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JOURNAL OF AGRICULTURAL RESEARCH

VOL. 71 WASHINGTON, D. C., DECEMBER 15, 1945 No. 12

INFLUENCE OF SOIL MOISTURE CONDITIONS ON APPARENT PHOTOSYNTHESIS AND TRANSPIRATION OF PECAN LEAVES [1]

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INTRODUCTION

An optimum supply of soil moisture is an important factor in the production of pecans (*Carya illinoensis* K. Koch; syn., *C. pecan*). Nevertheless, it is not uncommon for the moisture in orchard soils to vary from inadequate to excessive amounts during the same season. For example, in the early spring of 1942 the soil moisture in certain parts of the orchard of the United States Department of Agriculture Pecan Field Station at Brownwood, Tex., had decreased to the wilting point owing to lack of rain, whereas in late spring the soil in some parts of the orchard was saturated for as long as 5 weeks owing to excessive rainfall and inadequate drainage.

Such extremes in soil moisture may be expected to interfere materially with the normal functioning of vital processes of plants, thereby influencing their vigor and productivity. Heinicke and Childers (*7*)[2] and Schneider and Childers (*11*) demonstrated the deleterious effects of low soil moisture on photosynthesis and transpiration of apple leaves. Childers and White (*3*), Boynton (*2*), Childs (*4*), DeVilliers (*5*), and others showed harmful effects of low oxygen content in the soil, as a result either of poor aeration or of flooding, on the growth and metabolism of apple trees. The experiments herein reported were designed to determine the effects of various soil-moisture conditions on the fundamental processes of photosynthesis and transpiration of pecan foliage and to ascertain the degree of injury, if any, caused by unfavorable quantities of soil moisture and the rate of recovery of the foliage from such injury.

MATERIALS AND METHODS

MATERIALS AND EXPERIMENTAL PROCEDURE

The procedure described by Heinicke and Hoffman (*8*) was used to determine photosynthesis. The leaf cups, or assimilation chambers, were similar to those designed by Heinicke (*6*) as adapted for use with pecan leaves by Loustalot and Hamilton (*10*). Transpiration was measured by passing the air through a dehydrating agent before

[1] Received for publication December 22, 1943.
[2] Italic numbers in parentheses refer to Literature Cited, p. 532.

it reached the carbon dioxide absorption towers and determining the increase in weight due to the water absorbed thereafter.

Two experiments were conducted during the season of 1942: experiment 1, with seedlings growing in coarse sand; and experiment 2, with seedlings growing in heavy soil. All plants were started in early spring from selected seed of the Burkett variety. On April 15 lots of six seedlings each were selected for uniformity of size and vigor and were transplanted to 5-gallon glazed crocks filled with coarse sand, one lot to each crock. The sand was prepared for use by washing it with a 1-percent solution of hydrochloric acid and thoroughly flushing it with tap water. Drainage was provided by a 1-inch hole near the bottom of the crock. Hoagland and Arnon's (*9*) nutrient solution diluted to one-fourth strength was supplied to the plants at regular intervals or as needed. The seedlings used in experiment 1 continued to grow in the coarse sand, which had a wilting coefficient of 1 percent and a field capacity of approximately 6 percent. For experiment 2 a brown silty loam of the Catalpa series, having a wilting coefficient of 12.2 percent and a field capacity of approximately 34 percent, was used instead of the sand. On July 28 the seedlings were transplanted from the crocks of sand to crocks of this soil, where they were allowed to grow for 29 days before the experiment was started.

General procedures for the two experiments were similar. In each, three crocks of representative plants were placed on a bench outside the laboratory. The plants in one crock were designated as the check plants, those in a second crock as the flood plants, and those in a third crock as the drought plants. In each experiment, one mature leaf on each of two plants in each crock was selected for similarity in position and exposure. Usually two determinations of photosynthesis and transpiration were made daily, one in the morning and one in the afternoon. The morning determinations began at 8 a. m. and ended at 11 a. m.; the afternoon determinations began at 12 m. and ended at 3 p. m.

For periods ranging from 4 to 13 days before the treatments, the rates of photosynthesis and transpiration were determined, the soil moisture in all pots being maintained at approximately field capacity so as to establish the ratio, or normal relation, of the rates of the test plants to those of the check plants.

In the crocks containing the drought plants the sand or soil was allowed to dry out during a given period, whereas in those containing the check plants the moisture was maintained at or near field capacity. Determinations of carbon dioxide and of transpiration were continued during the drought periods until a critical point was reached; then the sand or soil was watered to field capacity, and determinations of photosynthesis and transpiration were continued for several days in order to observe the rate of recovery of the two processes from the effects of the drought. Samples of sand or soil for moisture analysis were taken at frequent intervals (daily during the critical periods), in order to determine the rate of drying of the soils.

