ANATOMICAL AND MORPHOLOGICAL DEVELOPMENT IN RELATION TO LEAF WATER BALANCE

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FEROZA BAIG

M.Sc.

Department of Botany,
Imperial College of Science & Technology,
London, S.W.7.

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ABSTRACT

Anatomical and morphological changes produced by (2-Chloroethyl)-trimethylammonium Chloride (C.C.C.) and Gibberellic acid on Helianthus annuus as a result of changes in water balance were investigated. Effect of wind as an additional factor producing the same type of changeswas also studied, and compared to plants treated with C.C.C. both as a foliar spray and soil drench. Plants were harvested at regular intervals and the primary data was recorded for growth analyses. Morphogenetic and metabolic condition of the plants was studied with special reference to the parameter α. The anatomical changes produced in response to adverse water conditions were studied and discussed. It was concluded that wind, C.C.C., or reduced soil moisture produced morphological and anatomical changes which confer advantageous adaptations. Plants grown under mesophytic conditions and treated with C.C.C. were found to develop pre-adaptation enabling them to withstand moisture stresses both with respect to soil and atmospheric drought.

CONTENTS

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INTRODUCTION

The present investigation was of the effects of wind and drought on the anatomy and growth of Helianthus annuus var. 'Pole Star'. This involved studies of the course of growth and development over time. An attempt is made to show that the changes in morphology and anatomy are casually related to the experimental factors and are also of survival value under the experimental conditions.

The effects of drought and exposure on plants have been studied both in the field and in the laboratory by many workers particularly since the beginning of this century. These effects for convenience can be considered under the following headings.

A) Water Balance

B) Effects of water deficits on growth and morphology

C) " " " " " anatomy

D) " " " " " physiological processes

E) " " wind on growth and anatomy

Since the present studies are concerned with the effects of growth on differentiating substances the literature on these is also summarised under the

following headings.

F) Gibberellic Acid

G) 2 Chloroethyl-trimethylammonium chloride.

A) The internal water balance and degree of turgidity depends on the relative rates of water absorption and water loss, and is affected by the complex of atmospheric, soil, and plant factors that modify the rates of absorption and transpiration.

The transpiration rate in well watered plants is fully controlled by plant factors such as leaf area, internal leaf structure, thickness of cuticle and extent of stomatal opening and by such environmental factors as solar radiation, humidity, temperature and wind.

The rate of absorption depends on the rate of water loss, the extent and efficiency of root systems, and by the availability of soil moisture. The rate of absorption is affected by aeration, concentration of the soil solution, soil temperature, as well as soil moisture tension.

It is not surprising that two processes controlled by quite different sets of factors do not always keep in step as shown by (Kramer 1949) the

rate of absorption even in moist soils tends to lag behind the rate of transpiration, chiefly because of the resistance to the movement of water into the roots.

On hot, sunny days whenever transpiration exceeds absorption water deficits develop in plants which are usually eliminated by absorption during the night. But if the soil moisture decreases gradually and absorption becomes slower and slower and midday deficit persists later and later, until permanent wilting finally occurs and growth ceases.

Thus plant deficits can be caused by excessive transpiration, by slow absorption of water or by a combination of the two. Deficits caused by excessive transpiration are shorter and less severe than caused by inadequate absorption. Plant growth is affected by the turgor, or internal water balance which depends on the relative rates of absorption and transpiration.

The internal water balance or turgidity of the plant represents the integration of all the factors affecting plant water relations. Thus, we need to give more attention to the internal water balance as a measure of whether or not plants are adequately supplied with water.

Little work has been done on the variations in water content of plants over more extended periods than 24 hours. Brown (1927) reports that the water content (presumably on fresh weight basis) of cotton plants is high at the seedling stage and thereafter decreases. Herrick (1933), Evenari and Ritcher (1937) and Portsmouth (1937) all used the dry weight basis for investigating seasonal changes in the water relations of various plants. Lloyd (1913) avoided the use of dry weight by expressing diurnal changes in water content on the basis of area. A similar method was used by Miller (1917) working on maize and sorghum.

Discs of leaf tissue were punched with a cork-borer from time to time and water content of standard number of discs measured. Also using a discing technique, Hawkins (1927) was able to demonstrate that the water content of cotton leaves expressed on the basis of area responded to irrigation. Dry weight however fluctuated independently. In this case area seems to be a more useful basis for expressing water content than dry weight.

Weatherley (1950) studied the methods of investigating the water relations of plants growing in the field and suggested that the water content of the leaves was a guide to the balance between transpiration and absorption; he found that discs punched from leaves could be made fully turgid by floating on the surface of water and calculated the ratio:

$$\text{R. T.} = \frac{\text{Water content of tissue in field}}{\text{Water content of same quantity of tissue when fully turgid}} \times 100$$

This ratio could be called relative turgidity and by the same technique Weatherley (1951) studied the water relations of the cotton plants growing in the field under normal agricultural conditions to determine how environmental conditions through the season affected the water deficits of the plants. Measurements of relative turgidity, transpiration, etc. were made at 2 or 3 hr. intervals through two 24 hr. periods and a comparison of fluctuations in soil moisture and meteriological conditions with fluctuations in relative turgidity in the cotton plants was made. Relative turgidities were determined by his original technique (Weatherley, 1950). He came to the conclusion that relative turgidity in a plant at a given time period

proved independent of its age, and was controlled by environmental conditions alone. The relative turgidity at sunrise was found to be less than 100 and varied from time to time through the season, the greater the evaporation the less was the relative turgidity of the tissues. The relative turgidity at 2.30 p.m. was found to be less than at sunrise, these relationships occurred whilst the soil moisture content was above a certain critical value. However, when the soil moisture content fell below this value the relative turgidity at sunrise and 2.30 p.m. became much reduced. There was evidence that under these conditions both soil moisture and atmospheric evaporation controlled the water balance of the plants. But when the soil moisture content was greater than the critical value the water balance of the plants was unaffected by fluctuations in soil moisture content and was largely controlled by evaporating power of the atmosphere.

However, the relative turgidity technique devised by Weatherley (1950, 1951) gave a very useful method of measuring the water content of the leaves, but it involved certain complications such as to obtain the initial and turgid water contents it was necessary

to obtain the dry weight of the samples but in practice, however, the use of final dry weight to estimate initial water content was found by Weatherley (1950) to be inaccurate since a significant decrease in dry weight occurred during the 24 hr. period of floating which had been adopted to permit the tissue to become fully turgid, and this led to the initial water content to be overestimated. Weatherley, therefore, considered it necessary to collect simultaneously a duplicate sample of tissue which was oven dried immediately to give the initial dry weight needed for the accurate determination of the water content. The use of second sample in this way was complicated by the errors which arose from chance differences between the duplicate samples.

A re-examination of the relative turgidity technique was published by Barrs and Weatherley (1962) and the three main sources of errors in the original technique (Weatherley, 1950, 1951) were recognised as 1) changes in the dry weight of the discs, 2) continued increase in water content after the attainment of full turgidity, 3) injection of the intercellular spaces at the cut edges of the discs. An examination of these sources of errors led to the following conclusions.

1) By regulating the light intensity approximately to the compensation point, dry weight changes can be reduced to unimportant proportions. This obviates the necessity of taking duplicate samples since the final dry weight can be used for calculating both the initial and turgid water content of the discs.

2) Water uptake by floating leaf discs can be divided into two phases, phase I in response to the initial water deficit, and phase II the continued uptake, due to growth. The aim of the technique was to measure phase I alone. Metabolic inhibitors eliminated phase II but their use in the technique is unpractical.

B) Effects of Water Deficits on Growth and Morphology

It has been observed by many workers, e.g. Davis (1942), Haynes (1948), Salter (1954), Gates (1955, 1957), Slatyer (1957), Wadleigh and Ayers (1945), that the deficiency of water retards growth whether it is measured in terms of growth in length or by yield. It has been observed by Davis (1942), Wadleigh and Gaunch (1948), Slatyer (1957) that the growth is retarded as soon as there is a slight

water deficit and progresses until the beginning of plasmolysis when it stops or comes to a standstill. The extent to which soil moisture effects physiological processes of plants is largely dependent upon the degree to which a certain water deficit is maintained absolutely constant or with fluctuations above or below an average level. Loomis (1934) and Thut and Loomis (1944) observed in maize that with an abundant water supply the growth of plants was greater during the day than during the night. However, when there was a considerable water deficit and the plants were grown at a soil moisture near the wilting point, the growth was greatest during the night. Thus indicating that the decrease in growth during the day was due to the development of a water deficit. Furr and Reeve (1945) found that the rate of elongation of the central stem of sunflower plant continuously decreases as the soil moisture is depleted from the moisture equivalent to the wilting percentage. They found that the stem elongation ceased at approximately the soil moisture content they identified as wilting percentage. The rate of stem elongation of sunflowers was markedly reduced before half the available water was depleted. Frei, E.

(1954) found that when sunflower plants were grown at different moisture tensions, the results showed a strong decrease of the plant weights and leaf areas with a soil moisture tension increase between 0 - 1 atmospheres.

It has been generally observed by many workers that in a dry soil the root growth is favoured more than shoot growth. Harris (1914) found that in wheat plants cultivated in soil with 30% field capacity, the shoot weight/root-weight ratio was 8:1, whereas in 15% field capacity it was only 3:1. Martin (1940) however, found that the growth of the leaves as compared with the root was more sensitive to water deficit. Similar phenomenon was observed by Ronnike (1957) for the hypocotyl of seedlings of Lupin, and by Davis (1942) for the stem of Cyperus rotundus.

The correlation of organs within the shoot is also modified as shown by Simonis (1947) that in dry conditions, the growth of leaves is retarded relatively much more strongly than that of the stem. The most precise data is supplied by Gates (1955, 1957) with respect to young tomato plants. As he

measured the growth during and after a period, which did not, however, exceed the wilting point, he saw the contrary behaviour of the leaf and stem, i.e. during the drying phase the growth of the leaf laminae is considerably retarded as compared with that of the control plants maintained in a moist state, whereas that of the stem is promoted. This is the effect of the reaction phase according to Stocker (1960). After the restoration of the normal water status, the situation is reversed and the curves in the figures intersect one another, i.e. the growth of the leaves is now promoted and that of the stem retarded. This according to Stocker (1960) is the effect of the restitution phase, which during the water deficit was unable to become effective owing to the lack of growth substrates. The root/shoot ratios are not so greatly effected by drought in the tomato plants.

C) The most striking and the most investigated morphogenetic effects of a deficiency of water are those exercised on the structure of the leaf. They were described for the first time by Sorauer (1873), then by Kohl (1886) and in detail by Zalenski (1904). They characterized the tendency of the changes due to

increasing water deficit as follows. The size of the epidermal cells and the sinuosity of their walls, the size of the hairs, stomata and mesophyll cells, the extent of the spongy parenchyma and that of the intercellular spaces are diminshed; whereas the length of the veins, the number of stomata and the number of hairs per unit area of leaf surface, the thickness of the outer walls of the epidermal cells, the formation of wax layers, the development of mechanical tissues and the formation of a typical palisade parenchyma with several layers, are increased. The same differences can appear in plants grown in dry and moist air, between sun leaves and shade leaves, and between upper and lower leaves of the same plant.

Regarding the influence of soil drought the work of Rippel (1919) on Sinapsis alba has been presented by Stockor (1960) (Reviews of Res. UNESCO) in detail which contains precise data for plants cultivated in soils with 85, 55, 40 and 25 per cent field capacity which indicates that the height of the plants, the dry weight, length of the leaves, leaf area, size of epidermal cell decreases while the number of stomata per unit area is higher in plants with higher water deficits. As indicated by the works of Rippel

(1919), Farkas and Rajathy (1952, 1953, 1954) the greater number of stomata in plants grown in dry conditions is accompanied by the diminution of the size of the guard cells and the epidermal cells.

The increasing density of the venation in the leaves of plants grown under dry conditions is accompanied by a greater development of the conducting strands. Little information so far has been available with regard to the influence on the vascular system in the stem, though it has been found by several workers that water deficiency promotes the development of the water-conducting system Farmer (1918). Stocker (1960) has reviewed the subject, concluding that water shortage initiates changes tending towards the morphological and physiological characters of the xerophytes. These may be briefly summarized as an increase in proportion of mechanical tissues, cuticular thickening and an increase in the osmotic concentration of the cell sap.

D) Effect of Water Deficit on Respiration

Iljin (1923) assumed that during desiccation, the plant passes through different phases; at first katabolism increases gradually reaches a maximum; when there is an excessive loss of water it decreases

and falls below the normal level. These according to Stocker (1960) were the reaction and restitution phases. In 1933, the research carried out by Kourssanov, Blagoveschenski and Kasakova (in Russia) clearly revealed the existence of both the phases. Further studies on the respiration of leaves in relation to water deficit are made by Yuncker (1916); Wood and Petrie (1938), Schneider and Childers (1941) Parker (1952) Wager (1954).

Stocker (1948) observed that on warm days when transpiration was high, young oat plants then showed, around midday, even with optimum watering, a considerable increase of respiration which was not determined by temperature. It was explained rather by the fact that a water deficit occurred during the morning, which initiated a reaction phase of the drought effect and caused an effect of increase in respiration. This phase of respiration increase was also shown by Schneider and Childers (1941) and Smith (1915). If during the afternoon the water balance did not deteriorate further, the restitution phase began, being shown by a gradual decrease of respiration, and when the water deficit was made good, it was followed by the nocturnal normalization phase. On

cloudy days there was no water deficit and consequently no increase of respiration. It was also observed by Kraft (see Stocker, 1960) on 13 days old plants of two oat varieties. These were grown at a constant water content of 70% field capacity then the watering was discontinued and the soil was dried to 30% field capacity. This water content was constantly maintained and when the water content of the leaves began to decrease especially in the afternoon the reaction phase started and on the following days, the increase of water deficit was seen to be accompanied by a continued further increase in respiration, which, even during the night, was hardly interrupted. On the fourth day the respiration increased reached its maximum. Subsequently, the restitution phase made its appearance, and as the humidity of the soil was constantly maintained at 30% from onwards the level of respiration began to decrease; if plants continue to be grown in this soil at the same constant level of dryness, the decrease of respiration, characteristic of the restitution phase continues until it falls below the original level. This was the hardening phase, during which the decrease of respiration is equivalent to the decrease of photosynthesis and production of

dry matter caused by the poor water status of the protoplasm.

The behaviour of photosynthesis is contrary to that of respiration. Iljin (1923) pointed out that photosynthesis decreased concomitantly with an increase in the water deficit, and that in this respect, both the width of the stomata and the water state of the protoplasm played a role. Further work on the behaviour of photosynthesis is done by Dastur (1925), Dastur and Dessai (1933), Bolas and Melville (1933), Melville (1937), Petrie, Arthur and Wood (1943) and Loustalot (1945). Rabinowitch (1945) found that the effect of water deficit on photosynthesis can be exercised not only direct through the water state of protoplasm but also indirectly through the width of the stomata. The actual dry matter production by photosynthesis closely depends on the water deficit and, expressed per unit of leaf area, it is considerably lower under extreme conditions than with plants grown in wet conditions, as the formation of new leaves is greatly retarded by a water deficit and the assimilating surface therefore remains smaller.

Effect of Water Deficit on Transpiration

Transpiration is reduced by the closure of the stomata but the water loss continues by the cuticle of the leaf. This loss varies from species to species, according to cuticular thickening but the major transpiration takes place through the stomata (Kramer 1959). Transpiration follows a diurnal course which is inversely correlated with the leaf water content. Kramer (1937) studied this relationship and found that transpiration rose to a maximum during the day, reducing leaf water content, and in the late afternoon transpiration rate fell and leaf water content began recovery so that equilibrium was restored by the following morning. He worked with full water supply. It is well-known that during times of rapid transpiration a decrease in moisture content of plant usually occurs, frequently accompanied by loss of turgor and wilting of leaves and other parts. Separate but simultaneous measurements of rates of transpiration and absorption indicate that during periods of moderate to high transpiration more water is being lost from the plant than is being absorbed (Livingston and Hawkins 1915; Kramer 1937). Kramer (1938) determined the cause of lag of absorption behind transpiration

when plants had adequate root system and abundant moisture supply. Kramer (1938) found that lag of absorption behind transpiration was greatly decreased in sunflower and tomato after the roots had been removed; this he probably thought was due to the cells between the epidermis and the xylem which offered considerable resistance to the passage of water and are probably responsible for the lag of absorption behind transpiration. Martin (1940) measured the transpiration of Helianthus annuus in relation to soil moisture content, with treatments watered at pre-determined intervals between field capacity and wilting points. He found that stomatal opening and transpiration did not change until a depletion to 2/3 of the available moisture.

Furr and Reeve (1945) found when determining the permanent wilting percentage for sunflower plants, that the rate (transpiration) decreases gradually as the condition of permanent wilt was approached.

Frei, E. (1954) grew sunflower plants at different moisture tensions and found that in 4 weeks old sunflower plants the highest intensity of transpiration and highest growth is connected with the lowest soil moisture tension. The results calculated

in percentages of the highest obtained transpiration and growth indicate that plant growth and transpiration intensity are strongly dependent on the soil moisture tension.

There has been much argument as to the time when transpiration begins to decrease in plants in drying soil. Veihmeyer and Hendrickson (1950) being contented that transpiration does not decrease materially until soil moisture falls almost to the permament wilting percentage; but now it seems clear that transpiration and other physiological processes are usually affected considerably earlier (Gates, 1955, Richards and Wadleigh, 1952 Slatyer 1955, 1957).

Effects of water deficits on Stomatal aperture.

Although there are several important aspects of stomatal physiology and function which require further study, it is now accepted that guard cell turgor controls aperture and that turgor can be influenced not only directly by general levels of plants turgor but also indirectly by such factors, as light, atmospheric humidity, wind and the relative turgor level of guard cells with that of adjacent cells.

In general leaf turgor directly affects stomatal aperture by influencing turgor pressure in the guard cells, and since in most cases, the osmotic levels in the guard cells are not dissimilar to those in the leaf tissue generally (Heath 1959a), zero turgor pressure in the leaf is associated with zero turgor pressure in the guard cells and hence with complete closure.

Stomatal opening seems to be one of the most sensitive plant processes with respect to the internal water deficits. A slight decrease in the turgidity is sometimes accompanied by increased opening of the stomata (Stalfelt 1955), but further reduction is nearly always accompanied by a decrease in stomatal aperture. Decreasing soil moisture also causes premature closure of stomata in citrus (Oppenheimer 1953, Oppenheimer and Elze 1941). Stomata close earlier each day as water becomes less available, until finally they remain open only for a short time in the morning (Aldrich and work 1934 in pear; Jones 1931 in peach; Maximov and Zernova 1936 in wheat).

Premature closure is undesirable because 1) at least in some species it cuts off the supply of carbon dioxide (Nutman 1937), although in others considerable carbon dioxide appears to enter through the epidermis (Dugger 1952, Freeland 1948, Mitchell 1936).

2) One effect of closure is to reduce transpiration, because by far the larger fraction of water loss occurs through the stomata. This reduction would be desirable in itself, but it also reduces photosynthesis by reducing the supply of CO_2.

When stomata are closed water loss is controlled by the characteristics of the cuticle or the waxy layer covering the leaf epidermis.

E Effects of Wind

The growth form of a plant is of great importance in relation to wind effects, as shown by Whitehead (1957). The plants show a marked dwarfing when grown in conditions of continuous exposure to wind. It was also found that leaf saturation deficits of plants exposed to wind for a time increased despite the fact that roots were in soil maintained at field capacity.

A number of experiments (Whitehead 1962, 1963) on plants grown in wind tunnels have shown that treated plants are more sturdy, having a thicker and shorter stem, with broader and thicker leaves. Roots are produced in greater quantity as compared to the shoots. Whitehead and Luti (1962) published numerical data concerning the anatomical features of controls and wind treated plants. The seedlings of Zea mays were exposed to a wind speed of 33 m.p.h. for 40 days and the anatomy of the leaveswas examined. The anatomical sections revealed that the degree of vascularization was much greater in the treated plants together with increased number of vessels, larger diameter of phloem elements and the number of fibres in the bundles of treated plants were three times larger as compared to the Controls. Considerable differencesin the dry weights were also noticed in two varieties of Zea mays. In both varieties the dry weight of the treated plants was less than that of the controls.

F. Brian, Elson, Hemming and Radley (1954) reported the plant growth-promoting properties of Gibberellic acid by a number of experiments on wheat and pea seedlings. They found that when Gibberellic acid

was supplied in a nutrient solution to wheat plants grown in water culture, it caused an increased growth of the shoots. The number of internodes were increased and the leaves were narrower and paler than those of untreated plants. The total dry weight of both pea and wheat was increased. The increase in dry weight they thought was mainly attributable to increased assimilation. The effect of Gibberellic acid on shoot growth of pea seedlings was studied by Brian and Hemming (1955). By studying this response on different varieties of pea using different concentrations of gibberellic acid they came to the conclusion that the growth rate of shoots of pea seedlings was significantly increased. The effects of gibberellic acid on growth and development of various species was studied by Marth, Audia and Mitchell (1956). They observed that when gibberellic acid was applied as a 1% lanolin paste mixture, it caused very rapid elongation of stems of most species. They found that under greenhouse conditions a number of garden plants were 50 to 300 per cent taller in 3 - 4 weeks after treatment with gibberellic acid. Ergle (1958) studied the growth responses of young cotton plants to gibberellic acid. He used several

concentrations of gibberellic acid and found that at growth promoting levels, the effects of gibberellic acid was largely confined to the stems and petioles of cotton plants.

Gray (1957) found marked effects of gibberellins on leaf size and shapes of different plants. The most pronounced effect of gibberellins was noted on tomato plants. Gibberellic acid concentration of 10 - 100 p.p.m. caused the new leaves to loose their indented edge and become entire. Leaves of tobacco became more elongated and pointed. He also noticed that the dry weight of bean and pepper plants increased by 25% in one week by a single spray of 10 p.p.m. gibberellic acid.

Alvim (1960) studied the growth behaviour of beans as affected by gibberellic acid when applied as spray with 50 p.p.m. solution. He found that gibberellic acid increased net assimilation rate, relative growth rate, stem dry weight, leaf area and plant height. Root dry weight was reduced and leaf dry weight was not subsequently altered. Increase in net assimilation rate caused by gibberellic acid was thought to be due to a more rapid translocation

of photosynthates from the leaves to the stem. Humphries and French (1960) studied the effect of gibberellic acid on leaf area and dry matter production in Majestic potato. They found that the dry weight and yield of potato plants could be increased by application of gibberellic acid. It was also suggested that the application of gibberellic acid had little effect on root size.

The effects of gibberellin on growth, dry matter accumulation, chlorophyll content and peroxidase activity were studied by Monselise and Halevy (1962). A number of spray concentrations of gibberellic acid were used ranging between 50 - 1600 p.p.m. on 6 month old sweet lime seedlings. They observed that increasing concentrations of gibberellic acid progressively increased shoot and internode length, did not influence the number of leaves and decreased leaf area. Dry weight of the shoots was progressively increased up to 400 p.p.m., while dry weight of roots decreased over all concentrations. Total dry weight of the plants was increased by gibberellic acid when related to leaf area or weight and to total chlorophyll content.

Effects of gibberellin on translocation dry matter accumulation and water content were studied

by Halvey, Monselise and Zplaut (1964). They studied the effect of gibberellin on five day old seedlings of Cucumis sativus L. grown on filter paper moistened with aqueous solutions containing various concentrations of gibberellins. Gibberellins increased movement of dry matter from the cotyledons, mainly to the hypocotyl, at concentrations as low as 10^{-6}M, the optimum being at about 10^{-3}M in light and 10^{-4} in darkness. Experiments with sweet lime and gladiolus plants treated with gibberellin showed that water content per leaf area was also increased.

