$ | $F_1M_1$ |
| I | Unirrigated | 1.63 | 1.91 | 1.33 | 1.61 | 1.59 | 1.95 | 1.43 | 2.31 |
| | Irrigated | 1.20 | 1.33 | 1.49 | 1.20 | 1.75 | 1.93 | 1.93 | 1.79 |
| II | Unirrigated | 1.98 | 1.61 | 1.59 | 1.59 | 2.02 | 1.61 | 2.07 | 1.88 |
| | Irrigated | 1.59 | 1.84 | 1.72 | 1.68 | 1.65 | 1.52 | 1.68 | 1.59 |
| III | Unirrigated | 1.79 | 1.75 | 1.49 | 1.65 | 2.14 | 1.91 | 1.98 | 1.98 |
| | Irrigated | 1.38 | 1.22 | 1.72 | 1.45 | 1.54 | 1.93 | 2.00 | 1.24 |
| IV | Unirrigated | 1.79 | 1.82 | 1.91 | 1.79 | 1.82 | 1.84 | 1.65 | 1.63 |
| | Irrigated | 1.86 | 1.70 | 1.84 | 1.88 | 1.59 | 1.70 | 1.93 | 1.82 |
| V | Unirrigated | 1.88 | 2.05 | 1.82 | 1.91 | 1.88 | 2.28 | 2.12 | 1.86 |
| | Irrigated | 1.93 | 1.82 | 2.00 | 1.79 | 2.17 | 1.84 | 1.70 | 1.84 |
| Average | Unirrigated | 1.81 | 1.83 | 1.63 | 1.71 | 1.89 | 1.92 | 1.85 | 1.95 |
| | Irrigated | 1.59 | 1.58 | 1.75 | 1.60 | 1.74 | 1.78 | 1.85 | 1.66 |

APPENDIX XII

Effect of Fertilizer Application in Perforated Plastic Sacks on N Foliar Concentration, 1-0 Black Walnut, One Growing Season Following Outplanting, August 20, 1967.

| Replication No. | Fertilizer Status | N foliar concentration (%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | No wind protection | | | | Wind protection | | | |
| | | Unirrigated | | Irrigated | | Unirrigated | | Irrigated | |
| | | $M_0$ | $M_1$ | $M_0$ | $M_1$ | $M_0$ | $M_1$ | $M_0$ | $M_1$ |
| I | Unfertilized | 2.36 | 2.46 | 2.56 | 2.16 | 2.22 | 2.58 | 2.20 | 2.24 |
| | Fertilized | 2.66 | 2.22 | 2.86 | 2.92 | 2.52 | 2.64 | 2.54 | 2.68 |
| II | Unfertilized | 2.32 | 2.56 | 2.22 | 2.28 | 2.50 | 2.28 | 1.86 | 2.12 |
| | Fertilized | 2.62 | 2.52 | 2.50 | 2.50 | 2.46 | 2.74 | 2.60 | 1.90 |
| III | Unfertilized | 2.50 | 2.24 | 1.94 | 2.30 | 2.00 | 2.48 | 1.86 | 2.22 |
| | Fertilized | 2.62 | 2.24 | 2.42 | 2.28 | 2.46 | 2.30 | 2.44 | 2.30 |
| IV | Unfertilized | 2.44 | 2.68 | 2.52 | 2.80 | 2.28 | 2.68 | 1.90 | 2.22 |
| | Fertilized | 2.75 | 2.64 | 2.66 | 2.44 | 2.32 | 2.36 | 2.50 | 1.98 |
| V | Unfertilized | 2.26 | 2.16 | 2.12 | 2.74 | 2.66 | 2.24 | 2.42 | 2.16 |
| | Fertilized | 2.12 | 1.84 | 2.66 | 2.34 | 2.32 | 2.34 | 2.38 | 2.30 |
| Average | Unfertilized | 2.38 | 2.42 | 2.27 | 2.46 | 2.33 | 2.45 | 2.05 | 2.19 |
| | Fertilized | 2.57 | 2.29 | 2.62 | 2.50 | 2.46 | 2.48 | 2.49 | 2.23 |