After the calibration, or pretreatment, period the drainage hole in the crocks containing the plants to be flooded was plugged and dilute nutrient solution was added until the level of the solution was 1 to 1½ inches above the surface of the sand or soil. The moisture that evaporated was replaced alternately with tap water and with dilute

nutrient solution, so that the level of the solution above that of the sand or soil was maintained. Determinations of photosynthesis and transpiration were continued on leaves of the flooded plants until definite trends in the rates, due to flooding, were evident or until a critical point was reached, after which the excess moisture was drained off. After the draining, further determinations were made in order to observe the rate of recovery, if any, from the effects of flooding.

At the time the flooded plants in experiment 1 were drained (August 23), one-half of the seedlings in each of the three treatments, check, drought, and flooded, were harvested for ash and total organic nitrogen analysis. The remaining plants were harvested on September 18. At each date of harvest entire plants were removed from the pots, the leaves were detached from the stems, and all tissues were placed in a drying oven at 105° C. for 24 hours; after this they were ground in a food mill and stored in aluminum cans until analyses were made. No analyses of plants were made in experiment 2. The official methods of analysis (*1*) for ash and for total organic nitrogen were used.

The percentages of soil moisture were determined from the loss in weight of soil dried for 24 hours at 105° C. The wilting coefficients were determined as the percentage of moisture remaining in the soils at the time of permanent wilting of sunflower plants growing in the soils. The soil samples were obtained by driving a metal tube one-half inch in diameter to the bottom of the pot, in the area occupied by the four seedlings not included in the test. Since six seedlings with well-developed root systems (see fig. 3, *A–C*) were growing in each pot, the soil was thoroughly permeated with roots. The sample of soil taken probably was as representative of the entire soil mass as could be obtained under the conditions without undue injury to the roots of the plants being studied.

METHOD OF CALCULATING RESULTS

Apparent photosynthesis was calculated as the average amount, in milligrams, of carbon dioxide assimilated per hour by 100 cm.^{2} of dorsal leaf surface; and transpiration as the average amount, in grams, of water lost per hour by 100 cm.^{2} of dorsal leaf surface.

The normal, or expected, rate of apparent photosynthesis was calculated as follows: The average number of milligrams of carbon dioxide absorbed per hour by 100 cm.^{2} of the proposed test leaves was divided by the average number of milligrams absorbed per hour by 100 cm.^{2} of the check leaves. The quotient was multiplied by 100 to obtain the percentage relation between the rate in the proposed test leaves and that in the check leaves. This percentage relation was considered as the rate which the proposed test leaves would be expected to maintain if they were not affected by the treatment, or 100 percent of the rate. Thereafter the percentage deviation from the expected rate in test leaves was calculated by multiplying the number of milligrams of carbon dioxide absorbed by the check leaves by the average percentage relation established between the check and test leaves before the treatment was begun. From this value, which represents the theoretical normal rate of the test leaves, the actual number of milligrams of carbon dioxide assimilated by the test leaves was subtracted, and the difference was then divided by the expected rate and multi-

plied by 100 to obtain the percentage deviation from the expected, or normal, rate.

Calculations of transpiration rates were similar to those for photosynthesis.

RESULTS

SEEDLINGS GROWING IN SAND

EFFECTS OF DROUGHT

The data in figure 1 show that the rates of photosynthesis of pecan seedlings growing in sand fluctuated somewhat around the average

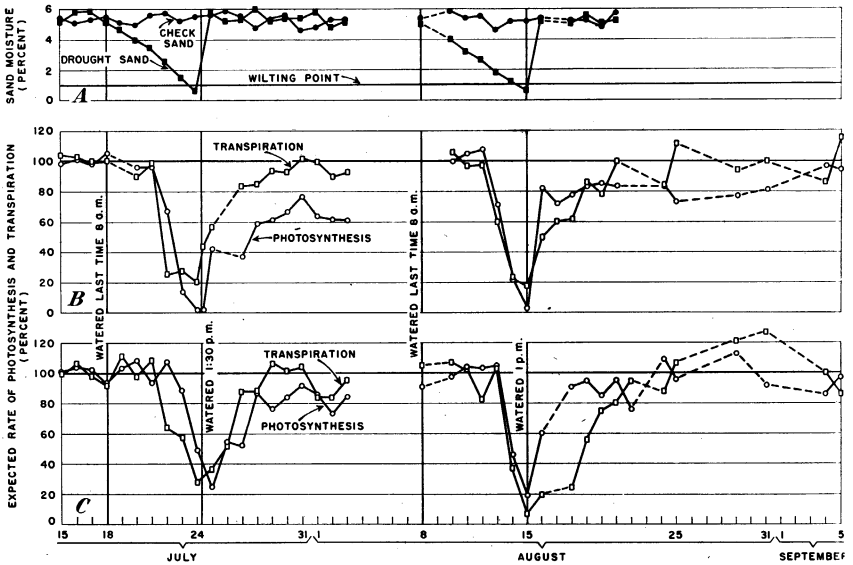

FIGURE 1.—Effect of drought on photosynthesis and transpiration of leaves of pecan seedlings growing in sand: *A*, Moisture percentages in sand; *B* and *C*, photosynthesis and transpiration (afternoon and morning determinations, respectively) expressed as percentage of expected rate.

rate during the 4-day calibration period (July 15 to 18). By the morning of July 22, the soil moisture was only 1.5 percent above the wilting point and the rate of transpiration was two-thirds of normal but photosynthesis was not appreciably affected. During the afternoon the rate of transpiration dropped sharply and photosynthesis was only two-thirds of normal. In general, the rates continued to drop until July 24, when the plants were watered again.