Effects on Anatomy

Foucht and Watson (1958) studied the effects of gibberellins on cell number and cell length in internodes of Phaseolus vulgaris. Microscopic studies of the first and third internodes of plants after 48 and 72 hr. treatment with aqueous solution of gibberellins showed that the application of gibberellins not only increased the length of the internodes of the seedlings but also increased the number and length of cells. An increase in cell number in seedlings of Hyoscyamus niger has also been shown by Sachs and Lang (1957). Greulach

and Haeslop (1958) suggested that growth promotion by gibberellic acid involved only cell division and not cell elongation. These conclusions were drawn by anatomical measurements of the third internodes of Phaseolus vulgaris supplied with 0.346 mg. of gibberellic acid. It was seen that the treated plants grew 1.96 times as tall as the controls and the third internodes averaging 2.28 times as long. The mean longitudinal, radial and tangantial diameters of cells from both the pith and cortical parenchyma were not significantly different from those of the controls.

With a number of experiments on Corchorus olitorius L., Hisbiscus cannabinus L., and Cannabis sativa L. Margaret Stant (1963) showed that the application of gibberellic acid had an elongating effect on fibre cell. She studied the effect of gibberellic acid on cell breadth, cell wall thickness and several other anatomical aspects which revealed that gibberellic acid accelerates and increases the longitudinal growth or extension of the cell and the cell wall becomes thicker.

G. In 1960 a new group of quaternary ammonium compounds was reported by Tolbert (1960). The most active compound, (2 chloroethyl)-trimethylammonium chloride was an analog of Choline, in that the hydroxyl group in Choline was replaced with a chlorine substituent. Its trivial name was Chlorocholine Chloride, abbreviated to C.C.C. The chemical retarded the growth of a larger number of species than any of the early compounds. N. E. Tolbert (1960) in his experiments with wheat seedlings noticed that when wheat plants were treated once with either 2 chloroethyl-trimethylammonium chloride (C.C.C.) or related compounds the major growth difference was the development of plants with shorter and thicker stems than in untreated plants, the leaves were of darker green colour. The shorter and thicker stems resulted in wheat plants which grew very erect with no tendencies towards lodging. In spray treatments 10^{-2}M solutions were not toxic and he found that the lowest concentration for effectiveness was in the range of 10^{-5}M solutions. One soil application at the same molarity was found to be more effective than spray treatment. Wittwer and Tolbert (1960) studied the effect of C.C.C. and

related compounds on growth, flowering and fruiting responses. They observed slight, but significant increases in dry matter accumulation with tomato plants grown in solution cultures of 10^{-7}M C.C.C. Increasing amounts of the chemicals caused corresponding reductions in vegetative extension and low levels of C.C.C. and related compounds resulted in increased vegetative and dry matter accumulation.

Halevy and Kessler (1963) in experiments with Phaseolus vulgaris found that plants when treated with C.C.C. were less susceptible to water stress than untreated ones. High temperatures following periods of low light intensities caused wilting in controlled plants, while treated plants remained turgid. In these experiments the water supply of Phaseolus plants was stopped after the expansion of the third leaf. Five days after last watering the leaves of the control plants started wilting and growth ceased and most plants were desiccated after 30 days. The treated plants remained turgid and continued growth for 22 days after last irrigation. Humphries (1963) found that when Sinapsis alba and Raphanus sativus were applied with aqueous solutions of C.C.C. at

different concentrations to the surface of the soil the dry weight of the stem decreased with increase in dose of the C.C.C. Leaf and fruit weights were not much affected and there was a decrease in total dry weight of the plants.

Mayr and Presely (1963) studied the anatomical changes induced in wheat plants with the application of C.C.C. They found that the size of the hypoderm ring increased with C.C.C. The size of the parenchyma ring and the number of cell rows were increased by the application of C.C.C. The number of the vascular bundles in the hypoderm was increased by C.C.C. Laborie M. E. (1963) studied the effects of gibberellin and C.C.C. on pigment metabolism and found that gibberellin and C.C.C. have inverse bearings on chlorophyll content expressed on leaf area basis. Gibberellin induced an increase in the area of the leaf and a decrease in its thickness. On the contrary, C.C.C. induced an increase in the thickness of the leaf and a decrease in its area, concentrating chlorophyll on a smaller area.

Some of the papers presented at the C.C.C. Research Symposium held at Geneva in June 1964 sponsored by the Cynamid International are given below:-

Marie-Esther Deroche found that the effect of C.C.C. on plant growth and colour was opposite to that of gibberellin in experiments conducted with young tomato and wheat plants. It was seen that C.C.C. induced an increase in leaf thickness and a decrease in leaf area, concentrating chlorophyll in a smaller area. However she found that the effect of C.C.C. and gibberellin on pigment metabolism were not opposite.

Halevy found that unirrigated potted bean plants treated with C.C.C. survived 10 days longer than untreated plants. The same phenomenan was observed when leaves were left to dry in the laboratory or drought chamber. Leaves of C.C.C. treated plants died 7 hrs. later than controls. Water content of treated leaves and roots was higher than that of controls. They found that plants sprayed with C.C.C. showed a significant increase in root growth.

Stoddard studied the effect of C.C.C. on

biochemical processes and applied C.C.C. as soil drench. He found that all C.C.C. concentrations higher than 10^{-2}M reduced the rate of leaf appearance, however, chlorophyll production was stimulated in the presence of C.C.C.

Damaty, Kühn and Linser (1964) found that when young wheat plants were grown in saline solutions with concentration higher than 5000 p.p.m. of dissolved mixture of salts of $NaCl_1$ $CaCl_2$ and $MgCl_2$ with a ratio of 1:0.85:0.15, the non treated plants showed more wilting and were more damaged that the treated plants. Treating the plants with C.C.C. also showed that plants could resist drought.

Plants treated with C.C.C. also contained more chlorophyll than did the untreated ones. The osmotic pressure of the plant sap was higher for the treated plants than the untreated ones. This osmotic pressure was 7,521 atm. for the treated plants and 6,682 atm. for the untreated ones when they both were seven days old. A conclusion that might be drawn from this is that water attraction in the plants treated with C.C.C. might be greater than the water attraction in the untreated ones.

MATERIAL AND METHODS

Material: The material used in this investigation was Helianthus annuus var. 'Pole Star'. Seeds were obtained from Professor Blackman, Department of Agriculture, Oxford.

Methods

Sowing: Seeds were sown in large trays filled with sand, leaving $\frac{1}{4}$" empty from the rim of the trays. The surface level was made uniform and very shallow holes with equal distances were made in rows on it. A definite number of seeds were placed one by one in each hole. After this operation the seeds were covered with a thin layer of sand on which was placed some blotting paper and then the trays were watered. The precaution of placing the blotting paper on the surface of the sand before watering was taken for the reason that when watering is done some of the seeds are pushed deeper into the soil and the germination is not even. The same technique for sowing of seeds was applied when the seeds were sown in growth cabinets. The number of seeds sown was three to four times more than the required number of seedlings and from these, seedlings of equal size were selected for transplantation. Germination usually occurred within a week.

Transplantation: The soil used in all the experimental work consisted of a mixture of sand and peat in 2:1 ratio which was sieved in fine mesh sieves 60 holes per square inch and to this mixture was added the appropriate amount of John Innes Compost fertiliser, all three ingredients were thoroughly mixed together. Transplantation for all the experiments was made into 250 ml. beakers with holes at the bottom except in the experiments where the plants were grown at different moisture regimes. A small portion of glass wool was placed at the base of each beaker before filling it with the soil. The weight of the quantity of the soil was determined which filled the beaker about half an inch below the rim and the same quantity of soil was weighed (c. 280 gr.) into all the beakers used for the experiment.

Seedlings of equal size and at the stage when the cotyledons had just expanded were selected for transplantation. The seedlings were then removed one by one very carefully, taking care to avoid damage and were then planted one in each beaker. The beakers for all the experiments except for the experiment with different soil moisture regimes, were watered thoroughly so as to maintain them at field capacity throughout the

duration of the experiment, the technique employed for watering in the different levels of soil moisture regime experiment will be considered later.

The field capacity of the soil was determined as follows.

The weight of a 250 ml. beaker with hole at the bottom was determined, a small amount of glass wool was inserted at the base and a known quantity of soil which was thoroughly dried was weighed into the beaker. The beaker was watered slowly till the soil was completely saturated and it was then left for 24 hours to drain off the excess water, and was then weighed again, the weight of the amount of water retained was determined. The field capacity of the soil used (mixture of sand and peat) was found to be 38% weight of water retained / weight of dry soil. In the experiment where Helianthus annuus was grown at different moisture regimes the weight of all the beakers used in the experiment was determined and a known quantity of thoroughly dry soil was weighed in all the beakers and the individual moisture regimes were obtained by adding a set weight of water to the soil in the beakers whilst still on a Mettler electrical balance. The moisture regimes made up were 38%, 21%, 12 %, 6% and 4% weight

of added water/weight of dried soil. These regimes will be referred to as 100% (F.F.C.) 55%, 30%, 15% and 10% respectively. Throughout the duration of the experiment these moisture regimes were controlled by weighing the beakers every alternate day and any loss of weight was replaced by addition of water which was done very carefully so that the soil so far as possible was evenly wetted. The addition of peat was found necessary since it had more water retaining power.

The plants of Helianthus annuus grown at different moisture regimes were divided in three sets each containing five moisture levels, one of these sets were sprayed once a week with an aqueous solution of gibberellic acid, the second set sprayed with an aqueous solution of (2-chloroethyl)trimethylammonium chloride (CCC) once a week.

Spraying

Gibberellic Acid: An aqueous solution of gibberellic acid with strength of 100 p.p.m. was prepared by dissolving .1 gm of gibberellic acid powder (supplied by the B.D.H.) into 1000 c.c. of distilled water to which about 2 c.c. of wetting agent (tween 80) was added, the solution was left for some time till the gibberellic acid powder was fully dissolved and then stored in a cool place. Spraying was done once a week with an

atomizer, each plant was sprayed individually and received two sprays from the atomizer. Special care was taken that all plants were sprayed uniformly as far as possible.

(2-chloroethyl)trimethylammonium chloride: commonly called CCC was supplied by the Cynamid International Corporation. An aqueous solution of 1000 p.p.m. was prepared with a solution of CCC containing 50% active ingredients; 2 c.c. of this solution was added to 1000 ml. of distilled water and about 2 c.c. of wetting agent (Tween 80) was added to this solution when contents were fully dissolved. This solution was kept in a Frigidaire with a temperature above freezing point (c. 2^{o} - 4^{o}C.). The plants were sprayed once a week with this solution and spraying was done in a similar way as mentioned for gibberellic acid.

Soil Drench

In the experiment where the CCC was applied as soil drench in various concentrations such as 0.1, 0.2, 0.3, 0.4 and 0.5 of 100 % concentration of CCC was dissolved in 10 c.c. of distilled water and this solution was applied to the soil 3 days after the transplantation of the seedlings. Special precaution was taken during the watering of these plants and only

30 c.c. of water was given to each plant taking care that not even a small amount of CCC was drained off with the water given to the plants. Only one application of CCC as soil drench was found to be necessary as further applications proved highly toxic to the plants.

Harvesting: Plants were harvested at weekly intervals, the first harvest was done a fortnight after transplantation when the first leaves appeared to be fully mature. The plants for harvesting were chosen at random, each individual plant was harvested as follows: the masurements of the internodes were taken by means of a scale and the height of the plant from the surface of the soil was determined, the leaves were then cut just at the junction of the petiole and the outline of the leaves was drawn on a graph paper for determining the leaf area which was done by the help of a planimeter. The roots were thoroughly washed in water and sieved under water until practically free from sand. Every care was taken that all portions of the roots were recovered. The stem was separated from the region just above the beginning of the root, the fraction of the petioles was included with the stem. The leaves,

stem and roots were then enclosed separately in a large specially folded filter paper which was kept in an oven for drying at a temperature of 82°C. After 48 hours the weight of the leaves, stem and roots was determined separately on an electrical balance.

WATER BALANCE

The relative turgidity of the plants was determined by the same technique as used by Weatherley (1950) - discs of 1 cm. in diameter were punched by a specially made punching apparatus which consists of an elongated tube about 3 inches long, to one end of which is screwed a smaller and narrower tube of about half an inch long; the end of this smaller tube is sharp and the diameter of which is one centimetre. Internally to the elongated tube there is a piston type of solid rod which enables the discs to be ejected into the bottle as soon as they are cut. Leaf discs were cut from fully mature and healthy leaves each leaf was placed on a rubber bung and as soon as the discs were cut they were ejected into tared bottles, 20 - 25 discs were cut for one particular experiment. The bottles containing the discs were weighed and the fresh weight of the discs was determined, the discs were then floated on distilled water in closed petri

dishes. The petri dishes were placed in a water bath which is fixed at the base of a specially designed apparatus which consists of a large squared wooden frame closed at three ends, at the base of this frame is fixed a water bath while a light is fitted in the upper region of the frame at such a distance that the light reaching the floating discs was 70 ft. candles which was measured by a photometer. This light intensity approximates closely to compensation point where Respiration = Photosynthesis. This apparatus was placed in a 20°C. constant temperature room. The petri dishes were placed in the water bath and after every 3 - 4 hours the petri dishes were taken out and the discs placed gently on two or three layers of soft tissue and dried very carefully and the weight of the discs determined on an electrical balance in a similar way as before. Every care was taken not to injure or squeeze the discs to a slightest degree while drying. Filter papers or blotting paper were not used as they are somewhat hard and might have injured the discs. After weighing the discs they were again floated as before in petri dishes and the weight determined in the same manner as mentioned at 4 hour intervals until 24 hours, after the first weighing. The discs were then quick dried at a

temperature of 90°C. in an oven for 12 hours and their dry weight was determined. The relative turgidity was then calculated by the following formula

$$R.T. = \frac{\text{Fresh wt. of Discs - Dry wt. of Discs}}{\text{Saturated wt. of Discs - Dry wt. of Discs}} \times 100$$

Microtomy

Paraffin Sections: Transverse sections of stems, leaves, roots were cut by a microtome in order to study the anatomical features of plants grown at different moisture regimes, sprayed with CCC and gibberellic acid, CCC applied as soil drench and the plants grown in wind tunnel. Preparation of the permanent slides was done by the following method. Portions of stem, leaves and roots were selected so that specimens from different treatments were of comparable age and developmental stage. They were fixed in Formalin acetic alcohol for about two days and the air removed from the tissues by a suction pump. The material was then thoroughly washed with water and passed through a series of ethyl alcohol as shown below for dehydration.

1) One change in 30% Alcohol (for two hours)
2) " " " 50 % " (" " ")

3) One change in 70% Alcohol (for two hours)

4) " " " 90% " (" " ")

5) " " " Absolute Alcohol (for two hours)

6) " " " " " (overnight)

Infiltration: The material was passed through the following grades to ensure complete infiltration.

1) A mixture of 3 parts of Absolute Alcohol : 1 part of xylol ..... for ½ hr.

2) A mixture of Absolute Alcohol and xylol in 1 : 1 ratio ..... for ½ hr.

3) A mixture of Absolute Alcohol and xylol in 1 : 3 ratio ..... for ½ hr.

4) Pure xylol for 1 hr.

5) Pure xylol for 1 hr. (second change).

6) Fine Paraffin chips were added for dissolution in xylol containing material up to saturation point for 1 hr.

7) Passed to molten Paraffin (in oven) overnight.

8) Passed through several changes of molten paraffin to remove all traces of xylol.

Embedding: After infiltration the material was ready for embedding which was done in the following way.

Two pieces of brass L were placed on a glass plate so as to form a rectangle and molten Paraffin at

the melting point of 58°C. was poured into this rectangle and the portions of stem, leaves and roots were embedded in a row leaving sufficient distance between them so as to prevent damaging of material at the time of making smaller pieces. Air-bubbles around the material were removed by using a red hot needle around the material thereby making the block bubble free. The glass plate was then placed in a water bath till the block solidified it was then removed from water and the L pieces removed.

Microtoming: The blocks were cut into smaller pieces, corresponding to the number of portions of stem, leaves and roots embedded. These were then trimmed with great care into smaller and rectangular pieces. These were then mounted on to a block holder and serial sections were cut in the form of ribbons by a Cambridge microtome.

Mounting of Ribbons: A drop of Haupt's adhesive was smeared over a clean slide and it was then flooded with water by means of a dropper. Ribbons of suitable size were placed on the slide and the slide was warmed gently on a hot plate to stretch the ribbons. The slides were then kept in dust proof place for a few hours to dry.

Staining and Dehydration: After drying the slide, it was kept in xylol overnight and then transferred in xylol II for a period of one hour to remove all traces of Paraffin. It was then passed through the following series for staining and dehydration purposes:

1) In xylol 3 : Absolute Alcohol 1..... for 1 hr.
2) " " 1 : " " 1..... " 1 hr.
3) " " 1 : " " 3..... " 1 hr.
4) In Absolute Alcohol for 1 hr.
5) " 90% " " 15 minutes.
6) " 70% " " 5 minutes.
7) " saffranin in 50% Alcohol for ..... 2 hrs.
8) " 70% Alcohol for 1 minute.
9) " 90% " " 1 "
10) " light green prepared in 95% Alcohol for 2 minutes.
11) " Absolute Alcohol for 15 minutes.
12) " xylol for 10 minutes (for clearing).

Mounting: After this a few drops of Canada Balsam were put on the slide and a cover glass (2" x $\frac{7}{8}$") of thickness 1 was mounted over it very carefully. It was then put in the oven for a few hours at a temperature of 45°C. for drying. The slide was then ready for microscopic observations.

Anatomical Measurements Microscopic measurements of the transverse sections of stem, leaves and roots were done under low power, high power and x 2 objective.

Stem The outlines of xylem, phloem, sclerenchyma and cortex of five vascular bundles were drawn under low power. The area of these was determined by means of a planimeter. From this the average area of a single vascular bundle was calculated. Similarly the xsection area of the stem was determined. The area of the vascular bundle was expressed as percentage of stem xsection area. The number of bundles was counted. Cortex/Stele ratio was calculated.

Leaf The area of the vascular bundle in the mid-rib was determined as mentioned for stem. This was expressed as percentage of the mid-rib xsection area. The area of the cortex in the mid-rib was determined and expressed as percentage of mid-rib cross section area. The cortex/stele ratio was calculated.

Root The area of the vascular region internal to the pericycle and the area of cortex was determined. These were expressed as percentage of root xsection area. Cortex/stele ratio was calculated.

Note on Statistical treatment

Wherever there are factorial design experiments with several treatments and several harvests the significance of the difference of means has been calculated using the standard formula

$$d = \frac{x_1 - x_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

The significance of the treatment has been computed with reference to controls. The standard error of the mean has been calculated at 5% excluded probability. The value of t has been taken from students T table at corresponding degrees of freedom at 5% level. The degrees of freedom have always been taken as number of plants less one. The usual number of plants was 3 except in the wind treated plants where it was 4.

EXPERIMENTAL RESULTS

The 'leaf water balance' or the degree of turgidity of a plant is controlled by the relative rates of absorption and transpiration (Kramer 1937, 1938). It is a lack of balance between absorption and transpiration that causes fluctuations in the turgor of the cells and the degree of turgidity which can be maintained by a plant is limited by atmospheric, soil and plant factors, that modify the rates of absorption and transpiration.

The experiments described in the following pages were designed so as to study the effect of 'leaf water balance' on the growth, morphology and anatomy of Helianthus annuus. It was thought that the most obvious way to upset the water balance of the plants was firstly by interfering with the uptake of water through the roots by limiting the soil moisture and growing plants at various moisture regimes; and secondly by bringing about an increase in the rate of transpiration, which was brought about by growing the plants in the wind tunnel at a speed of 33 m.p.h. while being kept at full moisture regime throughout the experimental period. As given in Chapter I (Introduction) it is generally accepted

that more or less all plants respond to the treatments with growth promoting substances (gibberellins) and growth retarding substances (2-Chloroethyl trimthylammonium chloride, C.C.C.) the application of the former stimulates longitudinal extension growth in aerial organs of the plants while the application of the latter produces shorter, more compact plants with sturdier stems and shorter and less internodes. The various aspects of the applications of these substances and the responses of the plants have been studied by several workers (as mentioned in Chapter I) and so far it has been a practice of most of the workers to study the effect of gibberellin and C.C.C. on growth, morphology and other aspects, but very little or practically no work has been done to show how the plants treated with gibberellins and C.C.C. respond to moisture treatments and the effect of decreasing moisture regimes on the water balance, growth, morphology and anatomy of the treated plants. The effect of C.C.C. treated plants subjected to water stress has been studied by Halevy and Kessler (1963) who found that plants when treated with C.C.C. were less susceptible to water stress than untreated ones. These results to some extent

show that the C.C.C. treated plants being smaller and more compact may have less water requirements and might prove to be more tolerant and less affected by water defecits. In the following experiments, therefore, together with the normal (untreated) plants the effect of decreasing moisture regimes was studied on the 'leaf water balance', growth, morephology and anatomy of the C.C.C. and gibberellic acid treated plants. Gibberellic acid was included in these studies as it counteracts the effects of C.C.C. and it was therefore thought interesting to find out how far the treated plants respond to water defecits. Besides the effects of soil and atmospheric drought, on the C.C.C. treated plants were studied, in comparison to the normal plants. The experiments described in the following pages may be outlined as follows:

I Effect of decreasing soil moisture regimes on the growth, morphology, anatomy and water balance of control, gibberellic acid and C.C.C. treated plants.

II Effect of wind on growth, morphology, anatomy and water balance.

III Effect of C.C.C. applied as soil drench on

growth, morphology, anatomy and water balance.

IV Susceptibility of controls and C.C.C. treated plants to soil and atmospheric drought.

I. a. Effect of decreasing moisture regimes on Growth and Morphology

This experiment was conducted between April and June using 450 plants. Seeds of Helianthus annuus var. Pole Star were sown as mentioned in Chapter Material and Methods on page 38 and transplanted in 250 ml. beakers at a stage when the cotyledons had just expanded, one plant was transplanted to each beaker. The experiment was conducted by dividing the plants into three sets each set contained equal number of plants grown on five moisture regimes, 100%, 55%, 30%, 15% and 10%. The moisture regimes were maintained by weighing the beakers on alternate days and keeping the weight constant with the careful addition of water. The details of watering procedure are given in Chapter Material and Methods on page 40. The experiment was conducted in a greenhouse with natural daylength. Of the three sets of plants, one set was grown on

five moisture regimes which received no treatment and was kept as controls, the second set was sprayed at weekly intervals, with 1000 p.p.m. aqueous solution of C.C.C. and the third set was sprayed weekly with an 100 p.p.m. aqueous solution of gibberellic acid. The details of spraying etc. are given in Chapter Material and Methods on page 41. The first harvesting was taken a fortnight after transplantation when the first pair of leaves were fully mature, the succeeding harvests were done at weekly intervals. Due to the labour involved, it was not possible to harvest all three sets in a single day, so the plants were harvested at short intervals so that harvesting could be done at weekly periods for all sets. At the time of each harvest the developmental stage and general morphological conditions of the plants were determined by measuring the internode length, plant height, leaf area etc. Estimates of the growth processes were made at the same time.