## APPENDIX XIII

Foliar Concentrations of Mineral Nutrient Elements Delimiting Various Ranges of Nutritional Status in California Walnut (after FINN, 1966).

| Range | Mineral nutrient element concentration | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | N | P | K | Mg | Cu | Mn | B | Zn |
| | % | | | | | p.p.m. | | |
| Deficiency (deficiency symptoms noticeable) | 1.5 - 2.0 | .05 - .09 | .16 - .90 | .06 - .20 | 1 - 3 | 2 - 20 | 6 - 19 | 4 - 15 |
| Intermediate (deficiency symptoms may or may not be noticeable) | 2.0 - 2.5 | .09 - .12 | .90 - 1.2 | .2 - .3 | 3 - 4 | 20 - 30 | 19 - 35 | 15 - 20 |
| Normal range (deficiency symptoms rarely present) | 2.5 - 3.5 | .12 - .30 | 1.2 - 3.0 | .3 - 1.0 | 4 - 20 | 30 - 350 | 35 - 300 | 20 - 200 |

APPENDIX XIV

Mean Foliar K Concentration on July 17, 1968; 1-0 Black Walnut, Second Growing Season Following Outplanting.

| Replication | | Mean foliar K concentration, percent | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Unirrigated | | | | Irrigated | | | |
| | | $F_0M_0$ | $F_1M_0$ | $F_0M_1$ | $F_1M_1$ | $F_0M_0$ | $F_1M_0$ | $F_0M_1$ | $F_1M_1$ |
| I | No wind protection | 0.50 | 0.84 | 1.26 | 1.12 | 0.68 | 0.96 | 1.28 | 1.32 |
| | Wind protection | 0.75 | 0.94 | 1.28 | 1.28 | 0.96 | 1.18 | 1.26 | 1.32 |
| II | No wind protection | 0.60 | 1.00 | 1.00 | 1.22 | 0.84 | 1.08 | 1.08 | 1.32 |
| | Wind protection | 0.50 | 0.80 | 1.12 | 1.44 | 0.68 | 0.70 | 1.12 | 1.16 |
| III | No wind protection | 0.58 | 0.88 | 1.32 | 0.88 | 0.78 | 0.84 | 1.18 | 0.92 |
| | Wind protection | 0.58 | 0.60 | 1.08 | 1.08 | 0.94 | 0.84 | 1.40 | 1.08 |
| IV | No wind protection | 0.78 | 1.02 | 1.40 | 1.12 | 1.16 | 0.94 | 1.12 | 1.12 |
| | Wind protection | 0.96 | 1.00 | 1.32 | 1.08 | 0.88 | 0.86 | 1.40 | 1.12 |
| V | No wind protection | 0.44 | 0.94 | 1.06 | 0.80 | 0.80 | 0.75 | 0.96 | 1.00 |
| | Wind protection | 0.80 | 0.72 | 1.18 | 0.96 | 0.44 | 0.75 | 0.84 | 0.78 |
| Average | No wind protection | 0.58 | 0.94 | 1.21 | 1.03 | 0.85 | 0.71 | 1.12 | 1.14 |
| | Wind protection | 0.72 | 0.81 | 1.20 | 1.17 | 0.78 | 0.87 | 1.20 | 1.09 |

APPENDIX XV

Mean Foliar N Concentration on July 17, 1968; 1-0 Black Walnut, Second Growing Season Following Outplanting