The young leaves of the test plants wilted during the afternoon of July 22, but by the next morning they had recovered their turgidity; however, they were severely wilted in the afternoon. On the morning of July 24 the leaves had only partially recovered, and at 1:15 p. m. one of them showed a brown necrotic wedge along the edge of the leaf cup. The apparatus was immediately stopped, the test plants were watered, and a new determination was started. However, before the second determination was under way one of the test leaves had become brown all over, as though it had been burned by fire, and it was necessary to substitute for it an adjacent leaf on the same plant.

The color change in the leaf took place in less than 10 minutes after the first browning was noted. The young leaves and the tips and margins of some of the older leaves showed the brown necrotic areas, but none of them was completely killed. The atmospheric conditions during the afternoon of this day were favorable for high rates of evaporation, since the humidity was low, the temperature high, and the sunshine bright.

During the period immediately after the watering, photosynthesis did not increase but transpiration increased somewhat. Within the next 6 days transpiration gradually regained its original rate, but 10 days after the plants were watered photosynthesis was only about two-thirds of normal.

Beginning August 8, the sand in the test plot was again allowed to dry out. Since one new test leaf was used, the expected rates of transpiration and photosynthesis were recalculated from data obtained with this leaf. The first effects of the decrease in moisture were observed on the afternoon of August 13, when the sand moisture was 1.8 percent (0.8 above the wilting point) and photosynthesis and transpiration rates were reduced by about one-third. The young leaves had wilted, but by the next morning they were again turgid. Photosynthesis and transpiration determinations for the morning of August 14 were less than one-half of the expected rates, and in the afternoon both processes were further reduced to about one-fourth of normal. The young leaves were severely wilted during the afternoon, but the test leaves, which were mature, showed no signs of wilting.

Photosynthesis and transpiration showed further reduction on the morning of August 15, when the sand moisture was 0.4 below the wilting point and the young leaves of the test plant had not regained turgidity overnight. The plants were watered at 1 p. m., and determinations for the period following showed that carbon dioxide assimilation had almost ceased and that the transpiration rate was only one-fifth of normal. By the following morning photosynthesis had markedly increased. During the next several days both processes tended to attain normalcy, but the photosynthetic activity during the afternoon period remained at about 80 percent of the expected rate until September 4 and 5, when it almost attained its original relation to the controls.

Effects of Flooding

The data on the effects of flooding the roots of pecan seedlings growing in sand are presented in figure 2.

At 3 p. m. on July 19, after a calibration period of 5 days, excess water was added to the pot containing the test plants. The first apparent effect of the flooding became evident on July 23 when transpiration increased. On July 24 the transpiration rate continued above normal, while photosynthetic activity was about one-third below the rate expected. During the next few days photosynthesis was further reduced to approximately one-half of normal and more or less maintained that level until August 11, after which it gradually declined until August 24, 1 day after the excess water was removed, when the rate of carbon dioxide assimilation was reduced to approximately 37 percent and 18 percent of normal in the morning and afternoon, respectively.

The transpiration rate, which on July 23 and 24 was above normal, decreased rapidly during July 25 and 26. However, by July 27 transpiration had increased sharply and for the afternoon periods the rate was about normal and remained at that level until August 3; for the morning periods the rate was about 6 percent below normal and fluctuated around that level until July 31, then decreased rapidly until August 3. No determinations were made from August 3 to 8, but from the latter date to August 24 transpiration showed approximately the same degree of reduction as photosynthesis; the rates of both processes were about the same for the morning periods, but for the afternoon periods those of photosynthesis were much lower.

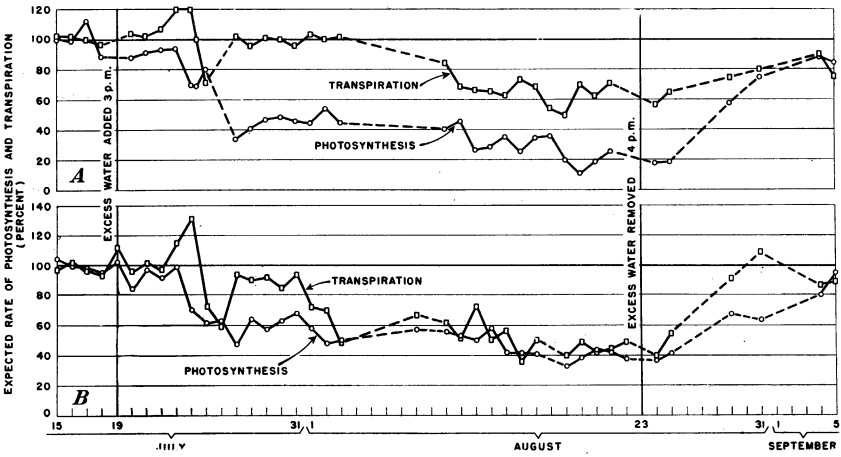

FIGURE 2.—Effect of flooding the roots on photosynthesis and transpiration of leaves of pecan seedlings growing in sand, expressed as percentage of expected rate: *A*, Afternoon determinations; *B*, morning determinations.