The general morphological condition of the plants of Helianthus annuus grown at different moisture regimes and treated with C.C.C., gibberellic acid and untreated (controls) prior to their final harvest is shown in Figs. 1, 2 & 3. It was observed

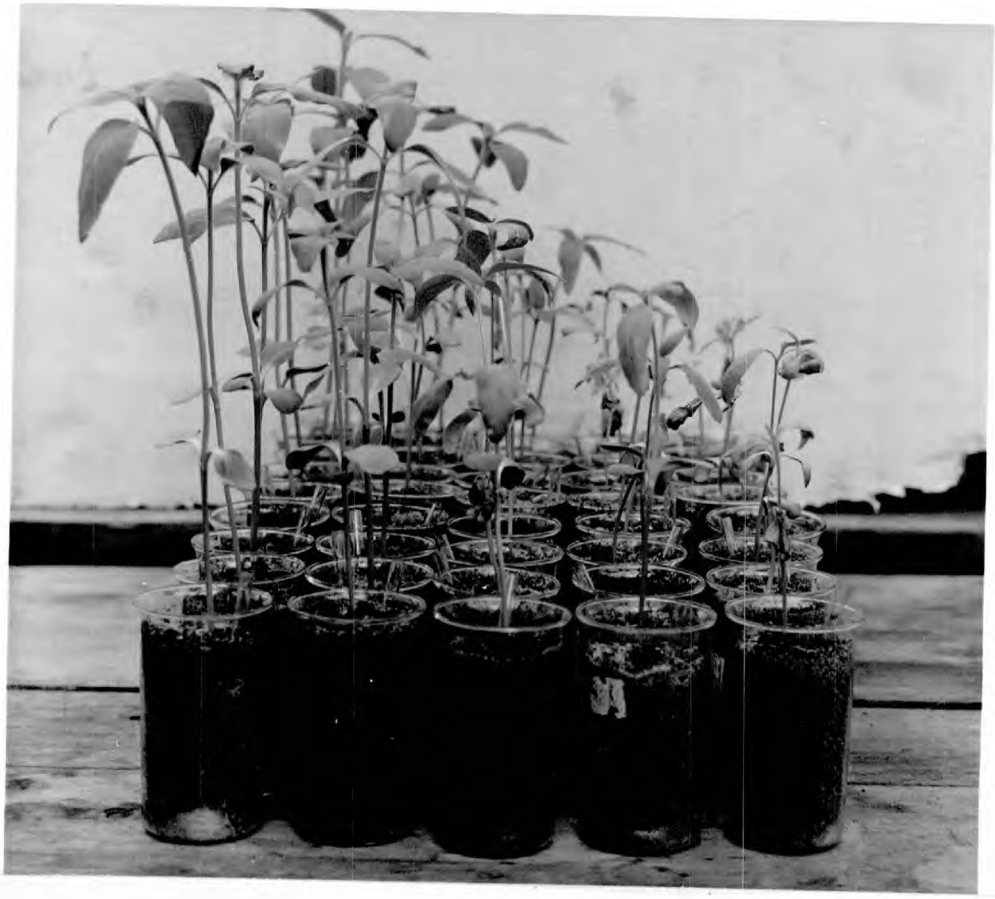


Fig. 1 showing the Control plants grown at five soil moisture regimes.

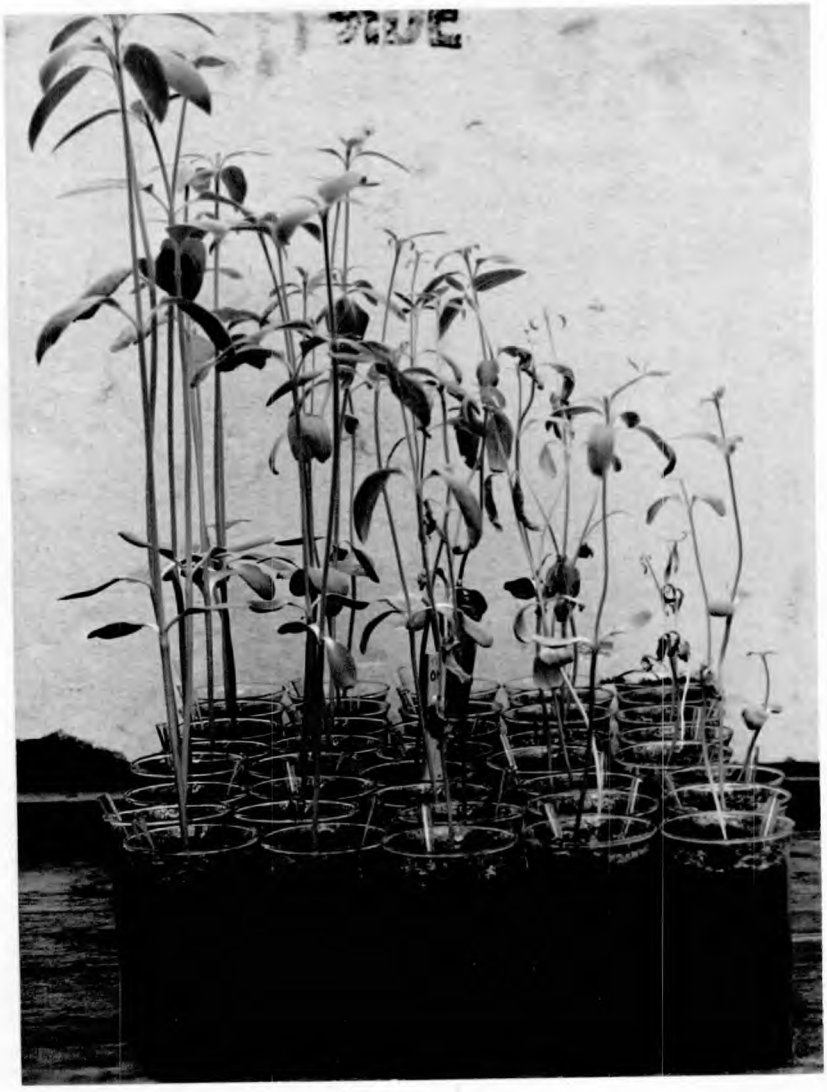


Fig. 2 showing the Gibberellic treated plants grown at five soil moisture regimes.

Fig. 3 showing the C.C.C. treated plants grown at five soil moisture regimes.

in all the sets of gibberellic acid treated, C.C.C. treated and controls that the rate of growth significantly decreases in all three sets as the soil moisture decreases. The lower the moisture regime the less the rate of growth, though the drought resistance of the C.C.C. treated plants was significantly higher among the plants of low moisture regimes. This could be seen as the rate of growth of these plants was not so markedly affected as that of the gibberellic acid treated and controls. The C.C.C. treated plants grown at lower moisture regimes were healthy and showed little sign of wilting or loss of vigour as compared to the other treatments. The controls and the gibberellic acid treated plants responded more or less similarly to the decreasing moisture regime except that the control showed signs of wilting after the third harvest whilst the gibberellic treated plants did not start wilting until the fourth harvest. In contrast to this the C.C.C. treated plants at 15% and 10% moisture regime appeared to be quite normal until the fifth harvest.

The various aspects of the morphological condition of the plants at the time of harvesting

are given for the controls, gibberellic treated and C.C.C. treated plants respectively, in Tables I a, b and c.

Table Ia

Controls The Mean Number of Leaves per Plant

Harvests	Moisture Regime				
	100%	55%	30%	15%	10%
1	4	4	4	4	4
2	6	6	4	4	4
3	8	6	6	4	4
4	10	8	8	6	4
5	12	10	10	8	6

Table Ib

Gibberellic Acid treated. The Mean Number of Leaves per Plant

Harvests	Moisture Regime				
	100%	55%	30%	15%	10%
1	4	4	4	4	4
2	6	6	6	4	4
3	8	8	6	6	6
4	10	10	8	8	8
5	14	12	10	-	-

Table Ic

C.C.C. treated. The Mean Number of Leaves per Plant

Harvests	Moisture Regime				
	100%	55%	30%	15%	10%
1	4	4	4	4	4
2	6	6	6	6	4
3	8	8	6	6	6
4	8	8	8	8	8
5	10	8	8	8	8

The mean number of leaves in the controls (Table Ia) shows a general tendency to decrease in number, as the soil moisture decreases, the lower the soil moisture regime the lesser the number of leaves. If the rate of increase in number of leaves is considered, it can be seen that at 100% soil moisture regime there is a regular increase in number of the leaves at the time of the harvests. In plants belonging to the 55% and 30% soil moisture regimes the increase in number of leaves was suppressed for one harvest, while in plants of the 15% moisture regime the increase in number of leaves was not observed for

two harvests, i.e. the second and third harvests. In the 10% moisture regime there was no increase in the number of leaves for three successive harvests. At the time of the first harvest the plants of the five different moisture regimes had the same number of leaves, four. The increase in number of leaves at the final harvest is three times in the plants of the 100% soil moisture regime, 2.5 times at the 55% and 30% soil moisture regimes, 2.0 times in the plants of the 15% soil moisture regime and in the plants of the 10% soil moisture regime the increase was only 1.5 times that of the first harvest. Thus the rate of new leaf formation in the plants of 100% moisture regime was double that of the 10% soil moisture regime. The mean number of leaves for gibberellic treated plants at all harvests is shown in Table 1b on page 61.

It is evident from Table Ib that the number of leaves is greater in the gibberellic acid treated plants than those of the controls, but, like the controls, the number of leaves also decreases with the decrease in the soil moisture regime. In the plants of the 100% soil moisture regime an increase of 2 in the number of leaves was observed for every harvest except the fifth harvest where it was 4.

Plants of the 55% soil moisture regime also showed a regular increase in the number of leaves, however in the 30% soil moisture regime this increase in the number of leaves was not observed for one harvest, the third harvest. The plants of the 15% and 10% soil moisture regime reacted in a similar manner to those of the 30% soil moisture regime up to the fourth harvest, there being no fifth harvest. The rate of leaf formation is higher among the gibberellic acid treated plants, at all five moisture regimes, than the corresponding soil moisture regimes of the controls.

When the leaves of the initial and final harvests of gibberellic treated plants are considered, it is found that the increase is 3.5 times at the 100% soil moisture regime, 3.0 at the 55% soil moisture regime, 2.5 at the 30% soil moisture regime and two times at the 15% and 10% soil moisture regimes. The rate of leaf formation at 100% soil moisture regime was less than double that of the 10% soil moisture regime plants.

(see page 62)

Table I indicates that the mean number of leaves of C.C.C. treated plants do not show a general tendency to decrease with a decrease in the soil moisture regime. The application of C.C.C. however,

retards the rate of new leaf formation at all the soil moisture regimes more or less equally. The overall increase in number of leaves from the first to the final harvest is 2.5 times in the plants of the 100% soil moisture regime and 2 times in the 55%, 30%, 15% and 10% soil moisture regimes. It may be concluded that the rate of leaf formation is higher among gibberellic acid treated plants than the controls. The rate of leaf formation in C.C.C. treated plants is lower than that of the controls. This might indicate that the application of gibberellic acid accelerates the rate of leaf formation, while in contrast to this, the application of C.C.C. retards the rate of leaf formation.

The effect of the decrease in the soil moisture regimes is much more pronounced among the gibberellic treated plants and the controls (as shown in Table Ia, Ib), than in C.C.C. treated plants. This indicates that the number of leaves at the lower soil moisture regimes is nearly half that of those at higher soil moisture regimes. The decrease in soil moisture regime has little effect on the C.C.C. treated plants as it did not affect the rate of leaf formation at the lower soil moisture regimes. This is indicated in Table Ic on page 62.

The decrease in soil moisture regimes does not affect the rate of leaf formation among the C.C.C. treated plants in contrast to the gibberellic acid treated plants and the controls. As far as the general appearance of the leaves was concerned those of the C.C.C. treated plants were generally slightly thicker, darker green in colour, glossy and somewhat broader at the base as compared to the leaves of the control plants. The leaves appeared to be quite normal even at the lower soil moisture regimes although there was a steady decrease in the size of the leaves.

The leaves of the gibberellic acid treated plants are elongated, slightly narrower, lighter green in colour and thinner than those of the controls. The leaves of gibberellic acid treated plants grown at lower moisture regimes appeared to be less healthy compared to those of C.C.C. treated plants at similar low moisture regimes but appreciably better than those of the controls. The size of the leaves decreased with the decrease in the soil moisture regime. Leaves at the 15% and 10% soil moisture regimes were very much smaller than leaves of the C.C.C. treated plants at the corresponding soil moisture regime. This is clearly indicated by the difference in their

leaf areas. The leaves of the control plants were very much affected by the decrease in the soil moisture regime and those of the lower moisture regimes did not appear to be healthy. This was especially so at the 15% and 10% soil moisture regimes where the older pairs of leaves started to wilt soon after the third harvest and the plants only survived with difficulty up to the fifth harvest.

The difference in the number of leaves at the lower soil moisture regimes among the gibberellic acid treated plants and the controls is mainly due to the reduction in the number of internodes, shown in Table 2a, b and c for the controls, gibberellic acid treated and the C.C.C. treated respectively.

Table 2a Controls

Mean No. of Internodes and Length of Stem in cms.

Harvest	Moisture Regime									
	100%		55%		30%		15%		10%	
	No.of Int.	L.of Stem	No.of Int.	L.of Stem	No.of Int.	L.of Stem	No.of Int.	L.of Stem	No.of Int.	L.of Stem
1	1	10.8	1	10.3	1	8.1	1	8.0	1	5.1
2	2	13.0	2	11.1	1	9.6	1	8.3	1	5.6
3	3	19.3	2	17.6	2	10.0	1	9.0	1	6.0
4	4	26.8	3	22.1	3	14.2	2	10.3	1	6.7
5	5	34.7	4	29.2	4	22.6	3	12.0	2	7.3
$\frac{\pm ts}{\sqrt{n}}$		±4.41		±3.9		±7.2		±3.34		± 1.96

Table 2b Gibberellic Acid

Mean Number of Internodes and Length of Stem in cms.

	Moisture Regime									
	100%		55%		30%		15%		10%	
	No.of Int.	L.of Stem	No.of Int.	L.of Stem	No.of Int.	L.of Stem	No.of Int.	L.of Stem	No.of Int.	L.of Stem
1	1	10.5	1	11.0	1	10.0	1	10.3	1	5.0
2	2	16.8	2	16.0	2	15.6	1	13.6	1	6.1
3	3	29.9	3	27.8	2	23.7	2	19.0	2	12.6
4	4	41.7	4	29.2	3	27.1	3	26.1	3	23.5
5	6	54.0	5	39.1	4	34.3	-	-	-	-
$\frac{\pm ts}{\sqrt{n}}$		±20.4		±1.13		±6.86		±4.13		±6.72

Table 2c C.C.C. Treated

Mean Number of Internodes and Length of Stem in cms.

	Moisture Regime									
	100%		55%		30%		15%		10%	
	No.of Int.	L.of Stem	No.of Int.	L.of Stem	No.of Int.	L.of Stem	No.of Int.	L.of Stem	No.of Int.	L.of Stem
1	1	9.0	1	8.7	1	10.3	1	7.5	1	6.5
2	2	13.5	2	12.8	2	11.5	2	10.0	1	9.7
3	3	19.8	3	18.0	2	14.8	2	11.6	2	10.6
4	3	24.6	3	20.5	3	18.0	3	15.8	3	13.3
5	4	29.1	3	22.4	3	20.0	3	17.3	3	15.9
$\pm\frac{ts}{\sqrt{n}}$		±7.76		±6.28		±3.5		±5.19		±3.47

As is evident from Table 2a the number of internodes among the controls decreases with the decrease in the soil moisture regime. The reduction in the number of internodes is accompanied by a reduction in the length of the internodes (see Tables Nos. 36, 37 & 38 Appendix) and thus the total height of the plant is affected. As may be seen in Table 2a, and graphically represented on page 70, the length of the stem is reduced at the 10% level by nearly five times as compared

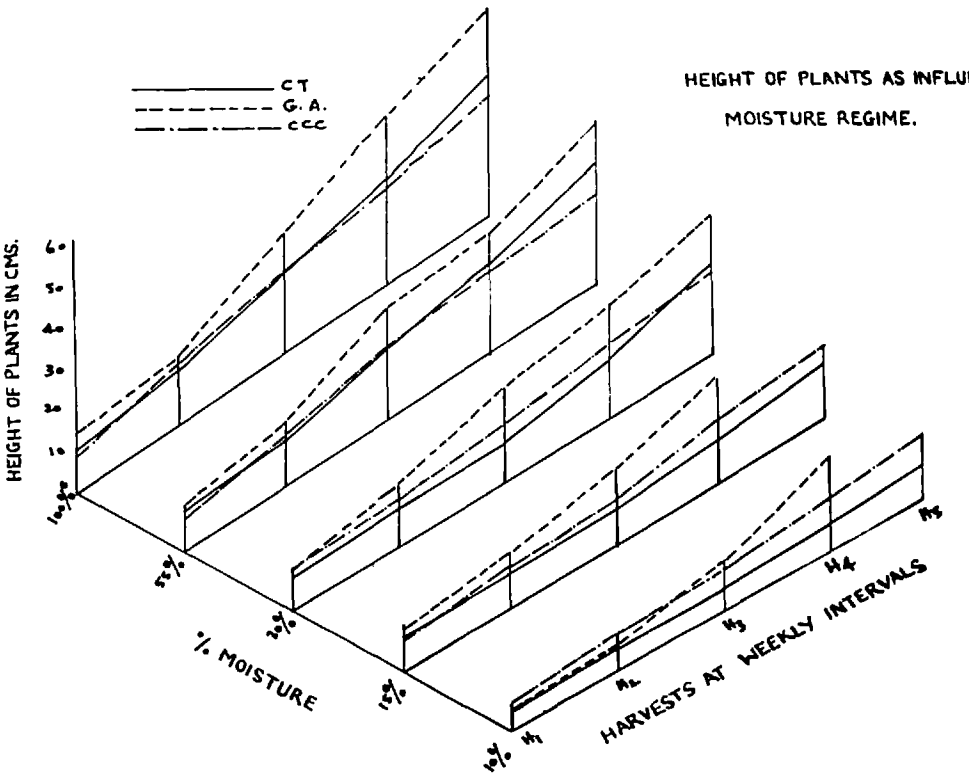


Fig. 3a

Moisture %		100%	55%	30%	15%	10%
C T	$\pm ts/\sqrt{n}$	± 4.41	±3.9	±7.24	±3.34	±1.96
CCC	$\pm ts/\sqrt{n}$	± 7.76	±6.28	±3.5	±5.1	±3.4
G A	$\pm ts/\sqrt{n}$	±20.98	±1.13	±6.86	±4.13	±6.72

to the length of the stem of plants of the 100% moisture regime. The number of internodes is reduced from 5 in the 100% moisture regime to 2 in the 10% regime. The length of the first internode is reduced from 13.5 to 1.1 cms. in the plants of the 100% and 10% soil moisture regime respectively. This is a ratio of about 12:1.

Table 2b indicates that like the controls the gibberellic treated plants, show a decrease in internode length and number as the soil moisture regime decreases. At the fourth harvest the length of the stem at the 10% level was less than half that of the 100% soil moisture regime plants (23.5 cms. as compared to 41.7 cms.) The decrease in the number of internodeswas found to be from 4 to 3, and the length of the first internode in the 100% soil moisture regime which was 17.8 cm was reduced to 8.7 cm. in the plants of the 10% soil moisture regime.

Table 2c on page 69 shows the mean number of internodes and the length of the stem of the C.C.C. treated plants grown at five moisture regimes. The number of internodes in the plants of all soil moisture regimes is similar, except at the 100% moisture regime where there are 4 instead of 3 as at the lower

regimes. The height of the stem is decreased from 29.1 cm. in the 100% soil moisture regime to 15.9 cm. at the 10% soil moisture regime. A reduction of rather less than a half. The height of the first internode decreased from 13 cm. at the 100% soil moisture regime to 6.2 cm. at the 10% moisture regime. The number of internodes in the C.C.C. treated plants is lower than those of the controls and gibberellic acid treated plants.

It is therefore concluded that the decrease in the soil moisture regime has a marked affect on the controls resulting in a significant reduction of the number of internodes, the length of the internodes and hence the height of the plant as a whole. There is a five fold reduction in height between the extreme soil moisture regimes of the control. In the gibberellic acid treated plants the height is reduced only about twice at the 10% soil moisture regime and in the C.C.C. treated plants the height is reduced by a similar amount when these are compared with the 100% soil moisture regime.

The application of gibberellic acid increases the height of the plant by increasing the number, and

the length of the internodes as compared to the controls. The application of C.C.C. decreases the height of the plant and the number of internodes with a slight decrease in their length. The length of the internodes of the C.C.C. treated at the 100%, 55%, 30% is lower than the controls, but at the 15% and 10% moisture regimes the number and the length of internodes of the C.C.C. treated plants exceeds that of the controls. Thus in these cases the decrease in the soil moisture regime does not affect the height of the stem and the number of internodes as it does in the other treatments. The decrease in the soil moisture regime significantly depresses growth among the controls, which show a general tendency to produce plants which are smaller in size, have thinner stems with less internodes, smaller and lesser number of leaves. At the 15% and 10% moisture regime the controls find it difficult to survive. Among the gibberellic acid treated plants the decreasing soil moisture regime has a slightly lesser affect than the controls, while in the C.C.C. treated plants the decrease in the soil moisture regime has very little effect.

Effect of Decreasing Soil Moisture Regime on Growth.

Leaf Area

The increase in the leaf area at successive harvests of the controls, C.C.C. treated and the gibberellic acid treated plants grown at five moisture regimes is graphically represented on page 75. It can be observed that at the 100% soil moisture regime the leaf area of the controls more or less dominates that of the C.C.C. and gibberellic treated plants. With a decrease in the soil moisture regime all three sets of plants show a general tendency of reduction of the leaf surface. This effect is slightly evident among the C.C.C. treated plants but has much depressing effect on the leaf areas of the controls and the gibberellic treated plants. Though under normal conditions of moisture supply i.e. at the 100% soil moisture regime the C.C.C. treated plants have slightly less leaf area than controls and gibberellic plants but as the soil moisture regime decreases i.e. at the 55%, 30%, 15% and 10% soil moisture regimes the leaf area of the C.C.C. treated plants is significantly higher than that of the controls and the gibberellic treated plants. Even at the 15% and 10% soil moisture regimes there is an increase of leaf

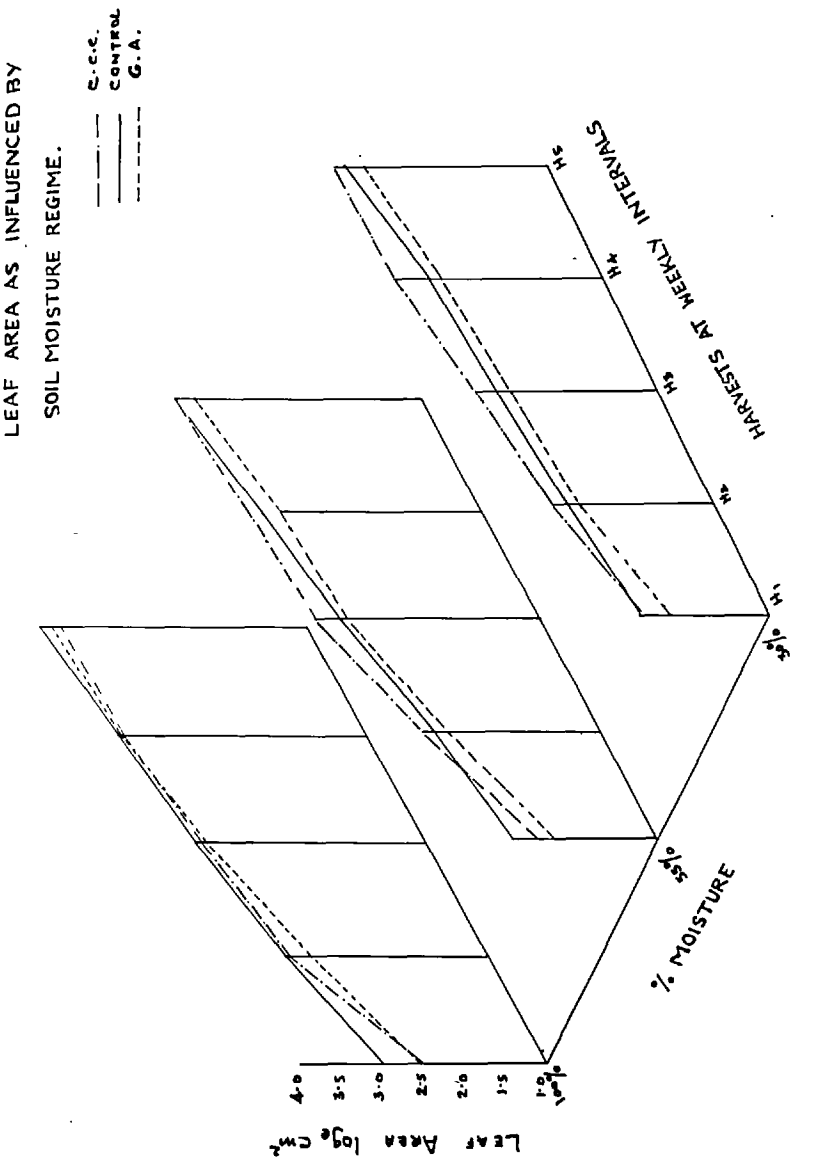


Fig. 4

Moisture %		100%	55%	30%
C T	$\pm ts/\sqrt{n}$	±15.98	±7.65	±19.98
CCC	$\pm ts/\sqrt{n}$	±9.32	±4.88	±4.13
	d	4.2	0.33	0.9
G A	$\pm ts/\sqrt{n}$	±11.94	±4.64	±4.79
	d	2.31	5.6	1.19

area with time among the C.C.C. treated plants. With contrast to this the leaf area of the Controls and gibberellic treated plants seems to be very much affected by the low moisture regime and shows marked fluctuations. In fact, at the time of the third harvest a decrease in the leaf area could be observed which was due to the reason that with time there was no further leaf formation and the margins of the first and second pairs of leaves started wilting and only the portions capable of photosynthesis could be taken into account. In general, under conditions of normal moisture supply the application of C.C.C. results in a slight reduction of leaf area as compared to the controls which is probably due to the lower number of leaves. Similarly the gibberellic treated plants also show slightly lower values of leaf area than the controls, which is probably due to the narrow, elongated leaves of the gibberellic acid treated plants.