| Replication | | Mean foliar N concentration, percent | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Unirrigated | | | | Irrigated | | | |
| | | $F_0M_0$ | $F_1M_0$ | $F_0M_1$ | $F_1M_1$ | $F_0M_0$ | $F_1M_0$ | $F_0M_1$ | $F_1M_1$ |
| I | No wind protection | 3.06 | 3.40 | 2.98 | 3.40 | 3.12 | 3.00 | 2.76 | 3.24 |
| | Wind protection | 3.32 | 3.22 | 3.04 | 3.50 | 3.38 | 3.46 | 3.16 | 3.52 |
| II | No wind protection | 2.98 | 3.38 | 3.44 | 3.38 | 3.00 | 2.90 | 3.42 | 3.28 |
| | Wind protection | 2.44 | 3.20 | 2.60 | 2.84 | 2.54 | 2.94 | 2.38 | 2.88 |
| III | No wind protection | 2.74 | 3.62 | 2.72 | 3.26 | 2.72 | 3.18 | 2.58 | 3.10 |
| | Wind protection | 2.40 | 2.54 | 2.54 | 2.98 | 2.36 | 3.06 | 2.44 | 3.02 |
| IV | No wind protection | 3.02 | 3.24 | 3.00 | 3.04 | 3.48 | 3.34 | 3.02 | 3.52 |
| | Wind protection | 2.48 | 3.10 | 2.70 | 3.20 | 2.60 | 2.64 | 2.60 | 2.82 |
| V | No wind protection | 3.10 | 2.94 | 2.90 | 3.14 | 2.84 | 3.28 | 2.28 | 2.80 |
| | Wind protection | 2.58 | 2.90 | 2.72 | 3.20 | 2.38 | 2.72 | 1.90 | 2.30 |
| Average | No wind protection | 2.98 | 3.32 | 3.01 | 3.24 | 3.03 | 3.14 | 2.81 | 3.19 |
| | Wind protection | 2.64 | 2.99 | 2.72 | 3.14 | 2.65 | 2.96 | 2.50 | 2.85 |

APPENDIX XVI

Relation of Oven-Dry Weight and Leaf Area of 1-0 Black Walnut; One Growing Season After Outplanting, Determined at the Tree Research Center on September 15, 1967.

No wind protection

Irrigated

| Rep. No. | $F_0M_0$ | | $F_1M_0$ | | $F_0M_1$ | | $F_1M_1$ | |
|---|---|---|---|---|---|---|---|---|
| | O.D.wt (gms) | Leaf ar. (sq.cms) | O.D.wt. (gms) | Leaf ar. (sq.cms) | O.D.wt. (gms) | Leaf ar. (sq.cms) | O.D.wt. (gms) | Leaf ar. (sq.cms) |
| 1 | 0.319 | 54.6 | 0.233 | 40.5 | 0.259 | 45.1 | 0.342 | 58.4 |
| 2 | 0.261 | 53.9 | 0.251 | 41.2 | 0.193 | 51.8 | 0.202 | 35.6 |
| 3 | 0.246 | 49.5 | 0.358 | 55.8 | 0.149 | 28.0 | 0.259 | 41.2 |
| 4 | 0.883 | 140.7 | 0.708 | 116.3 | 0.459 | 76.9 | 0.212 | 37.7 |
| 5 | - | - | 0.216 | 37.2 | 0.161 | 31.8 | 0.463 | 74.9 |
| TOTAL | 1.709 | 298.7 | 1.766 | 291.0 | 1.221 | 233.6 | 1.478 | 247.8 |
| | | | | Unirrigated | | | | |
| 1 | 0.281 | 45.5 | 0.234 | 41.8 | 0.357 | 65.8 | 0.228 | 37.8 |
| 2 | 0.181 | 30.9 | 0.322 | 61.6 | 0.233 | 36.4 | 0.331 | 56.1 |
| 3 | 0.284 | 49.2 | 0.292 | 49.9 | 0.300 | 51.6 | 0.303 | 40.9 |
| 4 | 0.421 | 77.9 | 0.195 | 30.4 | 0.236 | 36.4 | 0.438 | 76.2 |
| 5 | 0.285 | 35.5 | 0.237 | 34.1 | 0.251 | 47.2 | 0.177 | 55.5 |
| TOTAL | 1.452 | 239.0 | 1.280 | 217.8 | 1.367 | 237.4 | 1.477 | 266.5 |
| Total of no wind protection | 3.161 | 537.7 | 3.046 | 508.8 | 2.588 | 471.0 | 2.955 | 514.3 |

APPENDIX XVI (continued)