At 4 p. m. on August 23, the sand in the pot of flooded plants was drained and one-half of the plants of each of the three treatments were harvested for analysis. The fibrous roots of the flooded plants were black and dead, and many of the larger roots had died back as much as one-third to three-fourths of their length. Roots on the check and drought plants were all alive, and the color was normal. Figure 3, *A–C*, shows the root system of a representative plant from each treatment.

On August 24, the day following drainage of the flooded sand, there was no evidence that either photosynthesis or transpiration had begun to recover from the effects of the excess soil water; but on August 25 a slight recovery was indicated in both processes. Determinations on August 29, 6 days after the excess water had been drained off, showed a marked recovery in both processes, and by August 31 and September 4 and 5 both processes had attained average rates not far below those established before the plants were flooded.

About 2 weeks after the plants were flooded it was noted that the lenticels on the submerged portions of the stems had begun to enlarge and appeared white and spongy. At the time the excess water was drained off and the first plants were harvested for analysis, the lenticels had made considerable development. Figure 3, *D–F*, shows

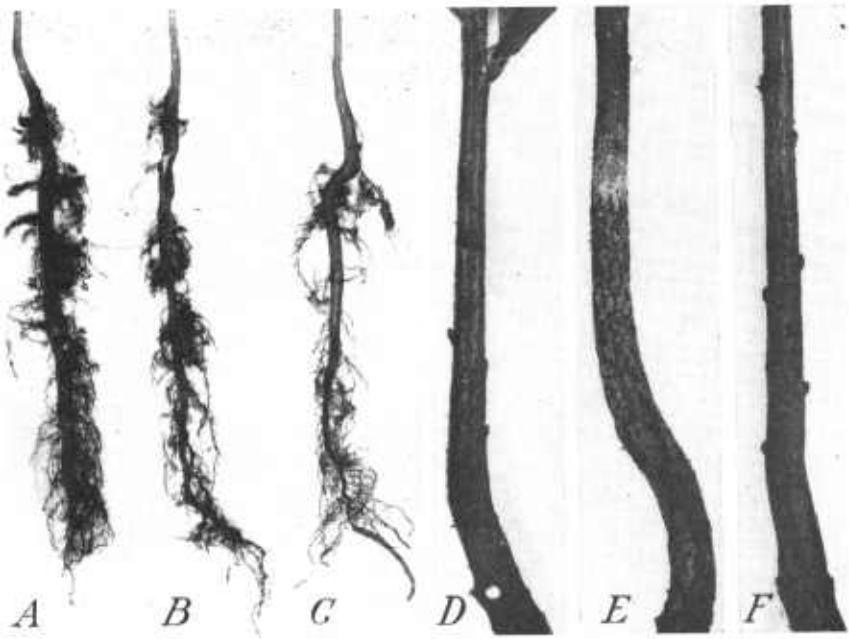

FIGURE 3.—*A–C*, Root systems of representative pecan seedlings grown in sand: *A*, Check plant; *B*, flooded plant; *C*, drought plant. Note sparse root system on drought plant. Most of the fibrous roots on the flooded plants are blackened and dead, and the taproot and many laterals are partly dead. *D–F*, Stems of representative pecan seedlings grown in sand: *D*, Check plant; *E*, flooded plant; *F*, drought plant. Note lenticular proliferation on stem of flooded plant.

the lenticels on a typical flooded plant compared with those on typical check and drought plants.

The leaves of flooded plants began to lose some of their green color about 3 weeks after they were flooded and soon became mottled in appearance. The mottling, which resembled symptoms characteristic of certain mineral deficiencies, became more pronounced during the period when the excess moisture was maintained, but within a week after the soil was drained the mottling began to disappear.

EFFECTS OF FLOOD AND DROUGHT CONDITIONS ON COMPOSITION OF PECAN SEEDLINGS

The data from the analysis of the plants harvested on August 23, at the time the flooded plants were drained (table 1), showed a marked difference in the percentages of nitrogen in the tissues of check and flooded plants (dry-weight basis). The percentage of nitrogen was 0.45 higher in check plants (stems and roots) and 0.69 higher in the leaves than in similar tissues of plants grown for 35 days in flooded sand. The tissues of plants subjected to drought conditions contained slightly lower percentages of nitrogen than those of the check plants. Analysis of the plants harvested September 18 (26 days after the excess water was drained from the sand) showed an increase of 0.1 in percentage of organic nitrogen in the leaves of both check and drought plants and of 0.38 in the leaves of flooded plants, but the leaves of the

check plants still contained a higher percentage of nitrogen than leaves of the flooded plants. The roots and stems of the check and drought plants showed no appreciable change in the percentages of nitrogen as compared with plants of similar treatments harvested August 23, but the roots and stems of the flooded plants showed a gain of 0.22 in nitrogen percentage.