The primary data of this experiment was used to derive measures of growth by usual methods of growth analysis. Blackman (1919), Briggs, Kidd and West (1920) and Fisher (1920) have shown that various estimates of growth processes over a period

of time can be derived from the primary growth data. The derivation of the estimates of the growth processes are based on the following definitions.

The relative growth rate R at any instant is the rate of dry weight increase per unit dry weight.

$$R = \frac{dw}{dt} \cdot \frac{1}{W}$$

where W is the total dry weight at time t.

The mean relative growth rate $\bar{R}$ over a time interval $t_2 - t_1$ is derived

$$\bar{R} = \log_e W_2 - \log_e W_1 \ldots\ldots\ldots I$$

where W_2 and W_1 are the total dry weights at times t_2 and t_1 respectively.

As Fisher (1920) showed this is independent of the way W is increasing with time.

The relative rate of increase of leaf area R_L at any instant is the rate of increase of leaf area per unit leaf area.

$$R_L = \frac{dL}{dt} \cdot \frac{I}{L}$$ where L is the leaf area at time t.

Similarly the mean relative rate of leaf area increase $\bar{R}_L$ over a time interval $t_2 - t_1$ can be

derived

$$\bar{R}_L = \log_e L_2 - \log_e L_1 \ldots\ldots\ldots II$$

where L_1 and L_2 are the leaf areas at times t_1 and t_2 respectively.

Again this is independent of the way L is increasing with time.

The mean relative rates have been expressed over a week.

In the course of their investigations involving the comparative growth of several species over a range of environmental conditions it has been found by Whitehead and Myerscough (1962) that the ratio of mean relative growth to mean relative rate of leaf area increase ($\frac{\bar{R}}{\bar{R}L}$) has considerable biological importance and can also be used in accurate determination of the mean unit leaf rate or net assimilation rate.

As derived by them (see Whitehead and Myerscough 1962) the following formula was used to calculate the ratio of mean relative growth rate to mean relative rate of leaf area increase (α).

$$\alpha = \frac{\log_e W_2 - \log_e W_1}{\log_e L_2 - \log_e L_1} = \frac{\bar{R}}{\bar{R}_L} \quad \ldots\ldots\ldots III$$

The comparison of the performance of plants under different conditions is made much easier and revealing if the value of α is used instead of taking into account the relative growth rate and relative rate of leaf area increase separately.

As in their general morphological development the plants of the three sets i.e. the controls, C.C.C. and gibberellic acid treated grown at five moisture regimes showed that the rate of increase in dry weight decreases with a successive decrease in the soil moisture regime. However this decrease was not significant in the C.C.C. treated plants as compared to the gibberellic acid treated plants and the controls where the plants at lower soil moisture regimes particularly at 15% and 10% were very much depressed in their gain of dry weight.

The values of dry weights at weekly harvests are given in Tables a,b,c for the controls, gibberellic and C.C.C. treated plants on pages 80 and 81.

Table 3 a

Mean Total Dry Weight of the Controls (Mgs.)

HARVESTS	MOISTURE REGIME				
	100%	55%	30%	15%	10%
H_1	107.7	81.6	74.3	61.4	44.6
H_2	168.9	100.5	88.4	66.1	48.7
H_3	264.4	169.6	113.7	68.5	53.8
H_4	410.5	237.2	146.2	87.9	56.2
H_5	627.9	396.7	244.9	132.8	72.4

Table 3b

Mean Total Dry Weight of Gibberellic Treated Plants (mgs.)

HARVESTS	MOISTURE REGIME				
	100%	55%	30%	15%	10 %
H_1	75.5	54.5	63.1	70.9	40.1
H_2	141.1	99.2	92.4	81.1	71.9
H_3	283.4	187.7	121.8	88.4	78.1
H_4	506.6	216.6	155.6	112.9	109.5
H_5	648.1	401.4	259.4	-	-

Table 3c

Mean Total Dry Weight of C.C.C. treated plants (mgs.)

HARVESTS	MOISTURE REGIME				
	100%	55%	30%	15%	10%
H_1	90.5	70.6	67.2	63.4	64.8
H_2	228.4	161.0	100.3	98.6	93.6
H_3	435.8	331.3	148.0	143.8	135.8
H_4	688.4	454.3	282.7	200.6	183.7
H_5	767.1	550.4	327.6	235.0	214.3

The table 3a shows that the more the decrease in soil moisture regime the less the gain in total dry weight of the plants. There is a very marked decrease in the rate of increase of dry weight at the 10% soil moisture regime.

In the gibberellic treated plants the dry weight was found to be greater at all the five soil moisture regimes than that of the Controls as can be seen from Table 3 b on page 80. This is probably due to the marked increase in the dry weight of the stem. The decrease in soil moisture regime seems to have less effect on the increase in total dry weight of the gibberellic treated plants, as compared to the

controls.

The Table 3 c shows that in the C.C.C. plants the decrease in soil moisture regime has less effect in the gain of dry weight than both the controls and the gibberellic treated plants. The total dry weight of the C.C.C. plants at all the five soil moisture regimes is significantly higher at all harvests as compared to the successive soil moisture regimes of the controls and gibberellic treated plants.

In general in the C.C.C. treated plants the difference in dry weight at the final harvest between 100% soil moisture regime and 10% soil moisture regime is very much less as compared to the controls and the gibberellic treated ones, whereas the giberellic treated plants are intermediate with regard to the difference in dry weight. Table 3c on page 81 further shows that for the total dry weight gained during the experimental period at the five moisture regimes, the dry weight of the C.C.C. treated plants is least affected by the decrease in the soil moisture regime. The controls were the most affected ones and the gibberellic acid treated the intermediate ones.

The higher values in the gain of dry weight in the C.C.C. treated plants are more or less due to the increased dry weight of the roots and the leaves. The total dry weights of the three sets of plants at successive harvests are graphically represented on page 84 and the $\frac{\text{shoot}}{\text{root}}$ ratios of the three sets of plants at five soil moisture regimes given (p. 85). The mean relative growth rate $\bar{R}$ was calculated using the Equation I (see page 77) for the three sets of plants at the five moisture regimes. This is given in Tables 4 a, b, and c for the controls, gibberellic treated and the C.C.C. treated plants respectively.

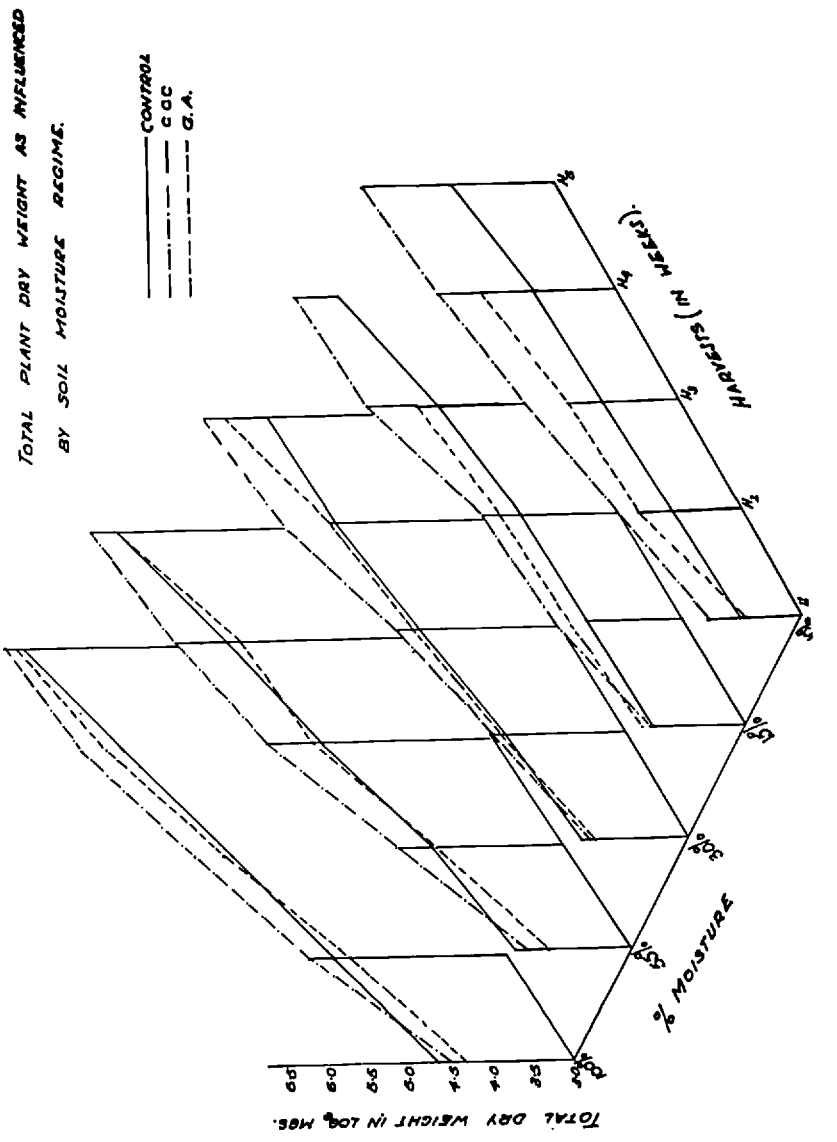


Fig. 5

Moisture %		100%	55%	30%	15%	10%
C T	$\pm ts/\sqrt{n}$	± 52.9	±135.7	±125.6	±24.8	±15.4
CCC	$\pm ts/\sqrt{n}$	±127.7	±159.8	± 56.1	±77.45	±67.7
	d	4.3	3.1	2.59	5.4	8.7
G A	$\pm ts/\sqrt{n}$	±82.02	±14.9	±43.01	±25.75	±19.76
	d	0.88	0.14	0.46	3.9	9.37

Shoot / Root RATIO AS INFLUENCED BY SOIL MOISTURE REGIME

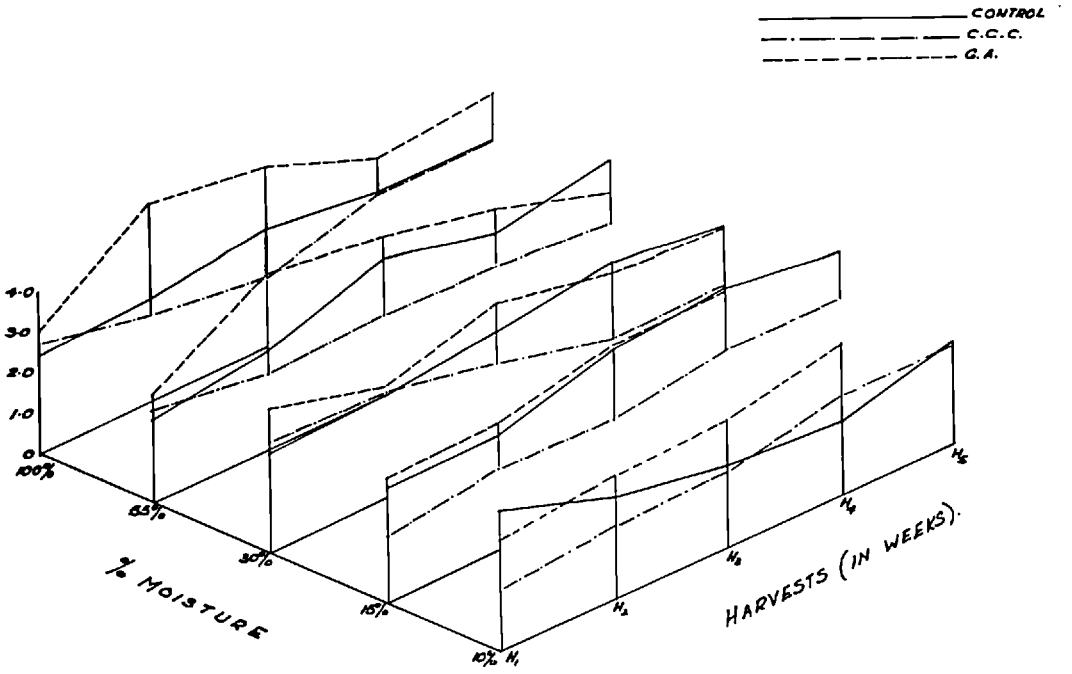


Fig. 6

Moisture %		100%	55%	30%	15%	10%
C T	$\pm$ ts/ $\sqrt{n}$	$\pm$0.08	$\pm$1.54	$\pm$0.66	$\pm$0.1	$\pm$0.13
CCC	$\pm$ ts/ $\sqrt{n}$	$\pm$0.22	$\pm$0.34	$\pm$0.14	$\pm$0.42	$\pm$0.32
G A	$\pm$ ts/ $\sqrt{n}$	$\pm$0.84	$\pm$0.2	$\pm$0.57	$\pm$0.88	$\pm$0.33

Table 4a

Mean Relative Growth Rates of the Controls mgs/mg/week

HARVEST INTERVAL	MOISTURE REGIME				
	100%	55%	30%	15%	10%
1 - 2	0.449	0.308	0.173	0.073	0.087
2 - 3	0.448	0.523	0.251	0.035	0.099
3 - 4	0.439	0.345	0.254	0.249	0.043
4 - 5	0.435	0.514	0.515	0.412	0.253

Table 4 b

Mean Relative Growth Rates of the Gibberellic Treated Plants mgs/mg/week

HARVEST INTERVAL	MOISTURE REGIME				
	100%	55%	30%	15%	10%
1 - 2	0.625	0.598	0.381	0.134	0.583
2 - 3	0.697	0.637	0.276	0.086	0.082
3 - 4	0.580	0.143	0.244	0.244	0.338
4 - 5	0.246	0.616	0.511		

Table 4 c

Mean Relative growth Rates of the C.C.C. treated plants mgs/mg/week

HARVEST INTERVAL	MOISTURE REGIME				
	100%	55%	30%	15%	10%
1 - 2	0.925	0.824	0.400	0.441	0.367
2 - 3	0.646	0.721	0.389	0.377	0.372
3 - 4	0.457	0.315	0.647	0.332	0.302
4 - 5	0.108	0.191	0.147	0.158	0.154

It can be seen from Tables 4 a, b and c that the mean relative growth rate decreases with time in all three sets of plants especially in the gibberellic and the C.C.C. treated plants and all three sets show a decline in the mean relative growth rate as the soil moisture regime decreases. The mean relative growth rate of the C.C.C. treated plants is significantly higher at all moisture regimes, as compared to the Controls and the gibberellic treated plants. This results in much increased dry weight of the C.C.C. treated plants (see Table 3 c) at all soil moisture

regimes. In fact the mean relative growth rate of the C.C.C. treated plants in the 1 - 2 harvest interval is double that of the controls. After the fourth harvest it can be seen that the mean relative growth rate of the C.C.C. treated plants falls considerably with time interval as compared to the gibberllic treated plants and the controls. A similar situation is observed among the gibberellic treated plants i.e. the mean relative growth rate of the gibberllic treated plants is roughly about $1\frac{1}{2}$ times more than the controls at the 1 - 2 harvest interval but after the fourth harvest it shows a significant decrease with time, while among the controls the fluctuations in the rate of mean relative growth rate are not so marked as in the gibberellic treated and the C.C.C. treated plants. The mean relative rate of leaf area increase of the three sets of plants is given in Tables 5 a, b and c. Table 5.

Table 5 a

Mean Relative Rates of Leaf area Increase $cm^2/cm^2/week$

HARVEST INTERVAL	MOISTURE REGIME				
	100%	55%	30%	15%	10%
1 - 2	0.443	0.304	0.213	-*	-
2 - 3	0.315	0.373	6.181	-	-
3 - 4	0.269	0.230	0.175	-	-
4 - 5	0.225	0.329	0.304	-	-

* Plants failing to survive leaf area decreasing.

Table 5 b

Mean Relative Rates of Leaf Area Increase $cm^2/cm^2/week$

HARVEST INTERVAL	MOISTURE REGIME				
	100%	55%	30%	15%	10%
1 - 2	0.633	0.587	0.390	-*	-
2 - 3	0.538	0.503	0.205	-	-
3 - 4	0.305	0.100	0.139	-	-
4 - 5	0.116	0.350	0.271	-	-

* Plants failing to survive leaf area decreasing.

Table 5 c

Mean Relative Rates of Leaf Area Increase $cm^2/cm^2/week$

HARVEST INTERVAL	MOISTURE REGIME				
	100%	55%	30%	15%	10%
1 - 2	0.888	0.837	0.436	0.505	0.440
2 - 3	0.347	0.430	0.229	0.254	0.275
3 - 4	0.208	0.141	0.346	0.186	0.178
4 - 5	0.037	0.074	0.063	0.071	0.078

A similar situation is observed when the mean relative rate of leaf area increase is considered in the three sets of plants at the five moisture regimes. Table 5 shows that with a decrease in moisture regime the mean relative rate of leaf area increase of the controls, C.C.C. treated and the gibberellic treated plants decreases.

The relation of the mean relative growth rate to the mean relative rate of leaf area increase i.e. α (calculated by Equation III) is given in Table 6 a, b,c and is represented graphically on page 93 for the Controls, Gibberellic and C.C.C. treated plants.

Table 6 a

Values of α between successive Harvests for Controls

HARVEST INTERVAL	MOISTURE REGIME				
	100%	55%	30%	15%	10%
1 - 2	1.01	1.01	0.81	-*	-
2 - 3	1.42	1.40	1.38	-	-
3 - 4	1.63	1.49	1.44	-	-
4 - 5	1.92	1.56	1.69	-	-

* Plants failing to survive α negative

Table 6b

Values of α between Successive Harvests for Gibberellic treated plants

HARVEST INTERVAL	MOISTURE REGIME				
	100%	55%	30%	15%	10%
1 - 2	0.98	1.01	0.97	-*	-
2 - 3	1.29	1.26	1.34	-	-
3 - 4	1.90	1.42	1.75	-	-
4 - 5	2.12	1.76	1.87	-	-

* Plants failing to survive α negative

Table 6c

Values of α between Successive Harvests for C.C.C. treated plants

HARVEST INTERVAL	MOISTURE REGIME				
	100%	55%	30%	15%	10%
1 - 2	1.04	0.98	0.91	0.87	0.83
2 - 3	1.85	1.67	1.69	1.48	1.35
3 - 4	2.18	2.22	1.86	1.78	1.69
4 - 5	2.86	2.56	2.32	2.20	1.96

It can be observed from Fig. 7 that the dry weight of the gibberellic treated plants and particularly of the C.C.C. treated plants was increasing at a much greated rate than the leaf area which suggests a higher synthetic efficiency of the leaves of the C.C.C. treated plants and the gibberellic treated plants, which needs further investigation along these lines, as this investigation is based on acquiring more information about the anatomical and morphological changes which occur in plants due to disturbance of the leaf water balance.

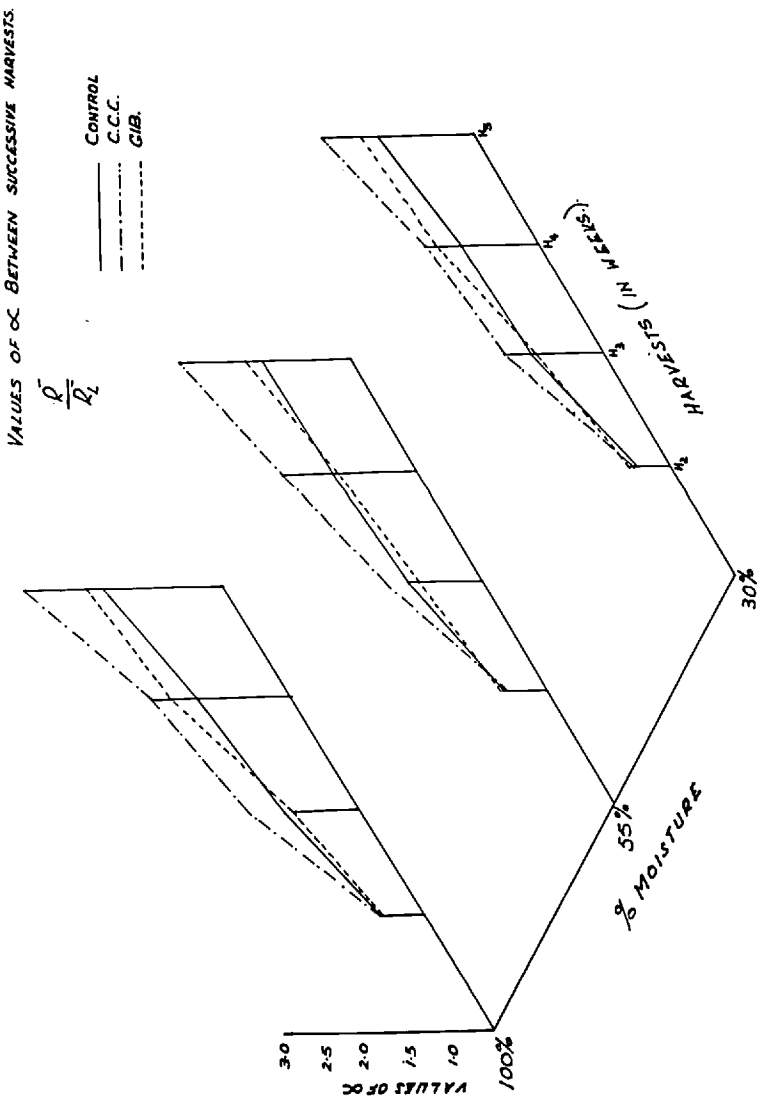

VALUES OF ∝ BETWEEN SUCCESSIVE HARVESTS.
$\frac{\rho}{\rho_1}$
CONTROL
C.C.C.
GIB.
VALUES OF ∝
3·0
2·5
2·0
1·5
1·0
100%
55%
30%
% MOISTURE
HARVESTS (IN WEEKS)

Fig. 7.

a, b and c

However from the Tables 54/(see Appendix) which show the specific leaf area of the three sets of plants it can be seen that the C.C.C. treated plants at all soil moisture regimes, generally have the smallest figures for specific leaf areas. This indicates that in the C.C.C. treated plants the dry weight of leaves per unit area is more as compared to the gibberellic treated plants and the controls. The next increasing values are those for gibberellic treated plants.

1b Effect of decreasing soil moisture regime on the Anatomy of the Controls, Gibberellic acid and C.C.C. treated plants.

The effect of the decrease in the soil moisture regime, on the anatomical features of the three sets of plants was studied. The material used for section cutting was fixed from the same set of plants which were used for 'growth analysis' and 'water balance'. Stems, leaves and roots, of comparable age and developmental stage were chosen and selected portions were fixed in formalin acetic alcohol and after dehydration and infiltration, the material was embedded in molten wax at 58°C. Transverse sections were then cut between 6 - 8 μ by means of a Cambridge microtome. Details of the procedure are given in Chapter Material and Methods on page ; because of the considerable time and labour involved in section cutting, studying and measuring the sections of the stems, leaves and roots of all three sets of plants, at five moisture regimes it was thought that the change in anatomical features, as affected by the decrease in the soil moisture regime might be well represented by simply studying the anatomy of the plants belonging to the 100% and 30% soil moisture regimes, and not all the rest. These plants could

indicate a general trend of change in the anatomical features when subjected to adverse water conditions.