Wind Protection

Irrigated

| Rep. No. | $F_0M_0$ | | $F_1M_0$ | | $F_0M_1$ | | $F_1M_1$ | |
|---|---|---|---|---|---|---|---|---|
| | O.D.wt. (gms) | Leaf ar. (sq.cms) | O.D.wt. (gms) | Leaf ar. (sq.cms) | O.D.wt. (gms) | Leaf ar. (sq. cms) | O.D.wt. (gms) | Leaf ar. (sq.cms) |
| 1 | 0.519 | 102.2 | 0.287 | 63.0 | 0.855 | 166.9 | 0.340 | 68.0 |
| 2 | 0.233 | 43.3 | 0.260 | 44.9 | 0.531 | 87.7 | 0.414 | 80.3 |
| 3 | 0.355 | 57.7 | 0.299 | 49.3 | 0.440 | 71.4 | 0.345 | 51.0 |
| 4 | - | - | 0.322 | 50.8 | 0.480 | 70.4 | 0.479 | 80.8 |
| 5 | 0.465 | 71.9 | 0.301 | 42.6 | 0.295 | 47.3 | 0.337 | 60.6 |
| TOTAL | 1.572 | 275.1 | 1.479 | 250.6 | 2.601 | 443.7 | 1.965 | 340.7 |
| | | | | Unirrigated | | | | |
| 1 | 0.632 | 126.3 | 0.213 | 36.3 | 0.357 | 62.5 | 0.252 | 50.6 |
| 2 | 0.212 | 34.9 | 0.248 | 41.1 | 0.420 | 67.5 | 0.450 | 78.3 |
| 3 | 0.202 | 35.3 | 0.348 | 59.6 | 0.529 | 88.5 | 0.214 | 35.7 |
| 4 | 0.242 | 41.9 | 0.319 | 54.8 | 0.284 | 47.1 | 0.367 | 56.7 |
| 5 | 0.206 | 35.4 | 0.423 | 68.1 | 0.644 | 123.8 | 0.665 | 99.4 |
| TOTAL | 1.494 | 237.8 | 1.551 | 259.9 | 2.234 | 389.4 | 1.948 | 321.2 |
| Total of wind Protection | 3.066 | 548.9 | 3.030 | 510.5 | 4.835 | 833.1 | 3.913 | 661.9 |

APPENDIX XVII

Leaf Area of 1-0 Black Walnut, Under the Treatments Applied, One Growing Season After Outplanting, Measured September 15, 1967.

| Replication No. | Mulching Status | Leaf area sq. cms. | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Wind Protection | | | | No Wind protection | | | |
| | | Irrigated | | Unirrigated | | Irrigated | | Unirrigated | |
| | | Fertilized | Unfertilized | Fertilized | Unfertilized | Fertilized | Unfertilized | Fertilized | Unfertilized |
| I | Not Mulched | 1952 | 2731 | 1491 | 3249 | 1025 | 1435 | 1671 | 1065 |
| | Mulched | 3139 | 2624 | 1890 | 3334 | 2086 | 1342 | 1297 | 1706 |
| II | Not Mulched | 2573 | 2489 | 2074 | 1898 | 2913 | 2380 | 2260 | 2155 |
| | Mulched | 2544 | 2101 | 3095 | 2934 | 2154 | 2584 | 2249 | 1727 |
| III | Not Mulched | 2362 | 2107 | 1305 | 1444 | 2177 | 1777 | 1771 | 1292 |
| | Mulched | 2522 | 2402 | 1985 | 2660 | 2779 | 1902 | 2085 | 2142 |
| IV | Not Mulched | 2821 | 3589 | 1843 | 1517 | 4239 | 4215 | 1540 | 2700 |
| | Mulched | 2758 | 3186 | 2702 | 1827 | 2869 | 3356 | 2755 | 2694 |
| V | Not Mulched | 2405 | 2065 | 2112 | 1491 | 1610 | 1928 | 1432 | 1758 |
| | Mulched | 2070 | 1835 | 4627 | 4412 | 2159 | 1137 | 2404 | 2467 |
| Average | Not Mulched | 2423 | 2596 | 1765 | 1920 | 2393 | 2347 | 1735 | 1794 |
| | Mulched | 2607 | 2430 | 2860 | 3033 | 2409 | 2064 | 2158 | 2147 |