TABLE 1.—*Organic nitrogen and ash in pecan seedlings grown in sand under different moisture conditions*

Lot No.	Treatment	Tissue	Date	Organic nitrogen (dry-weight basis)	Ash (dry-weight basis)
				Percent	*Percent*
1	Check	Roots and stems	Aug. 23	1.32	5.43
			Sept. 18	1.30	5.61
		Leaves	Aug. 23	2.49	9.60
			Sept. 18	2.59	9.88
2	Drought	Roots and stems	Aug. 23 [1]	1.23	5.25
			Sept. 18 [2]	1.25	5.63
		Leaves	Aug. 23 [1]	2.30	8.99
			Sept. 18 [2]	2.42	9.08
3	Flooding	Roots and stems	Aug. 23 [1]	.87	4.38
			Sept. 18 [2]	1.09	5.59
		Leaves	Aug. 23 [1]	1.80	7.58
			Sept. 18 [2]	2.18	8.19

[1] 35 days after lot 3 was flooded and 8 days after second drought was terminated in lot 2.
[2] 26 days after excess water was drained from lot 3 and 34 days after second drought was terminated in lot 2.

Analysis of plants harvested August 23 showed lower percentages of ash in all tissues of the flooded plants than in those of the check and drought plants. However, in the plants harvested September 18 the percentage of ash in the roots and stems of flooded plants had increased so that it was about the same as that in similar tissues of the check and drought plants. The leaves of the flooded plants also showed a marked gain in the percentage of ash from August 23 to September 18, but they were still 1.69 below the check leaves in percentage of ash.

SEEDLINGS GROWING IN SOIL

EFFECTS OF DROUGHT

The data on the effects of drought on pecan seedlings growing in soil are presented in figure 4.

During the calibration period (August 26 to September 7) all seedlings received ample moisture, but the test plants were not watered from September 7 to 23. During this time the soil moisture in the test pot gradually dried out until it was slightly below the wilting point.

The first effects of the drying were apparent on the afternoon of September 16, when the soil moisture dropped to 18 percent. At the same time there were small decreases in both photosynthesis and transpiration, and these continued to decrease at about the same rate during the afternoons of September 17 and 18.

The data for the morning determinations show no consistent deviations until September 21, when the transpiration rate dropped to one-half of normal. Photosynthesis was slightly depressed during the

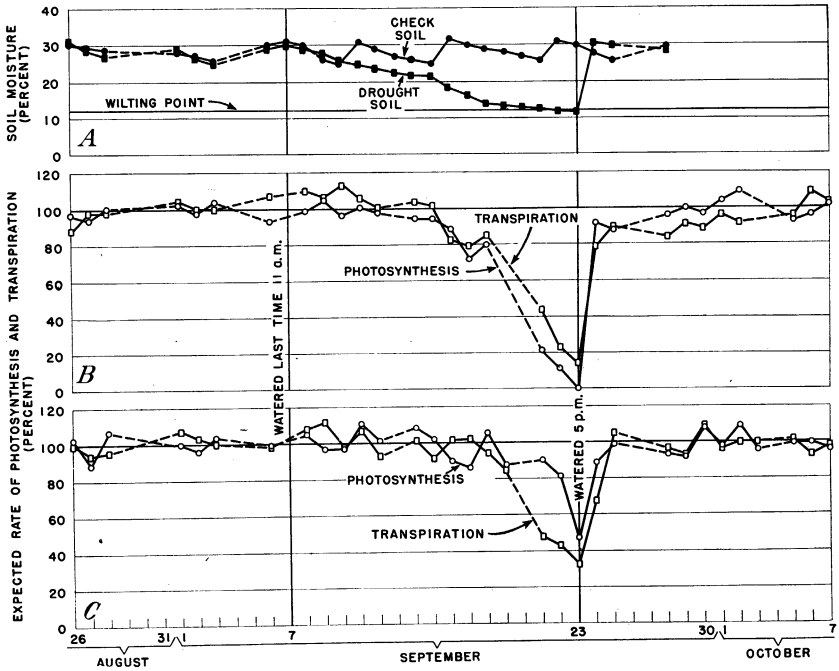

FIGURE 4.—Effect of drought on photosynthesis and transpiration of leaves of pecan seedlings growing in soil: *A*, Moisture percentages in soil; *B* and *C*, photosynthesis and transpiration (afternoon and morning determinations, respectively) expressed as percentage of expected rate.