The following features of the anatomy of the stems, leaves and roots were studied:

Stem:- Transverse sections from the middle of the first internodes were chosen for studying the anatomy of the stems in all three sets of plants. The number of vascular bundles in the stem were counted. The outlines of xylem, phloem and sclernchymatous fibres of five largest bundles were drawn using Camera lucida under low power. The area of these was recorded using a planimeter. The average area of xylem, phloem and sclerenchyma per vascular bundle was determined. The area of the cross section of stem was then determined under low power. The average areas of the xylem, phloem and sclerenchyma were then expressed as percentages of stem cross section area.

Leaf:- The material for sections of leaves was taken from the centre of fully mature leaves in each case. The areas of the vascular tissues were determined in the same manner as for the stem. The number of vessels was counted, the diameter of vessels was measured. The area of cross section of mid rib was determined, the number of palisade layers and the degree of

compactness of the spongy tissue was compared.

Roots:- The area of the cross sections of the roots was determined. The area of the vascular tissues internal to the pericycle and the area of the cortex was determined in the same way as done for stems and leaves. These areas were expressed as % of cross section of root.

The values of occular divisions under high power (x 40), low power (x 10) and differential objection (x 2) magnification are as follows:-

1 occular division under H.P. lens = 3.7μ

1 " " " L.P. " = 16.1μ

1 " " " x 2 " = 76.9μ

The magnification of camera lucida drawing is as follows:-

at low power (x 10) 1μ magnification = 183

at (x 2) 1μ magnification = 34

The anatomical features studied in the stems of the controls, Gibberellic acid and C.C.C. treated plants at the 100% and 30% soil moisture regimes are given in Table 7.

Table 7

Anatomical Features of the Stem of Controls, Gibberellic and C.C.C. treated Plants.

Moisture Regime	No. of vascular bundles	Areas of xy. ph. & scl. as % area of x section of stem		
		xylem cm^2	phloem cm^2	sclerenchyma cm^2
Control 100%	12	0.217	0.24	0.268
Gibb. 100%	12	0.237	0.183	0.231
C.C.C. 100%	12	0.42	0.333	0.381
Control 30%	12	0.282	0.322	0.336
Gibb. 30%	12	0.259	0.233	0.357
C.C.C. 30%	12	0.638	0.487	0.586

It can be seen from Table 7 that with a decrease in the soil moisture regime there is an increased development of the vascular tissues. The area of the xylem, phloem and sclerenchymatous fibres is greater in the stems of the 30% soil moisture regimes in all the three sets of plants. The increase of vascular tissues is more or less the same in the controls and Gibberellic treated plants but there seems to be a tremendous increase in the bulk of xylem tissue in

the C.C.C. treated plants, at the 30% moisture regime. The area of xylem is more or less double in the C.C.C. plants than areas of the controls and the Gibberellic treated plants at the 100% soil moisture level. The phloem elements and the sclerenchymatous fibres also show a better development in the C.C.C. treated plants at the low moisture regime. The areas of the xylem, phloem and sclerenchymatous tissues of the C.C.C. treated plants at the 100% soil moisture regime are also larger than those of the controls and the gibberellic treated plants and with the decrease in the soil moisture regime the C.C.C. treated plants show a marked increase in the development of the vascular tissues than the controls and the Gibberellic treated plants. The number of fully developed vascular bundles was practically the same i.e. 12, however in the C.C.C. treated plants it can be seen from Figs 8&9 on pages 100 & 101 that the number of under developed bundles is higher than the controls and the Gibberellic treated plants. It also appears from Figs. 8 & 9 on pages 100 & 101 that the cells in the C.C.C. treated plants seem to be smaller and more compact, i.e. with smaller intercellular spaces, while the cells of the gibberellic treated plants seem to be less compact whereas in the

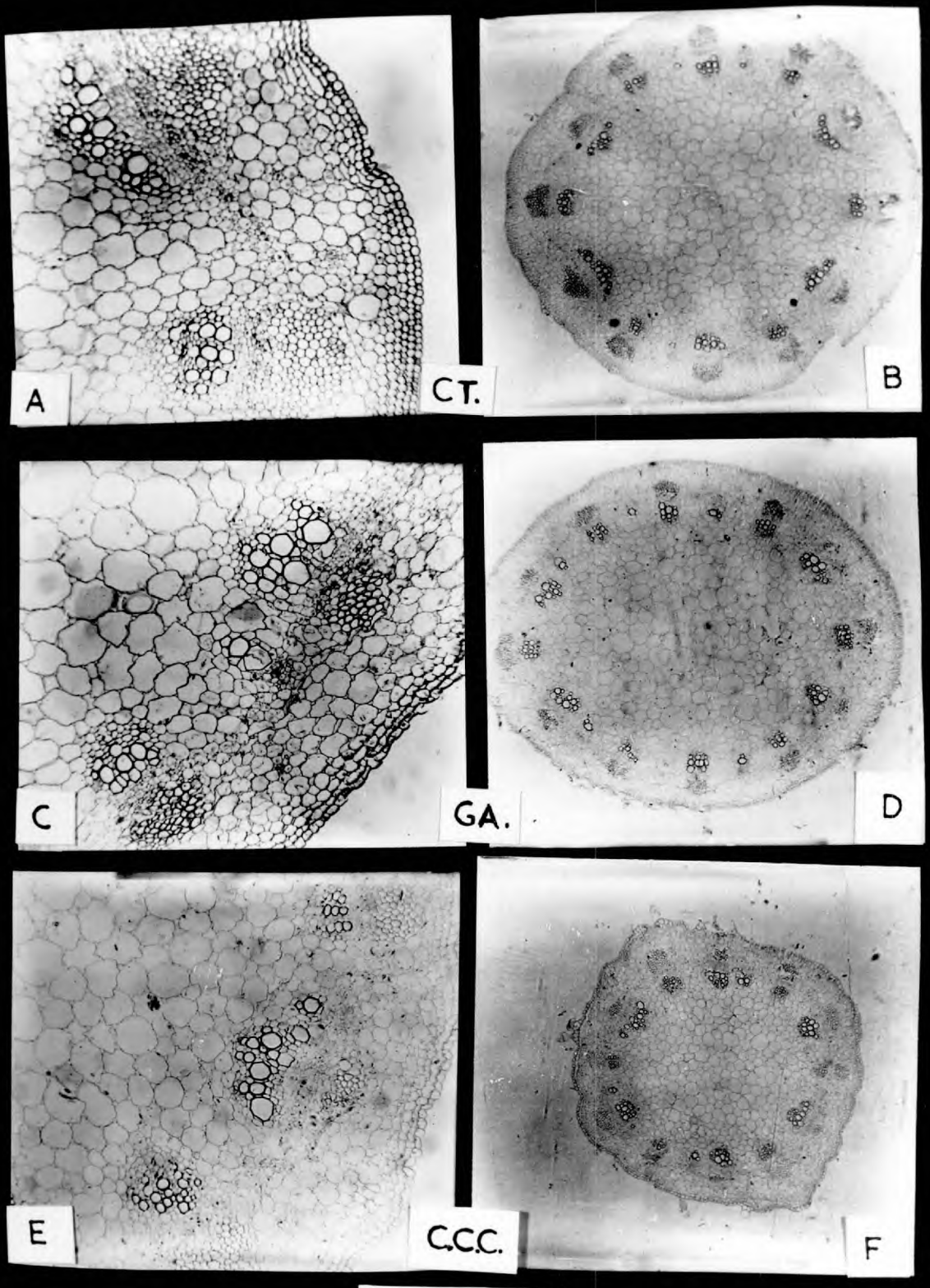


FIG. 8

T.S. STEM.

100%

Fig. 8

showing the transverse sections of stem at 100% S.M.R.

A = Portion of T.S. of Control under x 10

B = T.S. of Control under x 2

C = Portion of T.S. of G.A. under x 10

D = T.S. of G. A. under x 2

E = Portion of T.S. of C.C.C. under x 2

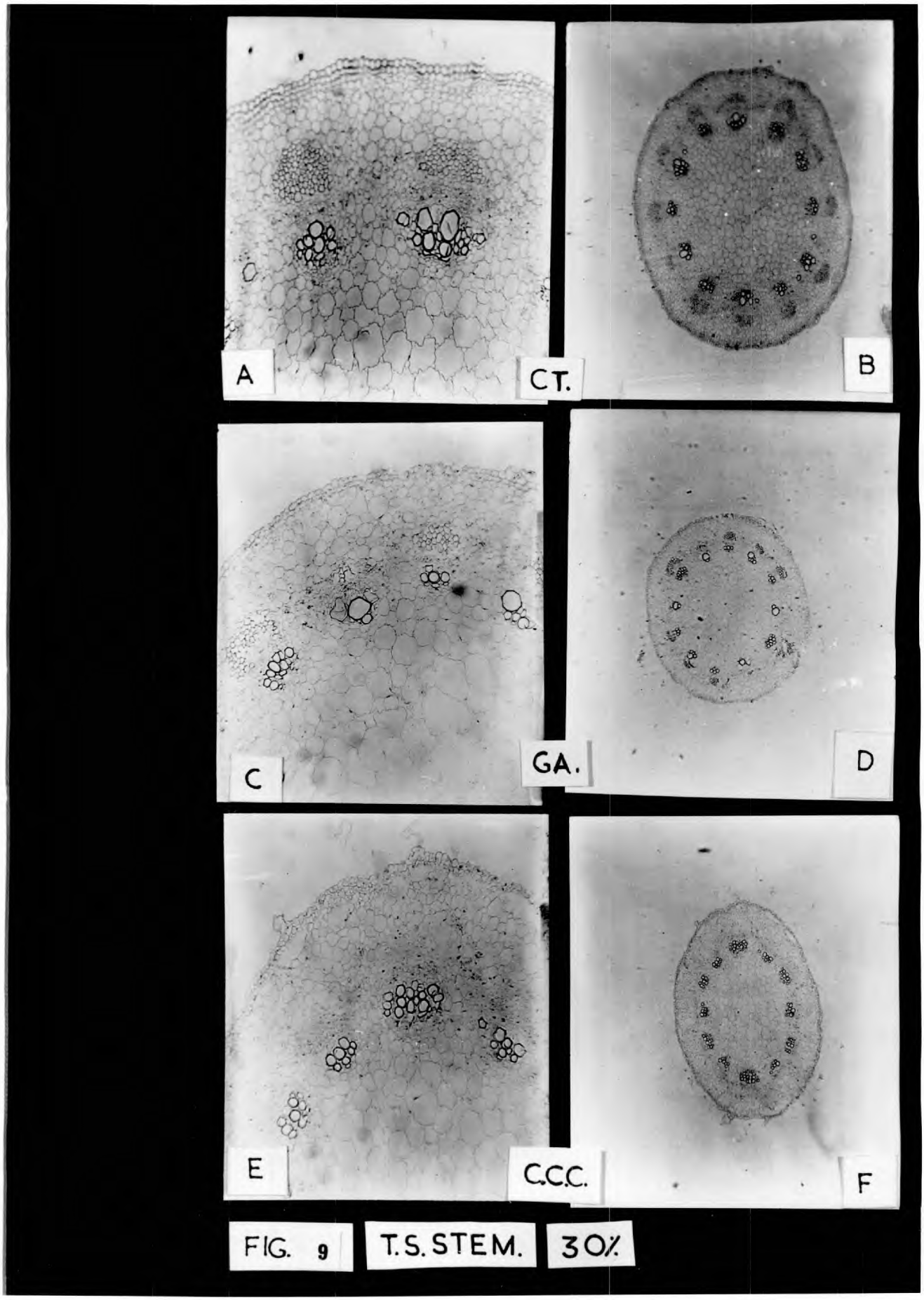


FIG. 9 T.S. STEM. 30%

Fig. 9 Page 101

showing the transverse sections of stem at 30% S.M.R.

A = Portion of T.S. of Control under x 10

B = T.S. of Control under x 2

C = Portion of T.S. of G.A. under x 10

D = T.S. of G.A. under x 2

E = Portion of T.S. of C.C.C. under x 2

controls the cells appear to be more or less intermediate between the treated plants. The size of the cells in the gibberellic treated plants increases accompanied by lesser number of cells per unit area, the C.C.C. treated plants show a position in contrast to this, the controls come intermediate to them.

The anatomical features of the leaves of the controls, gibberellic and C.C.C. treated plants at 100% and 30% soil moisture regime are shown in Table 8 (page 103 and Figs. 10 and 11 on pages 104 and 105).

Table 8

Anatomical features of the Leaves of the Controls, Gibberellic and C.C.C. treated plants

Plant Type	No. of vessels in central bundle	No. of Palisade layers	degree of compact-ness of spongy tissue	Areas of xy. ph.' scl.as % area of x section of mid rib.			No. of vessels over 14μ in central bundle
				xylem cm^2	phloem cm^2	Scleren-chyma cm^2	
Control 100%	29	1	not very compact	4.75	4.92	4.86	14
Gibberellic 100%	22	2	compact as compared to control	5.7	5.24	5.9	17
C.C.C. 100%	30	2	more compact than control and Gibb.	7.35	4.61	5.38	18
Control 30%	32	2	compact than 100%	5.54	5.91	5.74	13
Gibberellic 30%	24	2	more compact than 100%	5.78	5.53	6.42	14
C.C.C.	35	3	compact than 100%	11.1	6.66	8.0	20

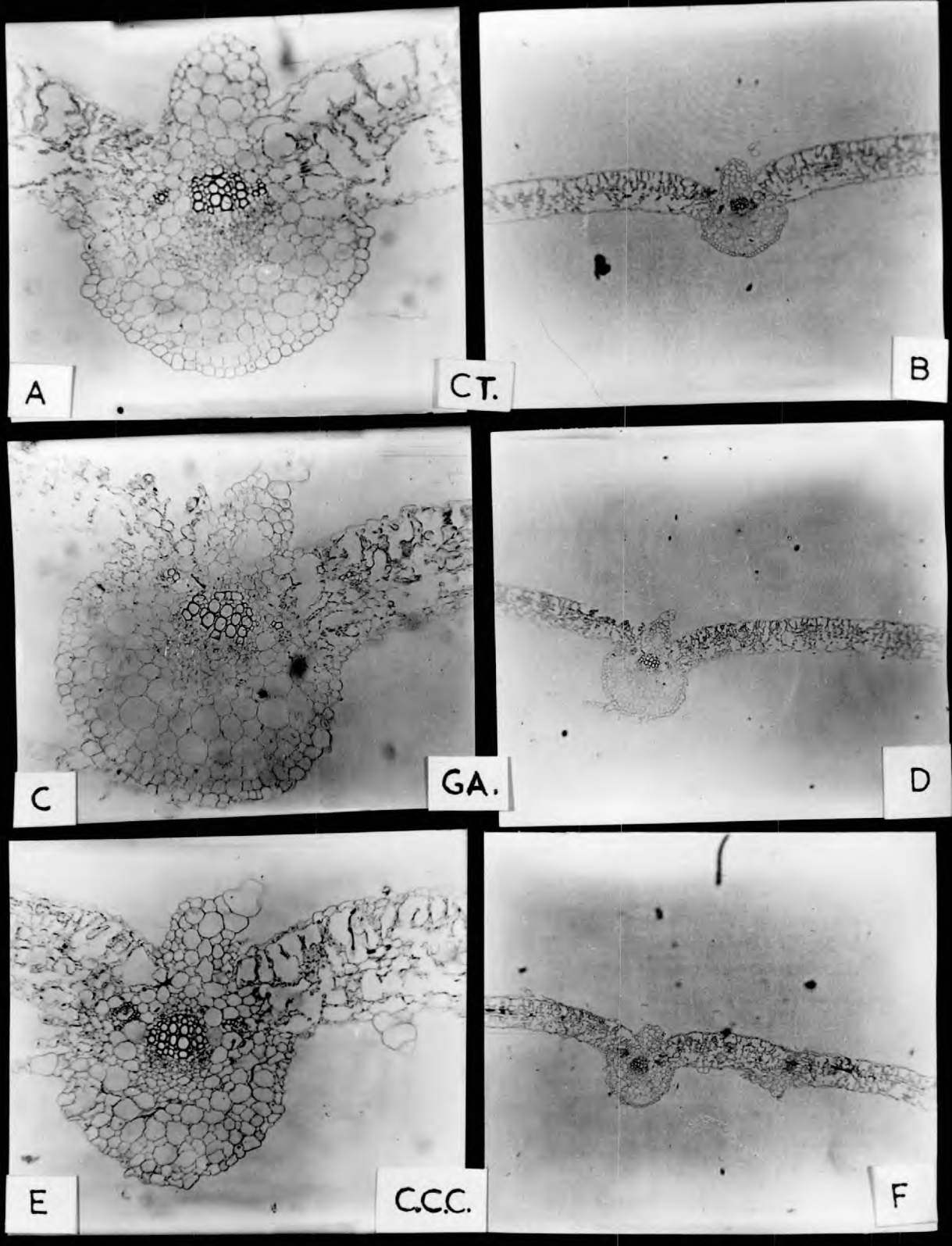


FIG. 10 T.S. LEAF. 100%

Fig. 10

showing the transverse sections of leaf at 100% S.M.R.

A = Portion of T.S. of control under x 10

B = T.S. of Control under x 2

C = Portion of T.S. of G.A. under x 10

D = T.S. of G.A. under x 2

E = Portion of T.S. of C.C.C. under x 2

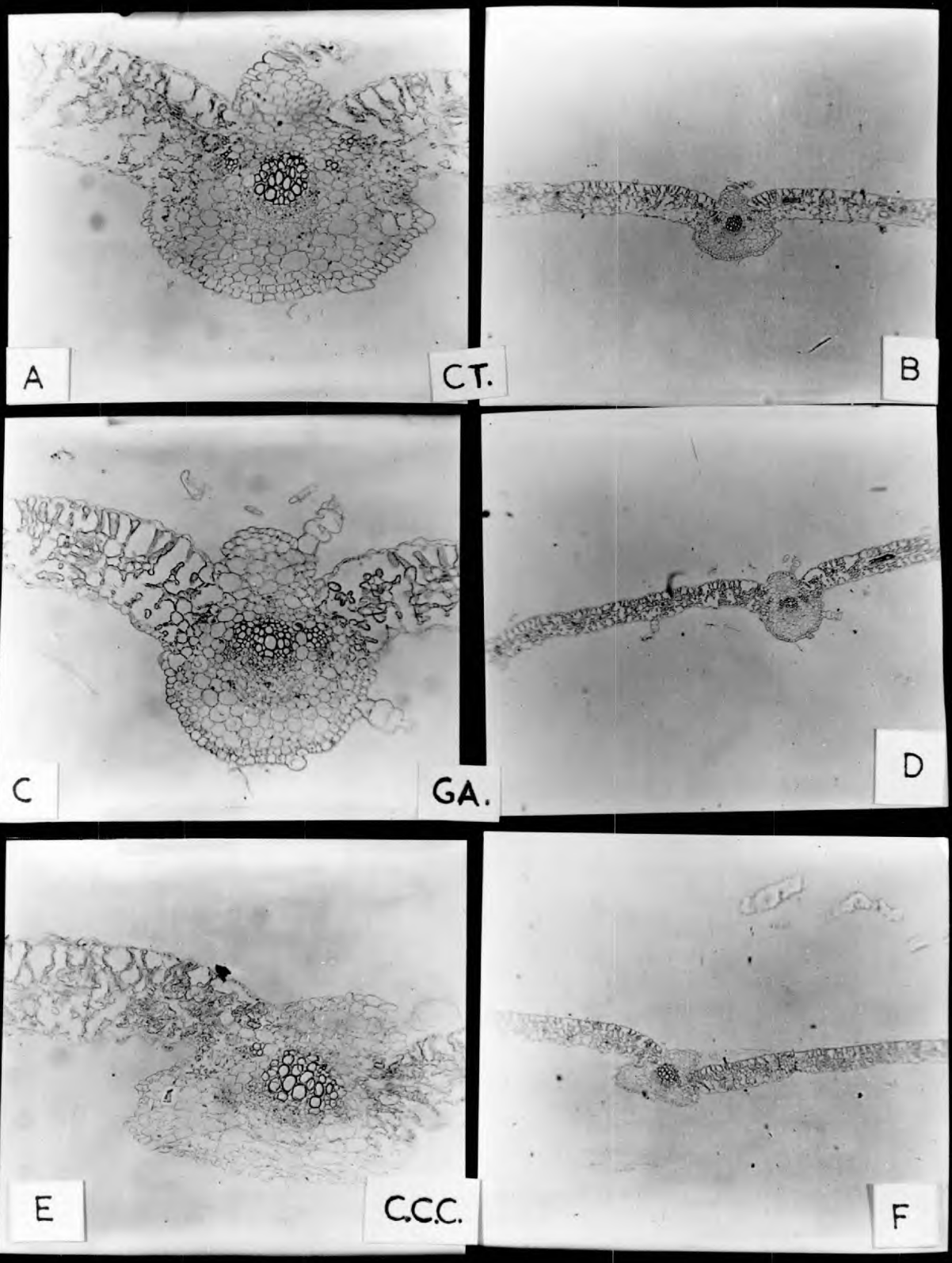


FIG. 11 T.S. LEAF 30%

Fig. 11 Page 105

showing the transverse sections of leaf at 30% S.M.R.

A = Portion of T.S. of control under x 10

B = T.S. of Control under x 2

C = Portion of T.S. of G.A. under x 10

D = T.S. of G.A. under x 2

E = Portion of T.S. of C.C.C. under x 2

It can be seen from Table 8 that the degree of compactness of the spongy tissue, the number of vessels, the number of palisade layers, the area of the vascular tissues is increased in the controls, Gibberellic and C.C.C. treated plants, at the lower moisture regime compared with the 100% treatment. However the diameter of the vessels in the controls and Gibberellic treated plants is slightly decreased and the number of larger vessels slightly reduced at lower soil moisture regimes, compared to plants grown at the higher soil moisture regimes. It is interesting to note, however, that the number and size of the larger vessels at the lower soil moisture regime is increased in C.C.C. treated plants. By comparing the leaves of the three sets of plants it was observed that both at 100% soil moisture regime and 30% the anatomy of leaves of the C.C.C. treated leaves shows that the leaf is very well developed; the tissues are more compact, with more palisade layers, larger number and greater diameter of vessels, and larger areas of the vascular tissues than both the control and the Gibberellic treated plants. That is to say that the C.C.C. treated plants at 100% and 30% moisture regimes show a greater development of xeromorphic characters which is also evident from Table 9 which shows the diameter of vessels of all three sets of plants.

Table 9

Diameters of Ten Largest vessels in μ of the Controls, Gibberellic and C.C.C. treated plants.

CONTROL		GIBBERELLIC TREATED		C.C.C. TREATED	
100% vessel diam. in μ	30% vessel diam in μ	100% vessel diam. in μ	30% vessel diam. in μ	100% vessel diam. in μ	30% vessel diam. in μ
40.7 x 29.6	33.3 x 29.6	33.3 x 27.7	33.3 x 33.3	37.0 x 29.6	40.7 x 33.3
37.0 x 25.9	25.9 x 22.2	37.0 x 27.7	25.9 x 18.5	29.6 x 18.5	37.0 x 27.7
29.6 x 22.2	37.0 x 22.2	37.0 x 29.6	22.2 x 20.3	29.6 x 22.2	40.7 x 27.7
25.9 x 25.9	37.0 x 22.2	37.0 x 31.4	16.6 x 14.8	33.3 x 25.9	33.3 x 25.9
33.3 x 25.9	29.6 x 22.2	29.6 x 22.2	14.8 x 14.8	22.2 x 22.2	29.6 x 25.9
25.9 x 22.2	22.2 x18.5	29.6 x 25.9	22.2 x 18.5	22.2 x 18.5	29.6 x 25.9
22.2 x 22.2	22.2 x 18.5	29.6 x 22.2	18.5 x 18.5	18.5 x 18.5	27.7 x 20.3
25.9 x 22.2	22.2 x 14.8	29.6 x 22.2	22.2 x 18.5	25.9 x 18.5	33.3 x 22.2
25.9 x 25.9	25.9 x 22.2	29.6 x 25.9	22.2 x 20.3	25.9 x 18.5	25.9 x 24.0
22.2 x 25.9	14.8 x 18.5	29.6 x 22.2	18.5 x 18.5	22.2 x 18.5	29.6 x 18.5

Table 9 shows the diameter of ten largest xylem vessels in the central bundle of the mid-rib of the leaves of Controls, Gibberellic and C.C.C. treated plants, at 100% and 30% moisture regimes. At the 100% moisture regime the Table 9 shows that the diameter of vessels is greater among the gibberellic treated plants, the intermediate among the Controls and the smallest among the C.C.C. treated plants. It is interesting to note that at the 30% soil moisture regime the diameter of vessels among the C.C.C. treated plants has increased whereas in the Controls and Gibberellic treated plants the diameter of the vessels is slightly reduced.