APPENDIX XVIII

Leaf Area of Best Tree in Each Plot on July 15, 1968; 1-0 Black Walnut, Second Season After Outplanting

| Replication | | Leaf area, $cm^2$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Unirrigated | | | | Irrigated | | | |
| | | $F_0M_0$ | $F_1M_0$ | $F_0M_1$ | $F_1M_1$ | $F_0M_0$ | $F_1M_0$ | $F_0M_1$ | $F_1M_1$ |
| I | No wind protection | 1667 | 1957 | 2285 | 1075 | 1837 | 1281 | 1828 | 2589 |
| | Wind protection | 3064 | 2125 | 3898 | 2590 | 3325 | 1790 | 4452 | 3436 |
| II | No wind protection | 2078 | 1686 | 537 | 2747 | 2944 | 2968 | 2800 | 3121 |
| | Wind protection | 3357 | 3395 | 4368 | 3317 | 3068 | 3615 | 3790 | 5146 |
| III | No wind protection | 2077 | 2285 | 2546 | 1868 | 2023 | 1806 | 2077 | 3433 |
| | Wind protection | 2925 | 4161 | 5705 | 6207 | 4159 | 4595 | 6776 | 5089 |
| IV | No wind protection | 3198 | 1738 | 2516 | 3966 | 961 | 3572 | 2575 | 1391 |
| | Wind protection | 2382 | 3664 | 3203 | 5870 | 4923 | 6457 | 5746 | 7588 |
| V | No wind protection | 2724 | 3259 | 2258 | 3766 | 3324 | 3228 | 1782 | 3809 |
| | Wind protection | 3667 | 3678 | 6493 | 6568 | 3295 | 5514 | 4010 | 2727 |
| Average | No wind protection | 2349 | 2185 | 2028 | 2684 | 2218 | 2571 | 2212 | 2869 |
| | Wind protection | 3079 | 3405 | 4733 | 4910 | 3754 | 4394 | 4955 | 4797 |

APPENDIX XX

Mean Height of the Current Year's (1968) Terminal Shoot on July 22, 1968; 1-0 Black Walnut, Second Season Following Outplanting

| Replication | | Mean height of the current year's terminal shoot, cms. | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Unirrigated | | | | Irrigated | | | |
| | | $F_0M_0$ | $F_1M_0$ | $F_0M_1$ | $F_1M_1$ | $F_0M_0$ | $F_1M_0$ | $F_0M_1$ | $F_1M_1$ |
| I | No wind protection | 16 | 16 | 19 | 12 | 13 | 11 | 26 | 27 |
| | Wind protection | 29 | 20 | 34 | 30 | 38 | 27 | 33 | 44 |
| II | No wind protection | 14 | 12 | 18 | 24 | 21 | 28 | 22 | 29 |
| | Wind protection | 17 | 24 | 30 | 35 | 16 | 23 | 21 | 31 |
| III | No wind protection | 14 | 12 | 19 | 21 | 10 | 18 | 16 | 28 |
| | Wind protection | 11 | 16 | 35 | 35 | 31 | 30 | 32 | 34 |
| IV | No wind protection | 23 | 15 | 27 | 25 | 31 | 41 | 33 | 24 |
| | Wind protection | 22 | 23 | 29 | 42 | 38 | 37 | 33 | 41 |
| V | No wind protection | 13 | 15 | 24 | 33 | 16 | 19 | 13 | 21 |
| | Wind protection | 25 | 27 | 46 | 47 | 21 | 19 | 20 | 18 |
| Average | No wind protection | 16 | 14 | 21 | 23 | 18 | 23 | 22 | 26 |
| | Wind protection | 21 | 22 | 35 | 38 | 29 | 27 | 28 | 34 |