morning of that day, but by afternoon it was reduced to one-fifth of the expected rate, while the transpiration rate was about the same as that of the morning period. The next morning the soil moisture had reached the wilting point and both processes were depressed somewhat further than on the previous morning; in the afternoon photosynthesis was further reduced to one-tenth and transpiration to one-fourth of the expected rates. During the morning of September 23 the soil moisture was below the wilting point and the rate of carbon dioxide assimilation was reduced to one-half of normal while transpiration was about one-third of the expected rate. By afternoon photosynthesis had ceased and there was more carbon dioxide in the air after it passed over the test leaves than before, indicating that the respiration rate was proportionately greater than that of assimilation. The leaves, which were mature, showed no signs of wilting; similar leaves of plants subjected to drought in sand did not wilt either.

The test plants were watered at 5 p. m., and on the morning of the following day (September 24) a marked recovery was noted in both photosynthetic activity (89 percent of normal) and in the transpiration rate (67 percent of normal); in the afternoon carbon dioxide assimilation had recovered to 92 percent and transpiration to 79 percent of the expected rates. Within the next 5 days both processes had attained approximately normal rates.

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Effects of Flooding

With a few notable exceptions, the effects of flooding on seedlings grown in soil (fig. 5) were similar to those on seedlings grown in sand. The pretreatment relation was established from August 26 to September 2, and the test plants were flooded at 8 a. m. on September 3. The first apparent effects of flooding were evident on the morning of September 8, when the rate of carbon dioxide assimilation was reduced by 21 percent; but in the afternoon there was no appreciable effect on the process. Subsequent determinations for morning and afternoon showed a steady decline in the rate of photosynthesis until September 23, when the excess water was removed. The amount of depression was considerably more severe in the afternoons than in the mornings, and the process had ceased by the afternoon of September 23.

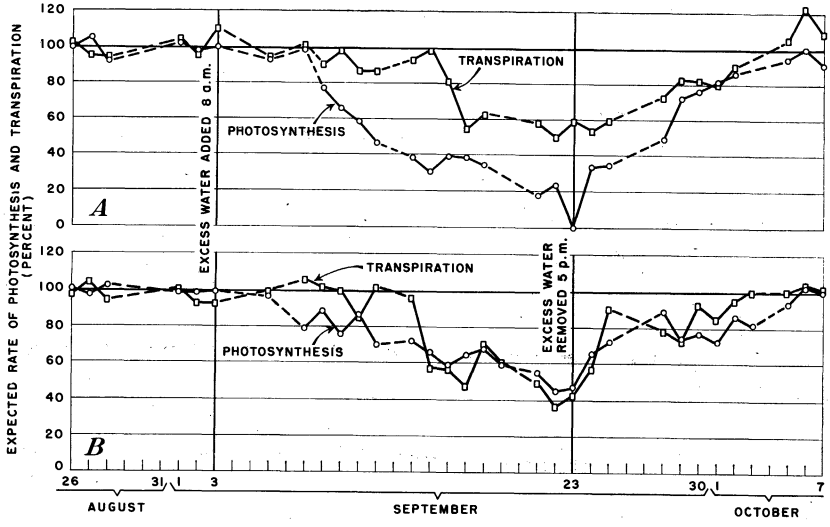

Figure 5.—Effect of flooding the roots on photosynthesis and transpiration of leaves of pecan seedlings growing in soil, expressed as percentage of expected rate: *A*, Afternoon determinations; *B*, morning determinations.

Although transpiration was generally somewhat depressed, there was no consistent reduction until the morning of September 15, 12 days after the plants were flooded. From this time until the soil was drained on September 23, transpiration declined gradually until it was about one-half of normal. The data for the morning of September 24, the day after drainage of the soil, show some recovery in both processes, and subsequent determinations show a gradual recovery to normal by October 7.

DISCUSSION

It is evident from the data presented that either deficient or excessive amounts of soil moisture resulted in subnormal rates of photosynthesis and transpiration in the leaves of pecan seedlings. The degree of depression of the rates depended, among other things, upon

the severity and duration of the adverse soil-moisture conditions and the atmospheric conditions prevailing at the time.

The direct cause of the depression of photosynthesis and transpiration in leaves of drought plants is undoubtedly a water deficit in the leaves. Although no stomatal observations were made, it is not unlikely that complete or partial closure of the stomata, which is usually correlated with loss of turgidity in the leaf cells, was a factor in the reduced photosynthesis rate under conditions of marked moisture deficiency in the leaves. There were no signs of wilting of the mature leaves, but there is little doubt that they suffered from a water deficit when the soil moisture was at or near the wilting point. The leaves usually overcame the water deficit to some extent during the nights, and because of the relatively cool temperature, high humidity, and reduced light conditions during the mornings, there were no appreciable effects on photosynthesis and transpiration until the moisture in the sand or soil approached the wilting point. On the other hand, both processes were reduced considerably in the afternoons before the moisture in the sand or soil had closely approached the wilting point.