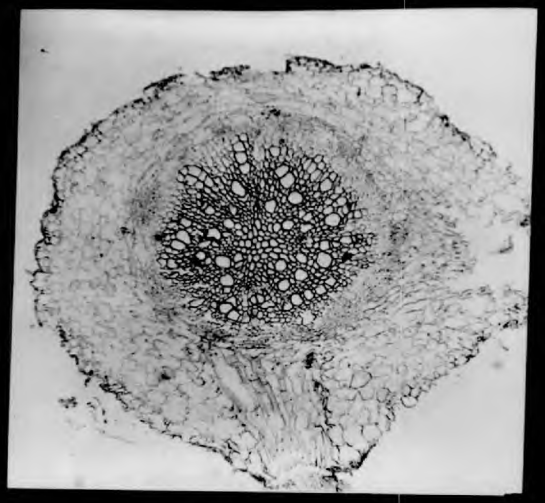
The anatomy of the roots of the three sets of plants was studied by measuring the areas of the region internal to the pericylce i.e. the vascular region and the areas of the region external to the pericycle i.e. the cortical region of the roots in the Controls, Gibberellic and C.C.C. treated plants which is given in Table 10 on page 109 and Fig. 12 on page 110.

Table 10

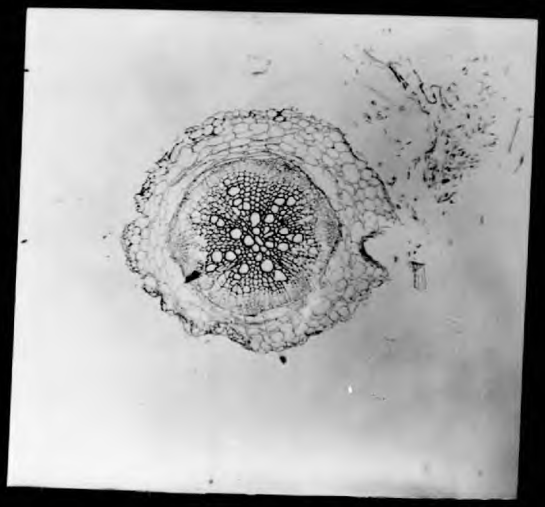
Anatomical Features of the Roots of Controls, Gibberellic and C.C.C. treated Plants.

MOISTURE REGIME	Areas of vas. & cort. Regions as % area of x section of Root.		Ratio of $\frac{\text{cortex}}{\text{vas. reg.}}$
	vascular region cm^2	cortical region cm^2	
Control 100%	20.5	79.4	3.87
Gibb. 100%	20.9	79.0	3.77
C.C.C. 100%	21.6	78.3	3.6
Control 30%	23.0	76.9	3.33
Gibb. 30%	28.6	71.3	2.5
C.C.C. 30%	41.6	58.3	1.4

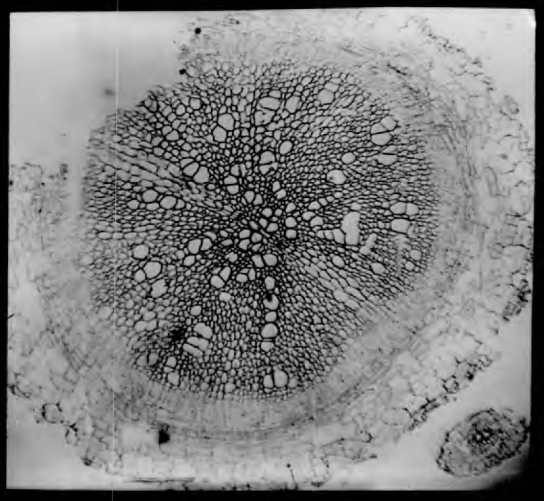
The Table 10 reveals that the area of the vascular region in the roots of the three sets of plants is increased compared to that of the corresponding higher soil moisture regimes. At the 100% moisture regime the areas of the vascular and cortical regions are more or less the same in the Controls and the Gibberellic treated plants. However in the C.C.C. treated plants the area of the vascular region is slightly larger and that of the cortical region smaller.



CT.



GA.



C.C.C.

FIG. 12 T.S. ROOT 30%

Fig. 12 Page 110

showing the transverse sections of roots of Controls, Gibberellic and C.C.C. treated plants at 30% S.MR.

It can also be seen from Table 10 that in the C.C.C. treated plants the area of the vascular region of the roots is much larger. For example at 30% soil moisture regime it is more or less double that at the 100% soil moisture regime.

In the Gibberellic treated plants the area of the vascular region at the lower moisture regime is increased by half only and the increase in the Controls is very small. At the 30% soil moisture regime the $\frac{\text{cortex}}{\text{vas. reg.}}$ ratio is also much smaller in C.C.C. treated roots as compared to the controls and Gibberellic treated ones.

This shows that there is a large response to C.C.C. treatment in the roots of plants grown at the lower soil moisture regime. The $\frac{\text{cortex}}{\text{vas. reg.}}$ ratio in the Controls and the Gibberellic treated plants is also smaller but not so great a reduction as in the C.C.C. treated plants. This shows that although C.C.C. treatment has the effect of producing a measure of "pre-adaptation" further adaptation is still possible at the lower moisture regime.

The $\frac{\text{cortex}}{\text{stele}}$ ratio expressed as percentage of the stem and leaf mid-rib cross section area were also calculated for the controls, C.C.C. and gibberellic treated plants at 100% and 30% soil moisture regimes. These are given in Tables 11 & 12 on pages 112 & 113.

Table 11 showing $\frac{\text{cortex}}{\text{stele}}$ ratios of the stems of Controls, gibberellic and C.C.C. treated plants.

Moisture Regime	area of cortex as percentage of stem x section area cm^2	cortex/stele ratio
C T 100%	20.2	2.33
G.A.100%	21.9	2.8
CCC.100%	23.2	1.71
C T. 30%	24.62	2.18
G.A. 30%	27.52	2.69
CCC. 30%	32.0	1.55

Table 11 shows the area of the cortex expressed as a percentage of the stem cross section area and the $\frac{\text{cortex}}{\text{stele}}$ ratio of the stems of controls, gibberellic and C.C.C. treated plants at the 100% and 30% soil moisture regime respectively.

It can be seen that with a decrease in soil moisture regime there is an increased development of the cortex which is very much evident in the C.C.C. treated plants as compared to the Controls and gibberellic plants. Table 11 also shows that with a decrease in the soil moisture regime the $\frac{\text{cortex}}{\text{stele}}$ ratio becomes smaller indicating that at the lower soil moisture regime there is a greater production of stele as compared to the cortex.

Table 12 showing cortex/stele ratios of the leaves of controls, gibberellic and C.C.C. treated plants.

	area of cortex as percentage of mid rib x section area cm^2	cortex/stele ratio
Control 100%	85.45	5.87
G.A.100%	83.16	4.93
CCC. 100%	82.63	4.69
Control 30%	82.8	4.77
G. A. 30%	82.25	4.63
CCC. 30%	74.16	2.87

Table 12 shows the area of the cortex expressed as a percentage of mid rib xsection area and the $\frac{\text{cortex}}{\text{stele}}$ ratio of the controls, gibberellic and C.C.C. plants at the 100% and 30% soil moisture regimes respectively.

It is evident from Table 12 that the area of the cortex is smaller in the C.C.C. treated plants as compared to the controls and the gibberellic treated plants. It also indicates that the area occupied by the stele is greater in the C.C.C. treated plants as compared to the controls and the gibberellic treated plants. This is also shown by the smaller $\frac{\text{cortex}}{\text{stele}}$ ratio of the C.C.C. treated plants.

By studying the anatomy of the stems, leaves and the roots it can be concluded that as the moisture regime decreases the plants of all three sets tend to respond to adverse water conditions by developing xeromorphic characters. In particular this consists of an increase of vascular and conducting tissues in the stems and roots. An increase in the leaf of the number of vessels, number of palisade layers and the greater compactness of the cells. All these can be considered advantageous in water relations of the

individuals possessing them. The degree of xeromorphic characters developed varies from species to species, some are more responsive to drought than others. The application of C.C.C. induces the xeromorphic characters even under mesophytic conditions and increasingly so even with more adverse water conditions. The treated plants even when grown under mesophytic condition are already "pre-adapted" to water stress and therefore have a great chance of survival should any period of sudden drought occur.

Water Balance

The relative turgidities of the Controls, Gibberellic and C.C.C. treated plants were determined using Weatherley's technique (1950, 51, 62). This method was employed because the determination of relative turgidity of leaves as used by Weatherley appears to be a satisfactory and relatively simple method. A knowledge of relative turgidity of leaves enables towards a better understanding of water relationships. It is also an indicator of general physiological activity.

The relative turgidity of the three sets of plants was determined from the same set of plants as used for the estimation of growth, anatomy and morphology. The relative turgidities of one set of plant grown at five moisture regimes was determined at the same time. Temperature and relative humidity were recorded. In the following pages the relative turgidities of the Controls, Gibberellic and C.C.C. treated plants are discussed.

Measurements for the relative turgidities were done in the early morning. Twenty discs were punched from fully mature leaves of different plants. The discs were quickly ejected into the weighed bottles. The fresh weight of the discs was then determined. The

discs were floated in petri dishes containing distilled water. The petri dishes were floated in a water bath maintained at 20°C. The light was fixed at compensation point. (Details of this procedure are given in the Chapter 'Material and Methods' on page 44). At three hour intervals the discs were removed, carefully dried and weighed again. Five readings were taken up to 24 hours. The last reading was taken at an interval of twelve hours. The increase in the fresh weight of the discs is given in Tables/ 55, 56 and 57 in appendix on pages 237, 238 and 239.

Tables a, b and c show the percentage increase in water content of the discs for 24 hours, for the Controls, Gibberellic and C.C.C. treated plants. These are graphically represented on pages 119, 120 and 121.

Table 13 a

Percentage increase in water content in gms. of the discs in Controls

TIME IN HOURS	MOISTURE REGIME				
	100%	55%	30%	15%	10%
3	102.8	96.8	67.1	128.0	139.1
6	143.0	158.4	133.5	196.2	231.9
9	158.1	174.0	154.7	224.3	271.0
12	163.1	188.0	164.9	247.0	306.9
24	168.3	204.0	191.0	271.2	329.0

Table 13b

Percentage increase in water content in gms. of the discs in Gibberellic treated plants.

TIME IN HOURS	MOISTURE REGIME				
	100%	55%	30%	15%	10%
3	85.7	142.7	141.2	165.6	205.0
6	105.1	169.9	174.6	214.8	268.6
9	123.8	193.0	204.3	255.8	317.0
12	146.8	207.7	234.9	301.0	372.0
24	184.9	237.9	280.0	386.9	466.1

Table 13c

Percentage increase in water content of the discs of C.C.C. treated plants in gms.

TIME IN HOURS	MOISTURE REGIME				
	100%	55%	30%	15%	10%
3	60.2	83.0	121.5	162.3	188.5
6	97.0	133.7	172.2	219.6	243.9
9	125.0	152.1	208.0	252.0	274.3
12	142.2	168.1	236.5	274.7	298.7
24	185.0	211.3	271.7	292.8	307.9

PERCENTAGE INCREASE IN WATER CONTENT OF THE LEAF DISCS OF CONTROLS AS INFLUENCED BY SOIL MOISTURE REGIME.

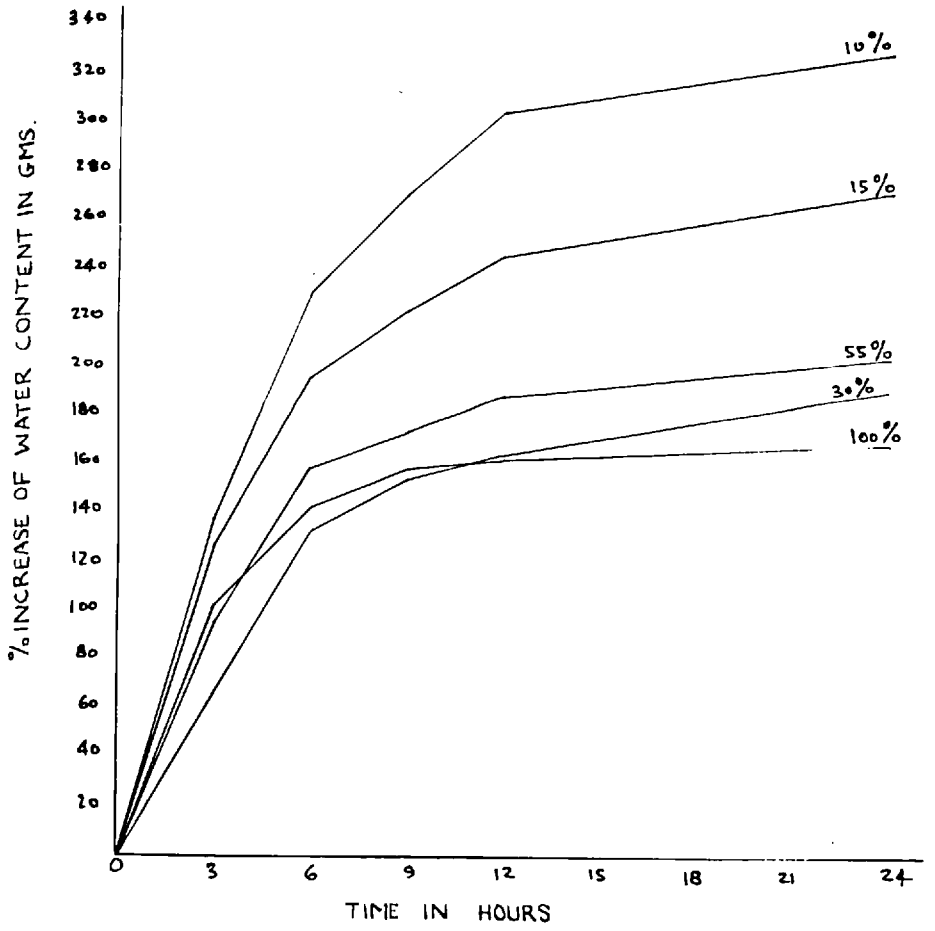


Fig. 13
The relative turgidity for 100% was calculated after 6 hrs.
" " " " 55% " " " 12 "
" " " " 30% " " " 24 "
" " " " 15% " " " 12 "
" " " " 10% " " " 12 "

PERCENTAGE INCREASE IN WATER CONTENT OF THE LEAF DISCS OF GIBBERELLIC TREATED PLANTS AS INFLUENCED BY SOIL MOISTURE REGIME.

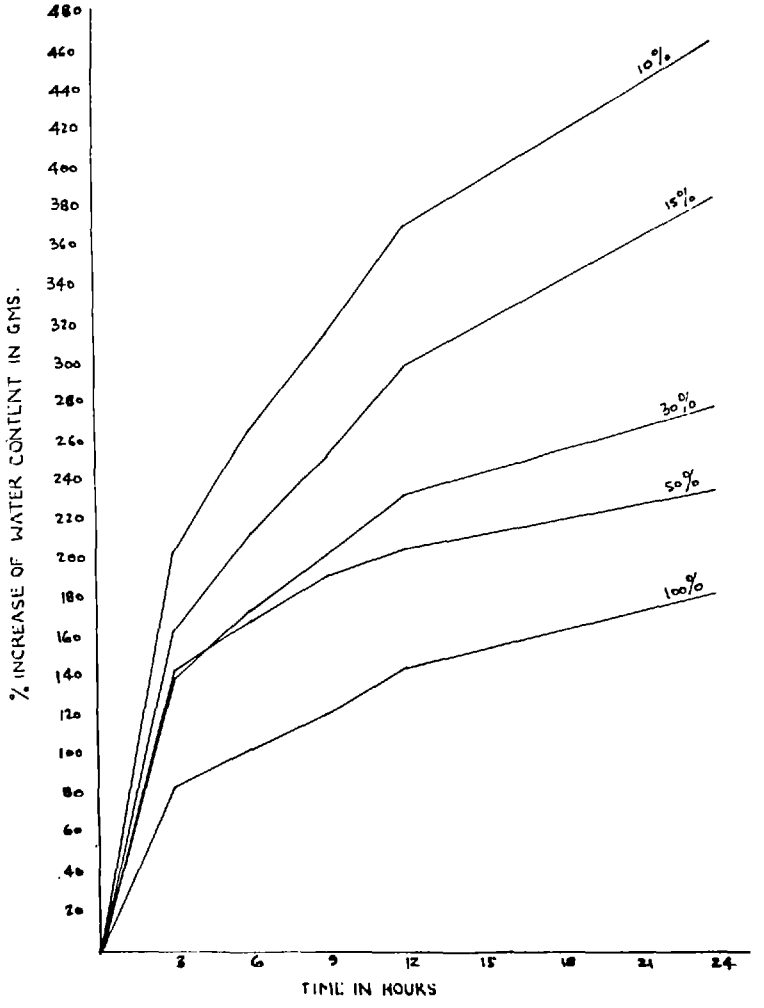


Fig. 14
The relative turgidity for 100% was calculated after 12 hrs.
" " " " 55% " " " 9 "
" " " " 30% " " " 12 "
" " " " 15% " " " 12 "
" " " " 10% " " " 12 "

PERCENTAGE INCREASE IN WATER CONTENT OF THE LEAF DISCS
OF CCC TREATED PLANTS AS INFLUENCED BY SOIL MOISTURE REGIME.

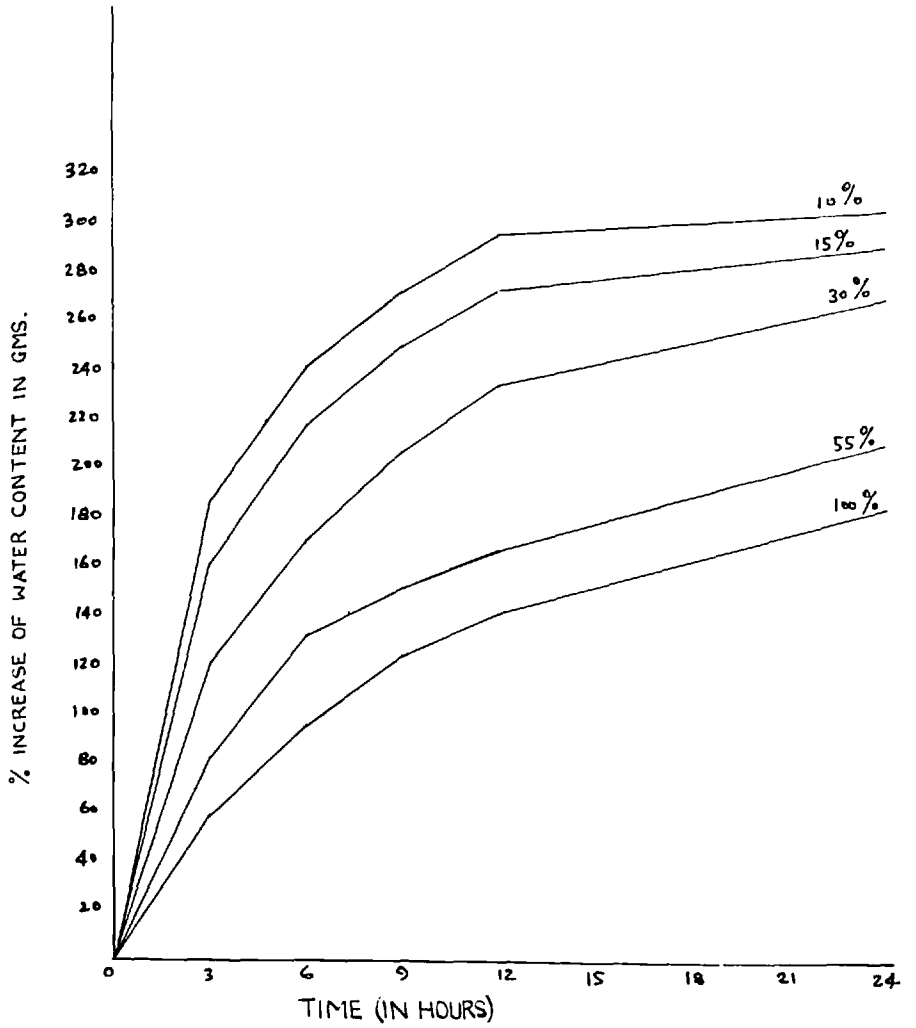


Fig. 15
The relative turgidity for 100% was calculated after 12 hrs.
" " " " 55% " " " 12 "
" " " " 30% " " " 12 "
" " " " 15% " " " 12 "
" " " " 10% " " " 12 "

Tables 13 a, b and c show the rate of uptake of water by the discs for 24 hrs., for the controls, Gibberellic and C.C.C. treated plants. In all three sets of plants it can be seen that the amount of water absorbed by the discs increases with the decrease in moisture regime.

The Table 13a and the graph on Fig. 13 show that in the Controls at 100% soil moisture regime the rate of uptake of water was found to be slow. After 2 - 3 reading it became more or less steady. At 55% soil moisture regime the rate of water uptake was found to be higher than at 100% soil moisture regime. After 2 - 3 reading it was more or less steady but not quite as it was at the 100% soil moisture regime. Similarly the rate of water uptake at 30%, 15% and 10% soil moisture regimes increases with the decreasing soil moisture regime. Particularly at 15% and 10% soil moisture regimes the rate of uptake of water was found to be very higher even at the fourth reading, i.e. after 12 hrs. However, at the final reading the rate of water uptake became somewhat steadier. Finally it also reveals that the total amount of water absorbed in 24 hrs. at 10% soil moisture regime was more or less double that of 100%

soil moisture regime.

The relative turgidities for all the soil moisture regimes were calculated using the following formula:

$$R.T. = \frac{\text{Initial wt. of the Disc - Dry wt. of the Disc}}{\text{Saturated wt. of the Disc - Dry wt. of the Disc}} \times 100$$

See Table 14.

It was found that the relative turgidity decreases with the decrease in soil moisture regime. It can be concluded that the lower the soil moisture regime the lower the relative turgidity and higher the rate of water absorption. The overall absorption of water in Controls in 24 hrs:-

at 100% soil moisture regime - 168.3 gms.
" 55% " " " - 204.0 gms.
" 30% " " " - 191.0 gms.
" 15% " " " - 271.2 gms.
" 10% " " " - 329.0 gms.

Table 14

Relative turgidities of the Controls, gibberellic and C.C.C. treated plants.

Plant Type	MOISTURE REGIME				
	100%	55%	30%	15%	10%
Control	85.3	85.1	84.3	81.6	78.9
Gibb.	86.5	82.7	78.3	76.5	72.5
C.C.C.	86.1	84.0	81.5	81.0	76.3

Table 13b on page 118 and Fig. 14 show that the rate of water absorption increases with the successive decrease in soil moisture regimes. It also shows that the rate of water absorption particularly at lower soil moisture regimes does not decrease significantly with the successive time intervals (as occurred in the Controls). Fig. 14 shows that the rate of absorption was not so steady as in the controls.

The total absorption of water by the leaf discs of gibberellic treated plants in 24 hrs. was as follows:

at 100% soil moisture regime 196 gms.
at 55% " " " 238 gms.
at 30% " " " 280 gms.
at 15% " " " 386 gms.
at 10% " " " 466 gms.

It was found that the amount of water absorbed by the Gibberellic leaf discs was more at all soil moisture regimes as compared to the Controls. It can be seen from the above mentioned figures and Table 13 b on page 118/that at 10% soil moisture regime 271 gms. more water was absorbed by the discs than at 100% soil moisture regime. While in the Controls the difference in absorption of water at 10% and 100% soil

moisture regime was 160 gms. This shows that the leaf discs of gibberellic treated plants absorbed water at a greater rate as compared to the controls. The relative turgidities of the gibberellic treated plants at five moisture regimes are given in Table 14 on page 123. It can be seen from the Table 14 that with successive decrease in soil moisture regimes the relative turgidity of the plant decreases. The decrease in relative turgidities with decreasing soil moisture regimes was greater compared to the controls. It can also be seen from Table 14 that the difference between the relative turgidities of the plants at 100% and 10% soil moisture regimes was 14 whereas in the controls it was 6. It can be seen that the application of gibberellic acid disturbs the relative turgidity at lower soil moisture regimes to a greater extent than in the control plants. The appearance of the gibberellic treated plants at comparable soil moisture regimes was very similar to that of the controls despite the differences in the relative turgidity.

Table 13 c on page 118 and Fig. 15 show that the rate of water absorption increased with decrease

in soil moisture regime. From Fig.15 on page 121 it can be seen that after fourth reading, i.e. after twelve hours the rate of water absorption becomes more or less steady. The total absorption of water by the leaf discs of C.C.C. treated plants at the five soil moisture regimes was as follows:-

at 100% soil moisture regime - 185 gms.
at 55% " " " - 212 gms.
at 30% " " " - 282 gms.
at 15% " " " - 292 gms.
at 10% " " " - 308 gms.

The Tables 13a,b & c show that at 10% compared with the 100% soil moisture regime 123 gms. more water was absorbed by C.C.C. discs, 160 gms. by the Controls and 271 gms. by the gibberellic treated plants. It seems clear that the ability of the C.C.C. treated plants to maintain an adequate water balance in their leaves was greater than that of the controls and very much greater than that of the gibberellic treated plants.

The difference between the amount of water absorbed in 24 hrs. by the leaf discs of 10% soil moisture regime and 100% soil moisture regime is least in the C.C.C. treated plants compared to controls and gibberellic treated plants. It is most probable that

the better survival and growth of the C.C.C. plants as compared with Controls and gibberellic treated plants was due to this fact. The relative turgidities of the C.C.C. treated plants at five moisture regimes are given in Table 14 on page 123. It can be seen that with successive decrease in soil moisture regime the relative turgidity decreases. The decrease in the relative turgidity (with the successive decrease in the soil moisture regime) has much greater effect on the Controls and the Gibberellic treated plants as compared to the CCC treated ones.

Stomata

The number of the stomata of the controls, gibberellic acid and C.C.C. treated plants at the 100% soil moisture regime was counted. The technique used was to spread the Bexol solution evenly on the leaf surface of which the stomata were to be studied. After 10 - 15 minutes when the solution got dried forming a thin film on the surface of the leaf. Very carefully the layer of solution was removed and was placed on a slide so that the side in contact with surface of the leaf faces upwards. This was mounted in a small amount of glycerine jelly. After 2 - 3 minutes the slide was ready for observation. It was found that Bexol solution was very useful in taking the impressions of the leaf surface as the peeling of the epdiermal strips were very difficult to obtain and moreover they were not very clear. This solution proved very useful and it was also seen that it did not disturb in any way the position or the number of stomata. However precaution should be taken when removing the film of solution from the leaf surface, because if it is not removed carefully it might stretch which would alter the position of the stomata. The stomata of the lower surface of the leaves of the controls, gibberellic and C.C.C. treated plants at 100% soil moisture regime were counted under x 10 objective which

are as follows.

Table 15.

Number of Stomata of the Controls, gibberellic and C.C.C. treated plants.

	No. of stomata per cm^2.
CONTROL	156
Gibberellic treated	118
C.C.C. treated	178

The Table 15 shows that the number of stomata are greater in the C.C.C. treated plants as compared to the controls and gibberellic treated plants. Whereas the number of stomata in the gibberellic treated plants is lowest. It can also be seen from Fig. 32 that the stomata in the leaves of C.C.C. treated plants appear to be smaller, while those of the leaves of gibberellic treated plants appear to be larger than the controls.

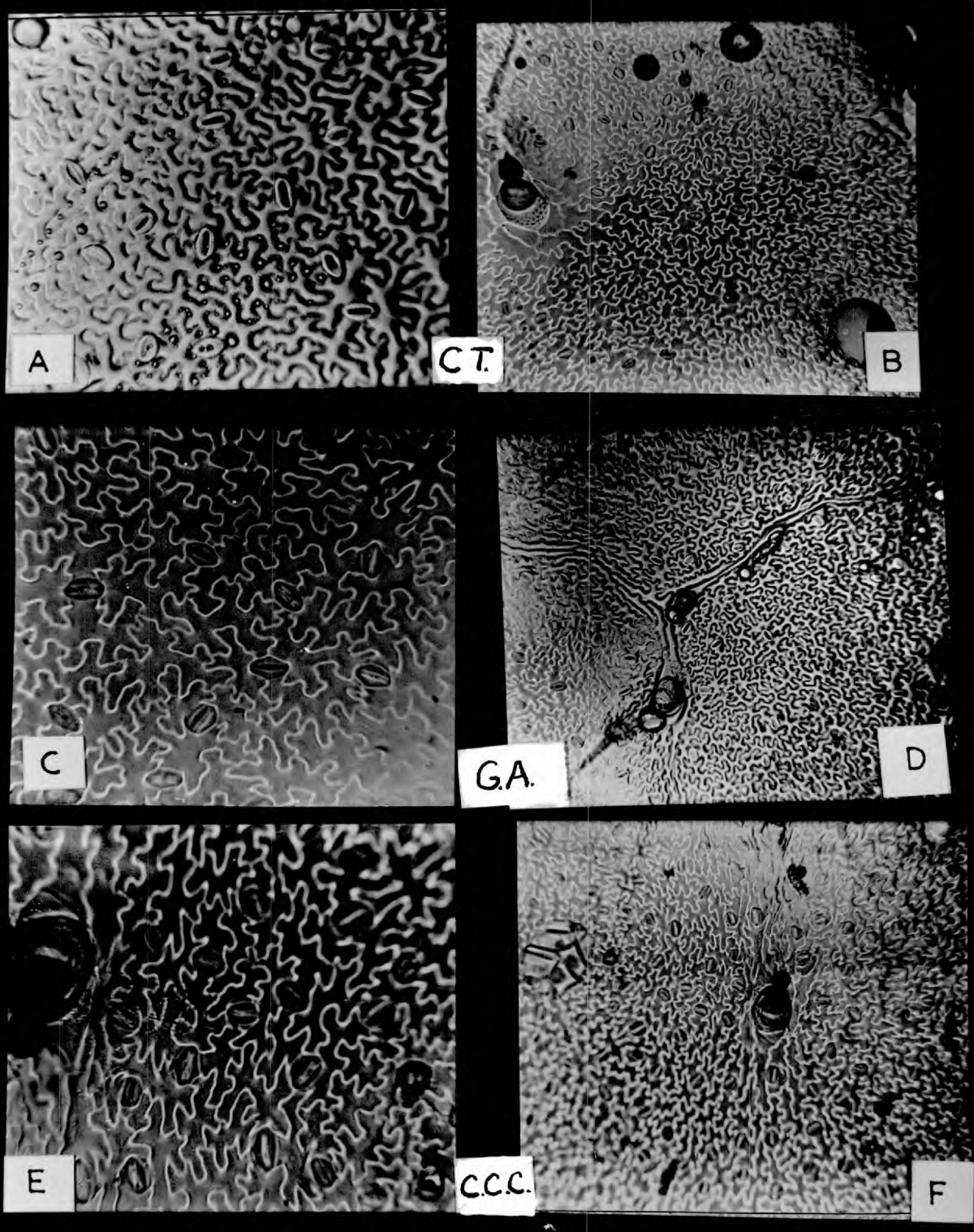


FIG. 32 STOMATA.

Fig. 32 Page 130

showing the stomata on the lower surface of the leaf at 100% S.M.R.

A = stomata of C.T. under x 10

B = " " " " x 2

C = " " G.A. " x 10

D = " " " " x 2

E = " " C.C.C. " x 10

F = " " " " x 2

The Effects of Wind on Growth, Morphology, Anatomy and Water Balance

The effects of wind on growth, morphology, anatomy and water balance of Helianthus annuus were studied.

Seeds of Helianthus annuus var. 'Pole Star' were sown in sand and transplanted in 250 ml. beakers. The soil used was a mixture of sand and peat in 2:1 ratio. Details of this are given in Chapter Material and Methods on page 38 . One plant per beaker was planted. The plants were placed in the wind tunnel at the stage of fully opened cotyledons. These plants were grown exposed to wind at a speed of 33 m.p.h. A second set of plants was also grown inside the wind tunnel which was not exposed to the wind. These were kept as Controls. The soil was kept at field capacity throughout the experiment. The plants were grown with natural daylength. The experiment was conducted between 9th June - 7th July. The initial and the successive harvests were done at weekly intervals. The height of the plants, the internodes and leaf area were determined in the same way as mentioned in Chapter II on page 43.

Fig. 16 shows the wind treated plants and the Controls. It can be seen from Fig. 16 that the plants which are grown exposed to wind and the Controls show a great deal of morphological difference. The wind treated plants are shorter in height. This is accompanied by the reduction in the length of the internodes.

The Table 16 shows the average internode lengths and the height of the controls and the wind treated plants.

Table 16a Controls

The Average Internode Length and Height of Plant in cms.

Harvests	Internode lengths				Height of the plant
	1st Int.	2nd Int.	3rd Int.	4th Int.	
1	1.0	-	-	-	6.3
2	5.35	.25	-	-	11.3
3	11.4	0.95	0.2	-	19.35
4	15.75	1.3	0.65	0.2	26.9
$\frac{\pm ts}{\sqrt{n}}$	±3.15	±0.24	±0.12		±1.61

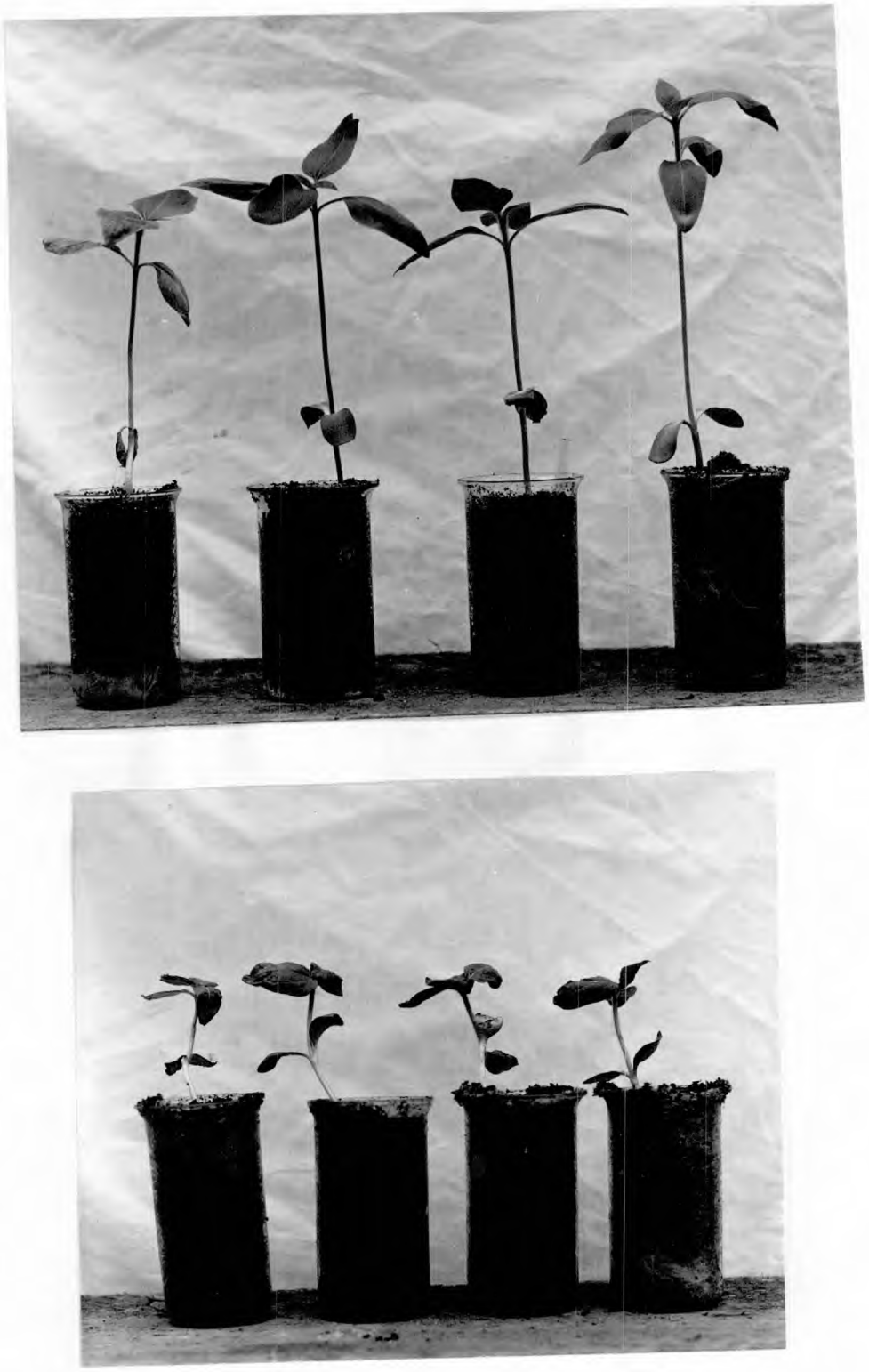


Fig. 16 showing the controls (above) and plants grown in wind tunnel (below).

Table 16 b Wind Treated Plants

The Average Internode Length and Height of Plant in cms.

Harvests	Internode lengths				Height of the Plant
	1st Int.	2nd Int.	3rd Int.	4th Int.	
1	0.66	-	-	-	5.3
2	2.8	0.16	-	-	7.86
3	3.87	0.37	0.125	-	9.75
4	5.35	1.35	0.175	-	13.65
$\pm \frac{\sigma ts}{\sqrt{n}}$	±2.4	±1.11	±1.45		±2.0

As can be seen from Tables 16 a and b the average internode length and the plant height of the wind treated plants and the Controls show a great deal of difference. The number of internodes in the Controls was found to be greater as compared to the wind treated plants. The wind treated plants also show a great reduction in the length of the internodes. The height of the wind treated plants was half as compared to the Controls.

The leaves of the wind treated plants were smaller and thicker. The surface of the leaves appeared to be wrinkled. The area of the leaves

was very much smaller in the wind treated plants as compared to the Controls. The average leaf areas of the wind treated plants and the Controls at successive harvests is shown graphically on page 136. Fig. 17

From Fig. 17 it can be seen that the average area of the Control plants at successive harvests was many times more than that of the plants grown in the wind tunnel.

The reduction of the leaf area in wind treated plants was accompanied by a reduction in the total dry weight of the plant. The average total dry weight of the wind treated plants and the Controls are given in Table 17. These are graphically represented on page 137 Fig. 18.

Table 17

Mean Total Dry weights of the Controls and Wind treated plants in mgs.

Harvest	CONTROL	WIND
1	141.5	109.4
2	300.9	151.5
3	619.7	203.2
4	1154.3	339.2

EFFECT OF WIND ON GROWTH.

LEAF AREA AT SUCCESSIVE HARVESTS.

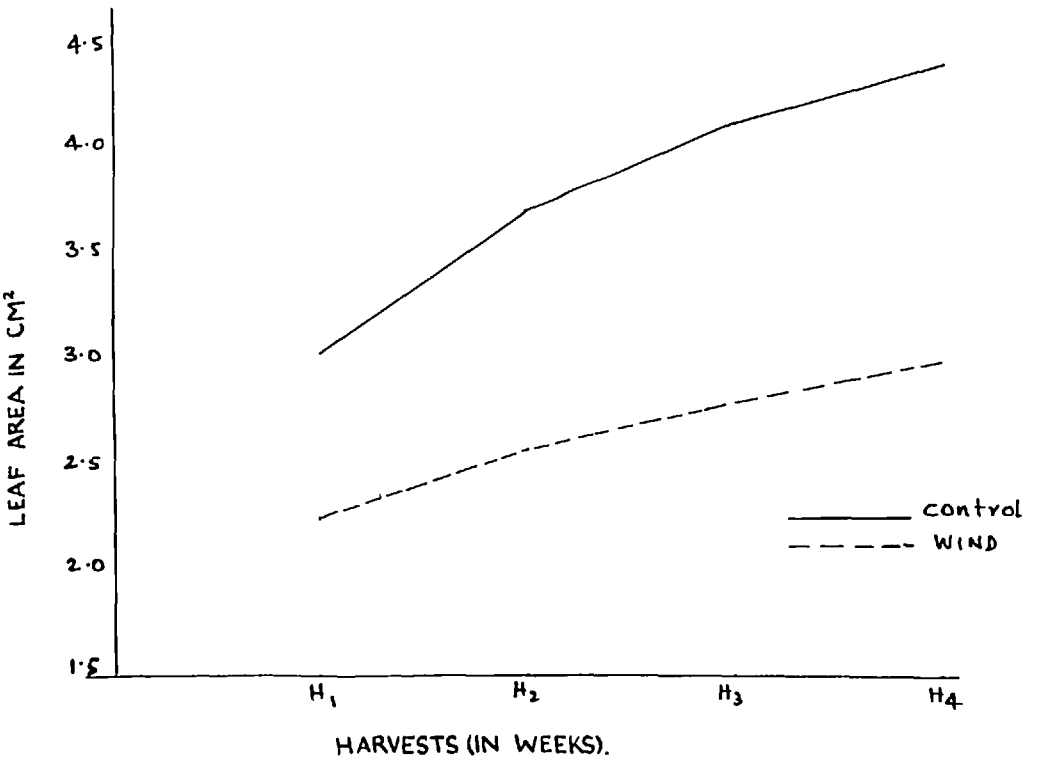


Fig. 17

	CONTROL	WIND
$\pm$ ts/$\sqrt{n}$	$\pm$4.96	$\pm$4.65
S.E. of diff. of means		33.77

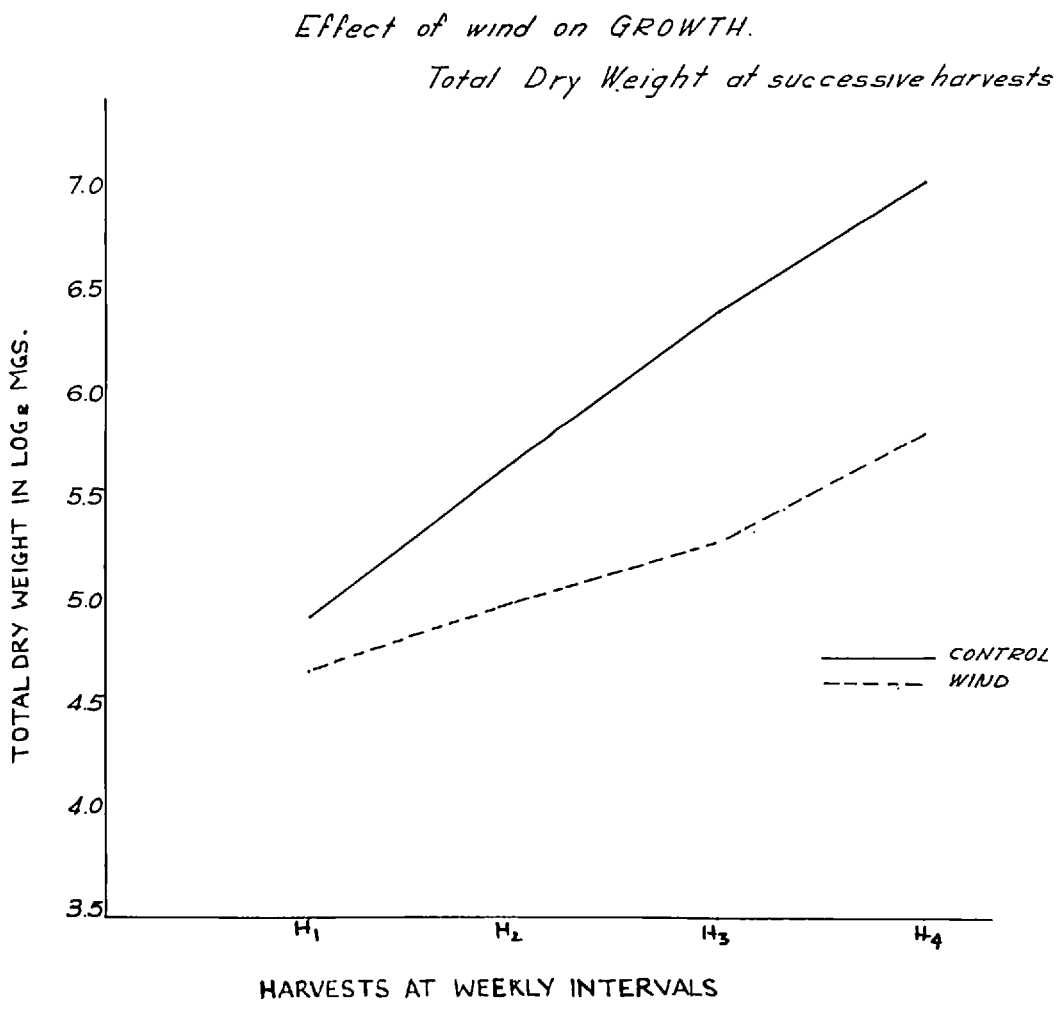


Fig. 18

	CONTROL	WIND
$\pm ts/\sqrt{n}$	±176.28	±102.98
S.E. of diff. of means		± 15.64

It can be seen from Table 17 that at each successive harvest the dry weight of the wind treated plants is much less than the controls. Although the wind treated plants show a reduction in the total dry weight but this reduction is comparatively more in the shoot dry weight as compared to the root dry weight. This can be clearly shown by the $\frac{\text{Shoot}}{\text{Root}}$ ratios given in Fig.19 on page 140. The $\frac{\text{Shoot}}{\text{Root}}$ ratio of wind treated plants is lower than that of the Controls. This indicates that the root system is well developed or better developed than that of the Control plants.

The mean relative growth rates and the mean relative rates of leaf area increase of the wind treated and the controls were calculated as mentioned on page 77 . These are given in Tables 18 & 19 respectively.

Table 18

Mean Relative growth rates of Controls and Wind treated plants in mgs./mgs./week.

Harvest Interval	CONTROL	WIND
1 - 2	0.754	0.324
2 - 3	0.722	0.283
3 - 4	0.621	0.512

Table 19

Mean Relative Rate of Leaf Area increase in $cm^2/cm^2/week$.

Harvest Interval	CONTROL	WIND
1 - 2	0.686	0.329
2 - 3	0.406	0:212
3 - 4	0.273	0.292

As it can be seen from Tables 18/ and 19 that the mean relative growth rate of the wind treated plants is much less than the Controls. However, the mean relative rate of leaf area increase of the wind treated plants seem to be less affected. The relationship between the mean relative growth rate and the mean relative rate of leaf area increase $(\frac{\bar{R}}{\overline{RL}})$ i.e α is shown in Table 20 and graphically represented on page 141.

EFFECT OF WIND ON GROWTH.