It is natural to expect the depressions to be greater during the afternoons than during the mornings, because the vapor pressure gradients between the leaves and atmosphere are greater; such conditions probably would accentuate the effects of the drought in the afternoons, since it is unlikely that the root systems could absorb the small amounts of available water in the drought soils as fast as it could be removed by transpiration. During the morning periods, however, the leaf cells were probably more turgid and the temperature, light, and humidity conditions were less favorable for evaporation; as a result, transpiration and photosynthesis rates probably would be depressed less. In this connection it is interesting to note that for several days before the moisture in the heavy soil reached the wilting point the rates of photosynthesis and transpiration of the leaves were considerably depressed during the afternoon periods but were affected only slightly, if at all, during the mornings. For plants in sand this condition prevailed for only 1 day, and the difference in behavior was probably due largely to differences in the rates at which the moisture decreased in the two soil media.

Taylor and Furr (*12*) emphasized the distinction between the first wilting percentage (the soil moisture at which wilting occurs but at which plants will recover if placed in a saturated atmosphere) and the ultimate wilting percentage (the soil moisture at which the leaves will not recover turgidity even when in a completely saturated atmosphere). It seems probable that the plants growing in soil were in this so-called wilting range when they showed recovery in the morning but serious curtailment of photosynthesis and transpiration during the afternoon.

That the amount of injury caused by drought is largely dependent upon the prevailing weather conditions during the time that the soil moisture is at or near the wilting point, was indicated by the behavior of leaves during the three drought periods. In experiment 1, during the first drought period, the moisture in the sand was allowed to go below the wilting point on 1 day only, but the leaves suffered severe damage in a short time during the afternoon of that

day because of rapid evaporation due to high temperature and low humidity. In less than half an hour many of the leaves were visibly injured as a result of desiccation. During the second drought period, however, the atmospheric conditions were much less favorable for evaporation and there was no apparent damage to the leaves. Likewise, in experiment 2, with seedlings growing in heavy soil, the soil moisture was at or below the wilting point for 3 days during which the humidity was high, the weather was partly cloudy and relatively cool, and the leaves were not visibly injured. There was a marked depression in rates of carbon dioxide assimilation and transpiration in leaves of plants growing in both sand and heavy soil during the drought period, but in all cases there was also a marked recovery in the rates of both processes on the day after watering, which indicates that most of the leaf cells were not permanently injured by the water shortage.

The data obtained in the drought studies, insofar as they are applicable to field conditions, give emphasis to the importance, in semiarid regions or in orchards where irrigation is practiced, of maintaining the soil moisture at a level appreciably above the wilting point, particularly during the hot, dry months, when drought may impair the normal functioning of the leaves or cause permanent damage to the foliage and nuts and ultimately injure the entire tree. Furthermore, many of the young fibrous roots are killed during a period of drought, and as a result subsequent mineral deficiencies may occur in the tree before new rootlets can be formed after the drought is terminated.

The deleterious effects of flooding on photosynthesis and transpiration are undoubtedly due to depletion of the oxygen supply to the roots, causing abnormal root activity, such as a reduced rate of respiration, subnormal absorption of minerals and water, and eventually severe damage to the root system. The facts that the dry-weight percentages of organic nitrogen and ash in the tissues decreased during the period of flooding but increased rapidly after the sand was drained and that the mineral-deficiency symptoms which appeared in the leaves of flooded plants cleared up soon after the sand was drained indicate that flood conditions caused subnormal absorption of minerals by the plants.

SUMMARY

The effects of both excessive and inadequate amounts of soil moisture on photosynthesis and transpiration of pecan leaves were determined on pecan seedlings growing in coarse sand and in heavy soil.

In all instances, both soil-moisture extremes caused subnormal rates of photosynthesis and transpiration in the leaves, the degree of reduction depending primarily upon the severity and duration of the adverse soil-moisture conditions and on the atmospheric conditions during the critical periods.

Under drought conditions a marked reduction in the rates of both photosynthesis and transpiration occurred 1 or 2 days before the moisture in the sand or soil had reached the wilting point. Transpira-

tion and photosynthesis rates were usually depressed at about the same time, and as a rule the rates of both processes were depressed in the afternoon periods 1 or 2 days before any appreciable reduction was observed in the mornings, probably owing largely to wide differences in atmospheric conditions that prevailed during the afternoon and morning periods.

The amounts of reduction in the rates of photosynthesis and transpiration of leaves of pecan seedlings subjected to drought were closely correlated with the proximity of the soil moisture to the wilting point as well as with the atmospheric conditions during the critical periods of moisture shortage. Under conditions highly favorable for moisture evaporation, as in the afternoons, photosynthesis almost ceased when the soil moisture was at the wilting point or slightly below; but the reduction in transpiration was considerably less. Under conditions less favorable for evaporation, as in the mornings, the transpiration rates were reduced to a greater extent relative to the reduction in the rates of photosynthesis, although the actual reduction in transpiration was usually somewhat less than that under conditions highly favorable for evaporation.

The rate of recovery in photosynthesis and transpiration activity from the effects of drought was usually very rapid during the first day or two after termination of the drought, but several days more were required before the rates reached normal or their maximum.

A substantial reduction in the rate of photosynthesis in leaves of pecan seedlings with submerged roots was observed 5 days after submersion, but no consistent and definite depression of transpiration occurred until several days later. Photosynthesis was depressed to a greater degree in the afternoons than in the mornings, as was the case in plants under drought conditions. The photosynthesis rate of leaves of flooded plants in sand was reduced to a low of 11 percent of normal, while in leaves of flooded plants in soil it was reduced to cessation, thus indicating that the supply of oxygen to the roots was reduced to a greater degree in the latter medium.

The percentages of organic nitrogen and ash in tissues of seedlings subjected to flood conditions in sand for 35 days were considerably lower than in similar tissues of check plants. However, on the 26th day after the sand was drained the percentages of the constituents had increased considerably in relation to those for check plants but still remained lower, except that the percentages of ash in stems and roots were then about the same in the flooded and check plants. The percentages of organic nitrogen and ash were usually slightly lower in drought plants than in the check plants.

The results of these experiments emphasize the importance of good internal and surface drainage in pecan soils, in addition to an adequate moisture supply and a high moisture-holding capacity, and suggest possible causes of crop failures in orchards or groves in which the soils are subjected to drought or flood or to alternations of the two conditions.

LITERATURE CITED

(1) ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS.
1940. OFFICIAL AND TENTATIVE METHODS OF ANALYSIS . . . Ed. 5, 757 pp., illus. Washington, D. C.

(2) BOYNTON, D.
1940. SOIL ATMOSPHERE AND THE PRODUCTION OF NEW ROOTLETS BY APPLE TREE ROOT SYSTEMS. Amer. Soc. Hort. Sci. Proc. (1939) 37: 19–26, illus.

(3) CHILDERS, N. F., and WHITE, D. G.
1942. INFLUENCE OF SUBMERSION OF THE ROOTS ON TRANSPIRATION, APPARENT PHOTOSYNTHESIS, AND RESPIRATION OF YOUNG APPLE TREES. Plant Physiol. 17: 603–618, illus.

(4) CHILDS, W. H.
1941. PHOTOSYNTHESIS, TRANSPIRATION, AND GROWTH OF APPLE TREES AS INFLUENCED BY VARIOUS CONCENTRATIONS OF OXYGEN AND CARBON DIOXIDE IN THE SOIL ATMOSPHERE. Amer. Soc. Hort. Sci. Proc. (1940) 38: 179–180.

(5) DEVILLIERS, J. I.
1939. SOME RESPONSES OF MCINTOSH APPLE SEEDLINGS GROWING WITH THE ROOTS IN VARIOUS CONCENTRATIONS OF OXYGEN. Amer. Soc. Hort. Sci. Proc. (1938) 36: 86.

(6) HEINICKE, A. J.
1933. A SPECIAL AIR-CHAMBER FOR STUDYING PHOTOSYNTHESIS UNDER NATURAL CONDITIONS. Science (n. s.) 77: 516–517, illus.

(7) ——— and CHILDERS, N. F.
1936. THE INFLUENCE OF WATER DEFICIENCY IN PHOTOSYNTHESIS AND TRANSPIRATION OF APPLE LEAVES. Amer. Soc. Hort. Sci. Proc. (1935) 33: 155–159.

(8) ——— and HOFFMAN, M. B.
1933. THE RATE OF PHOTOSYNTHESIS OF APPLE LEAVES UNDER NATURAL CONDITIONS. PART 1. N. Y. (Cornell) Agr. Expt. Sta. Bul. 577, 32 pp., illus.

(9) HOAGLAND, D. R., and ARNON, D. I.
1938. THE WATER-CULTURE METHOD FOR GROWING PLANTS WITHOUT SOIL. Calif. Agr. Expt. Sta. Cir. 347, 39 pp., illus.

(10) LOUSTALOT, A. J., and HAMILTON, J.
1941. EFFECTS OF DOWNY SPOT ON PHOTOSYNTHESIS AND TRANSPIRATION OF PECAN LEAVES IN THE FALL. Amer. Soc. Hort. Sci. Proc. 39: 80–84, illus.

(11) SCHNEIDER, G. W., and CHILDERS, N. F.
1941. INFLUENCE OF SOIL MOISTURE ON PHOTOSYNTHESIS, RESPIRATION, AND TRANSPIRATION OF APPLE LEAVES. Pant Physiol. 16: 565–583, illus.

(12) TAYLOR, C. A., and FURR, J. R.
1936. THE EFFECT OF DECREASING SOIL MOISTURE SUPPLY ON SIZE OF LEMON FRUITS. Amer. Soc. Hort. Sci. Proc. (1935) 33: 71–81, illus.