SHOOT RATIO AT SUCCESSIVE HARVESTS.
ROOT

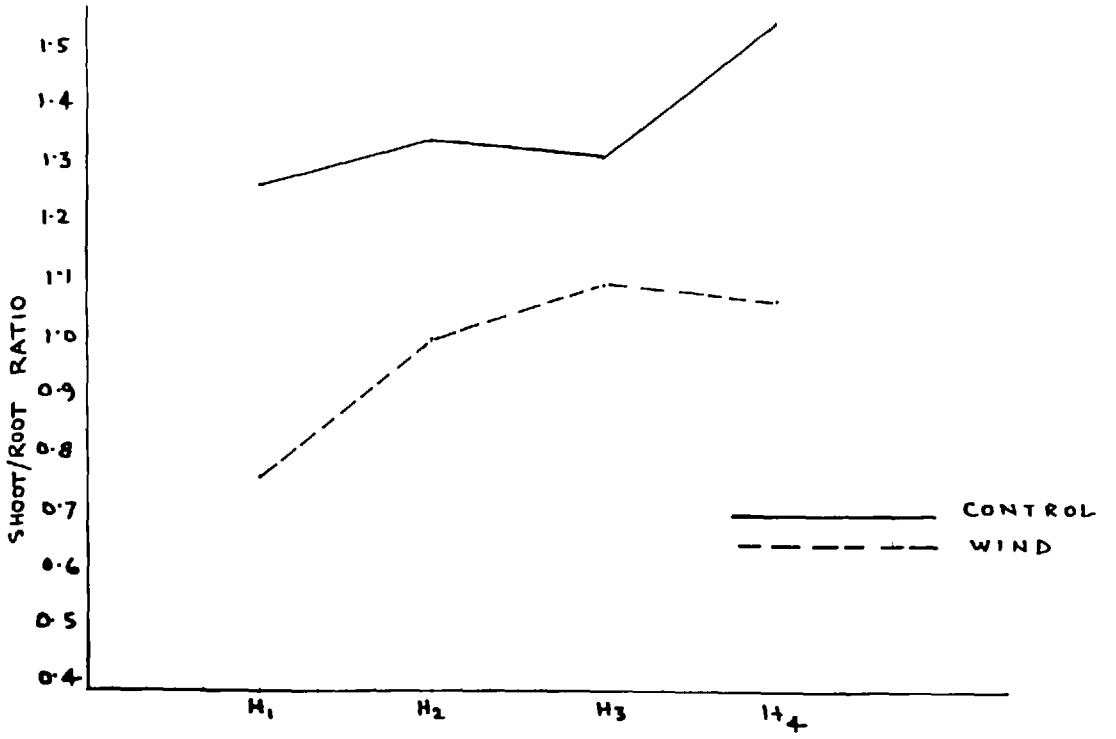


Fig. 19

	CONTROL	WIND
$\pm ts / \sqrt{n}$	±0.19	±0.16

EFFECT OF WIND ON GROWTH

VALUES OF α BETWEEN SUCCESSIVE

HARVESTS.

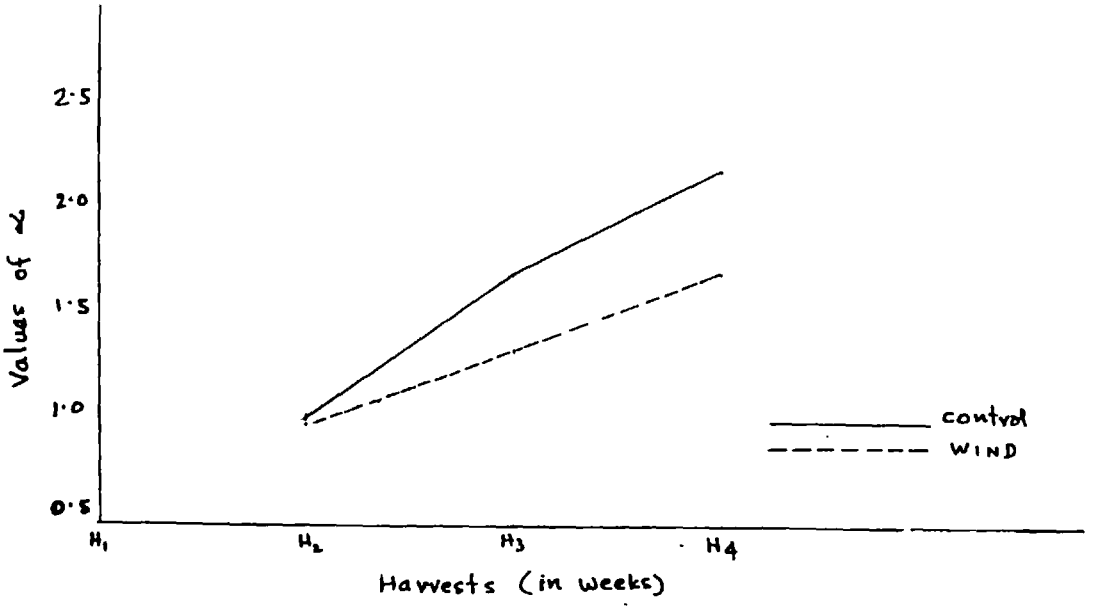


Fig. 20.

Table 20

Values of α between successive harvests for the Controls and wind treated plants.

Harvest Interval	CONTROL	WIND
1 - 2	1.0	.989
2 - 3	1.7	1.3
3 - 4	2.2	1.7

It can be seen that the control plants show much higher values of α as compared to the plants grown in the wind tunnel. This indicates that among the control plants the total dry weight of the plant was increasing at a greater rate than its leaf area. Whereas the α values of wind treated plants show that the total dry weight of the plant was increasing at a smaller rate than its leaf area.

Effect of Wind on Anatomy

The anatomy of the Controls and the plants grown in wind tunnel for five weeks was examined. Transverse sections of the stems and leaves were cut by the same procedure as mentioned on page 46.
The following features of the anatomy of the stem and leaf were examined.

Stem: The number of vascular bundles was counted. The areas of xylem, phloem, sclerenchyma and cortex were determined and expressed as percentage of stem x section area (for details see page 50). The cortex/stele ratio (as percentage of x section area of stem) was calculated.

Leaf: The areas of the xylem, phloem, sclerenchyma and cortex in the central bundle were determined and expressed as percentage of mid rib x section area (for details see page 50). The cortex/stele ratio (as percentage of x section area of mid rib) was calculated. The number of vessels was counted and the diameter of ten largest xylem vessels was determined. The number of palisade layers and the degree of compactness of the spongy tissue was compared. The number of vessels over 14μ was counted. The values of occular divisions, low power (x 10), differential objective (x 2) and camera lucida drawing magnifications are given on page 97.

The anatomical features of the stems of Controls and wind treated plants are given in Table 21.

Table 21

Anatomical Features of the Stem of Controls and Wind Treated Plants

Plant Type	No. of vascular bundles	Stem x section area	Areas of xylem, phloem and sclerenchyma as % of stem x section area				cortex/ stele
			xylem cm^2	phloem cm^2	Sclerenchyma cm^2	cortex cm^2	
Control	12	891.75	0.526	0.470	0.517	23.83	1.31
Wind	13	917.85	0.762	0.616	0.697	27.17	1.01

Fig. 21 on p. 146

From Table 21/ it is quite evident that the plants grown exposed to wind have well developed vascular bundles. It can be seen from Table 21 that the areas of the xylem, phloem and sclerenchyma when expressed as a percentage of stem x section area are greater in the wind treated plants as compared to the controls. The area of the cortex in the wind treated plants is greater as compared to the controls. While the $\frac{\text{cortex}}{\text{stele}}$ ratio is smaller showing that the development of the stele is better among the wind treated plants as compared to the Controls. The anatomical features of the leaves of the wind treated plants and the Controls are given in Tables 22 a,b. and Fig. 22 on page 147.

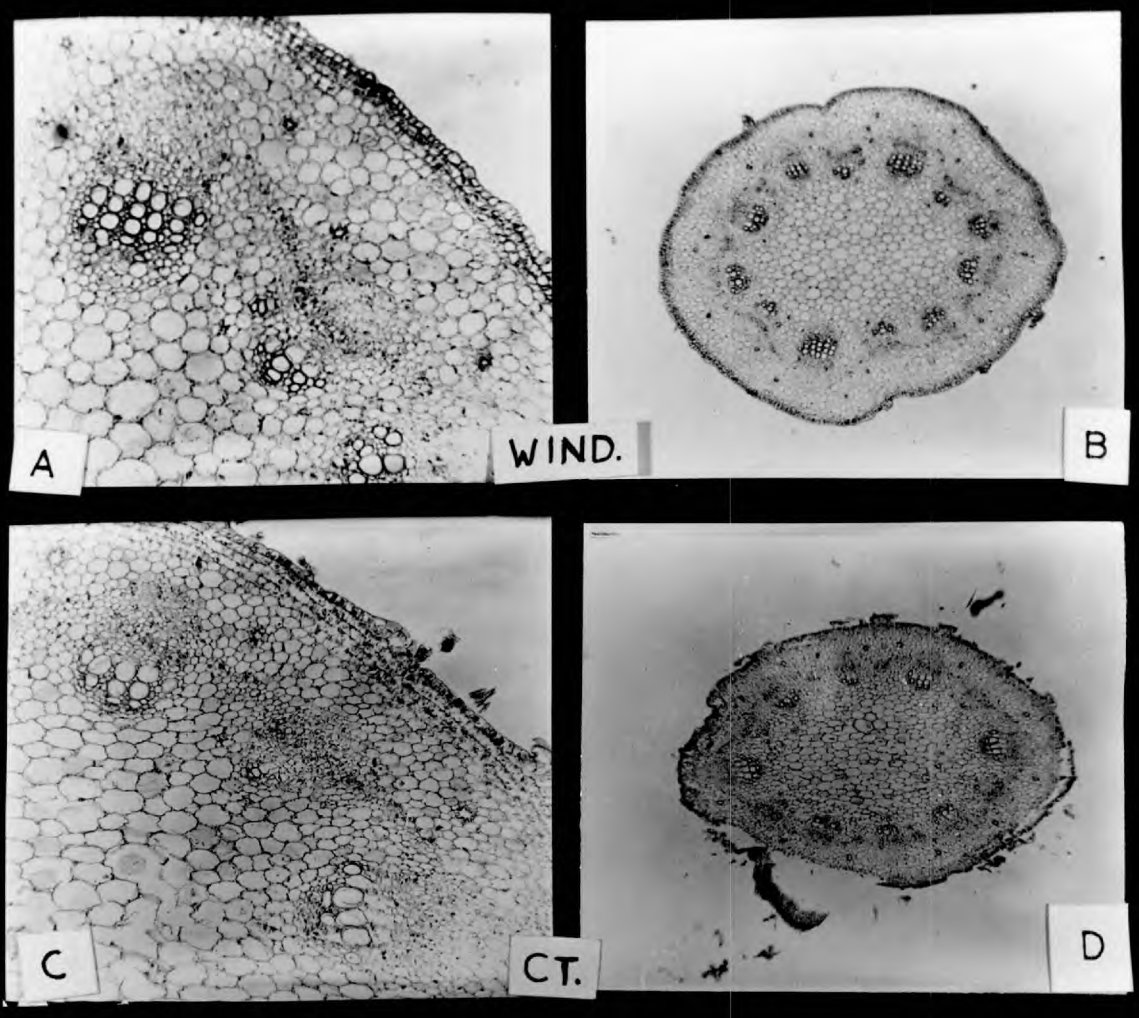


FIG. 21 T.S. STEM.

Fig. 21 Page 146

showing the transverse sections of stem

A = Portion of T.S. of wind under x 10

B = T.S. of wind under x 2

C = Portion of T.S. of C.T. under x 10

D = T.S. of C.T. under x 2

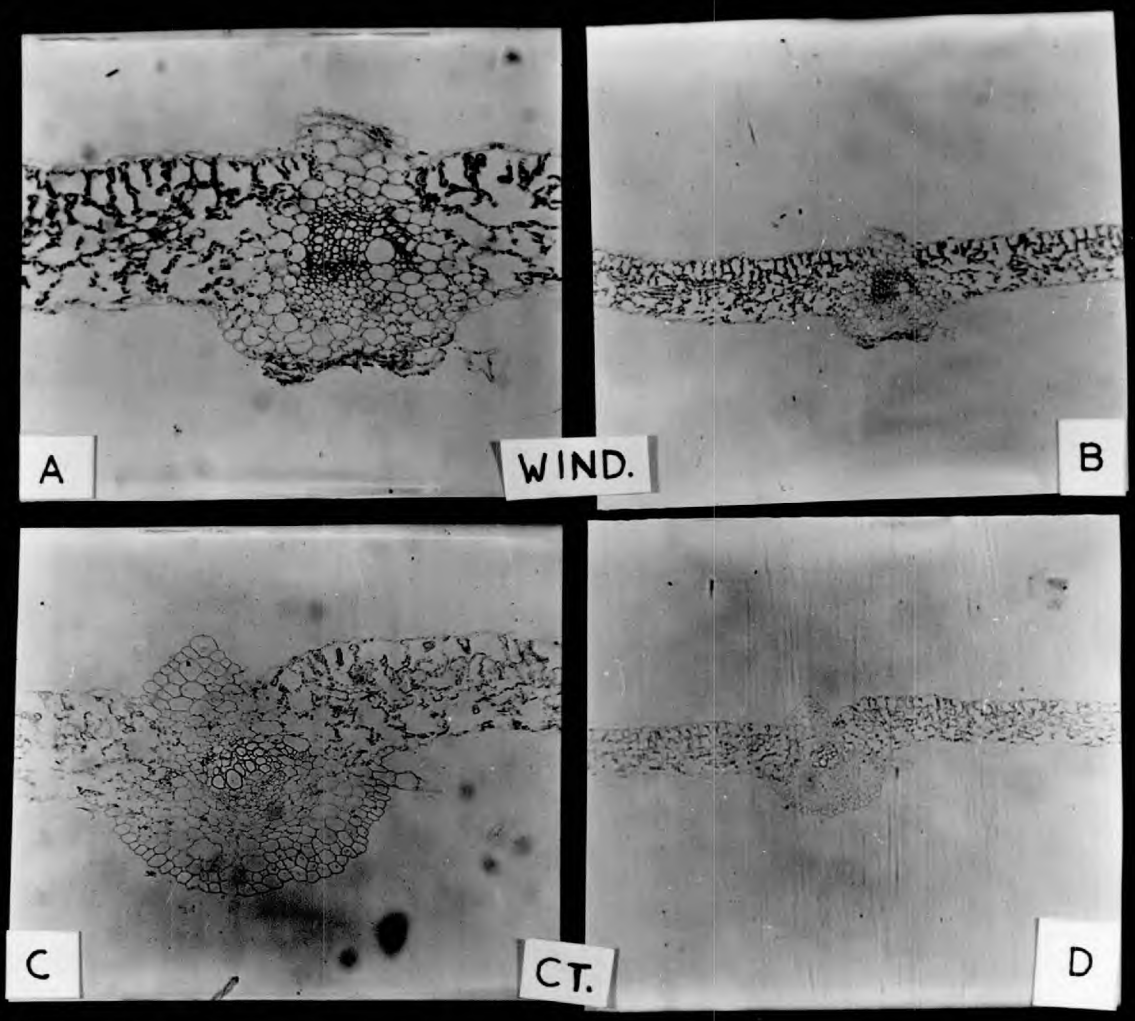


FIG. 22 T.S. LEAF

Fig. 22 Page 147

showing the transverse sections of leaf

A = Portion of T.S. of wind under x 10

B = T.S. of wind under x 2

C = Portion of T.S. of C.T. under x 10

D = T.S. of C.T. under x 2

Table 22 a

Anatomical features of the leaves of Controls and Wind Treated plants

Plant Type	No. of xylem vessels in central bundle	No. of xylem vessels over 14μ diameter	No. of Palisade layers	degree of compact-ness of spongy tissue
Control	28	17	1	less compact than wind
Wind	42	28	2	more compact than control

Table 22 b

Anatomical Features of the leaves of Controls and Wind Treated Plants

Plant Type	Mid rib x section area cm^2	Areas of xylem, phloem, sclerenchyma and cortex as % of mid rib x section area				cortex/ stele
		xylem cm^2	phloem cm^2	sclerenchyma cm^2	cortex cm^2	
Control	28.05	9.0	5.16	6.98	78.82	3.72
Wind	27.36	13.59	5.48	11.25	69.66	2.29

It can be seen from Table 22 that plants grown exposed to wind show a tendency to develop xeromorphic characters. It also shows that the number of vessels in the central bundle, the number of palisade layers, areas of xylem, phloem, sclerenchyma and the compactness of the spongy tissue are greater in the wind treated plants as compared to the controls. The number of vessels over 14 μ diameter is also greater in the wind tunnel plants as compared with the controls. The $\frac{\text{cortex}}{\text{stele}}$ ratio of the wind treated plants indicates a better development of the stele in the wind treated plants.

Table 23 shows the diameter of ten largest xylem vessels in the central bundle of mid rib of the controls and wind treated plants.

Table 23

Diameters of ten largest xylem vessels of the controls and the wind treated plants in μ.

CONTROLS	WIND
37.0 x 29.6	22.2 x 18.5
29.6 x 25.9	22.2 x 18.5
33.3 x 25.9	18.5 x 14.8
25.9 x 18.5	18.5 x 14.8
25.9 x 14.8	25.9 x 18.5
22.2 x 14.8	22.2 x 18.5
25.9 x 18.5	18.5 x 18.5
18.5 x 14.8	18.5 x 14.8
18.5 x 14.8	18.5 x 14.8
14.8 x 14.8	22.2 x 18.5

The Table 23 clearly indicates that the diameter of the xylem vessels in the wind treated plants is smaller as compared to the controls.

By comparing the anatomy of the stems and leaves of the Controls and wind treated plants it can be concluded that plants grown exposed to wind tend to develop xeromorphic characters.

Effect of wind on water balance.

The water balance of the plants grown in the wind tunnel for four weeks and the controls was studied. The relative turgidities of the controls and the wind treated plants were determined in the same way as mentioned on page 123.

The percentage increase in water content of the discs of controls and wind treated plants is shown in Table 24. It is graphically represented on page 153 Fig. 23.

Table 24

Percentage Increase in Water Content of the Discs of Controls and Wind treated plants.

TIME IN HOURS	CONTROL	WIND
3	109.2	216.3
6	113.2	251.9
9	117.7	261.3
12	121.7	268.0
24	132.2	271.3

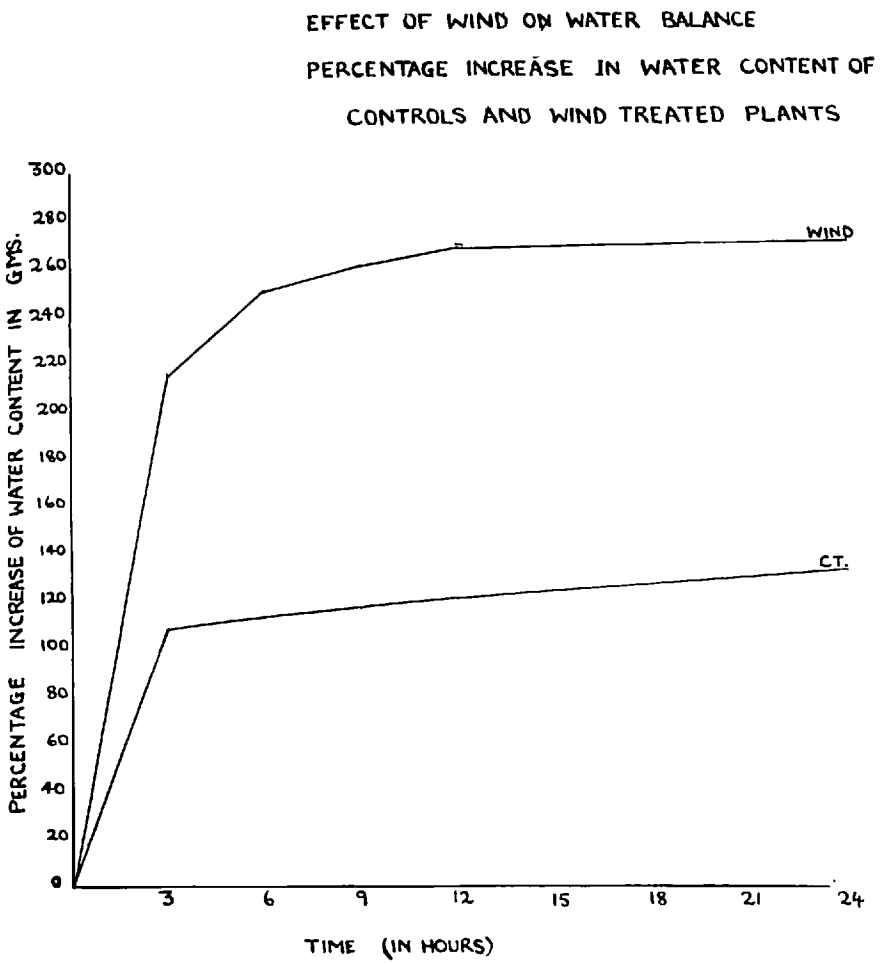


Fig. 23
The relative turgidity for Controls was calculated after 3 hrs. The relative turgidity for Wind treated plants was calculated after 6 hrs.

Table 24 shows the percentage increase in water content of 20 discs (1 cm. diameter) of controls and wind treated plants for 24 hrs. It can be seen that the water absorbed by the leaf discs of the wind treated plants at every reading was more than double compared to that absorbed by the leaf discs of the controls. The relative turgidity of the wind treated plants was found to be 86.1% as compared to the 88.8% of the controls. The measurements of relative turgidities of the controls and the wind treated plants were carried out at the same time.

Effect of C.C.C. on Growth, Morphology, Anatomy and Water Balance

This experiment was conducted so as to study the effect of C.C.C. applied as soil drench on the growth, morphology, anatomy and Water Balance. The seeds of Helianthus annuus var. 'Pole Star' were sown and transplanted as mentioned on page 38. The transplantation was done in 250 ml. beakers with holes. The seedlings were transplanted at a stage when cotyledons had expanded. Two days after transplantation aqueous solutions of C.C.C. at 0.1, 0.2, 0.3, 0.4 and 0.5% were applied to the soil. The details of C.C.C. treatments and watering are given in Chapter Material and Methods on page 42. The plants were grown at full field capacity throughout the experiment. The experiment was conducted in the greenhouse with natural daylength. A standard culture solution was given to the plants from time to time. The experiment was set on 7th June and the first harvest was done on 12th July. The succeeding harvests were done at weekly intervals. The morphological condition of the plants i.e. the Control and the C.C.C. treated plants is shown on page 156 Fig. 24. It can be seen that the

Fig. 24 showing the Control and the C.C.C. (soil drench) plants.

application of C.C.C. as soil drench causes a reduction in the height of the plants particularly at the higher concentrations, the height of the plants is very much reduced. The reduction in height is due to the reduction in the length of the internodes. The mean length of internodes of the Controls and the C.C.C. treated plants at successive harvests is shown in Table 25.

It can be seen from Table 25 (overleaf) that as the concentration of C.C.C. increases there is a constant reduction in the length of the internodes.

The leaf number was not significantly affected at lower concentrations but at higher concentrations it increased and the position of the leaves was also distrubed. As the formation of the leaves was not normal (opposite) but in some of the cases they appeared from irregular points on the stem forming a sort of canopy. The leaves of the C.C.C. treated plants were slightly thicker and etiolated at the higher concentrations of C.C.C. The leaf area of the C.C.C. treated plants at the time of harvests is graphically represented on page 159. Fig. 25. It can be seen from Fig. that the leaf

Table 25 Mean length of Internodes of the C.C.C. and the Controls (in cm.)

Harvests	Control		0.1 CCC		0.2 CCC		0.3 CCC		0.4 CCC		0.5 CCC	
	INTERNODE LENGTHS											
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
1	8.0	0.5	4.5	0.3	4.0	0.2	0.8	-	0.3	-	0.2	-
2	9.2	2.3	6.3	0.5	4.6	0.3	4.9	0.8	2.0	0.3	1.3	0.1
3	11.6	3.5	8.2	2.0	5.0	1.0	2.9	0.5	2.7	0.5	2.0	0.3
$\frac{\pm ts}{\sqrt{n}}$	±5.4	±1.08	±3.06	±1.13	±1.55	±0.49	±0.65	±0.22	±0.43	±0.15	±0.4	±0.11

EFFECT OF C.C.C. (SOIL DRENCH) ON GROWTH.

LEAF AREA AT SUCCESSIVE HARVESTS.

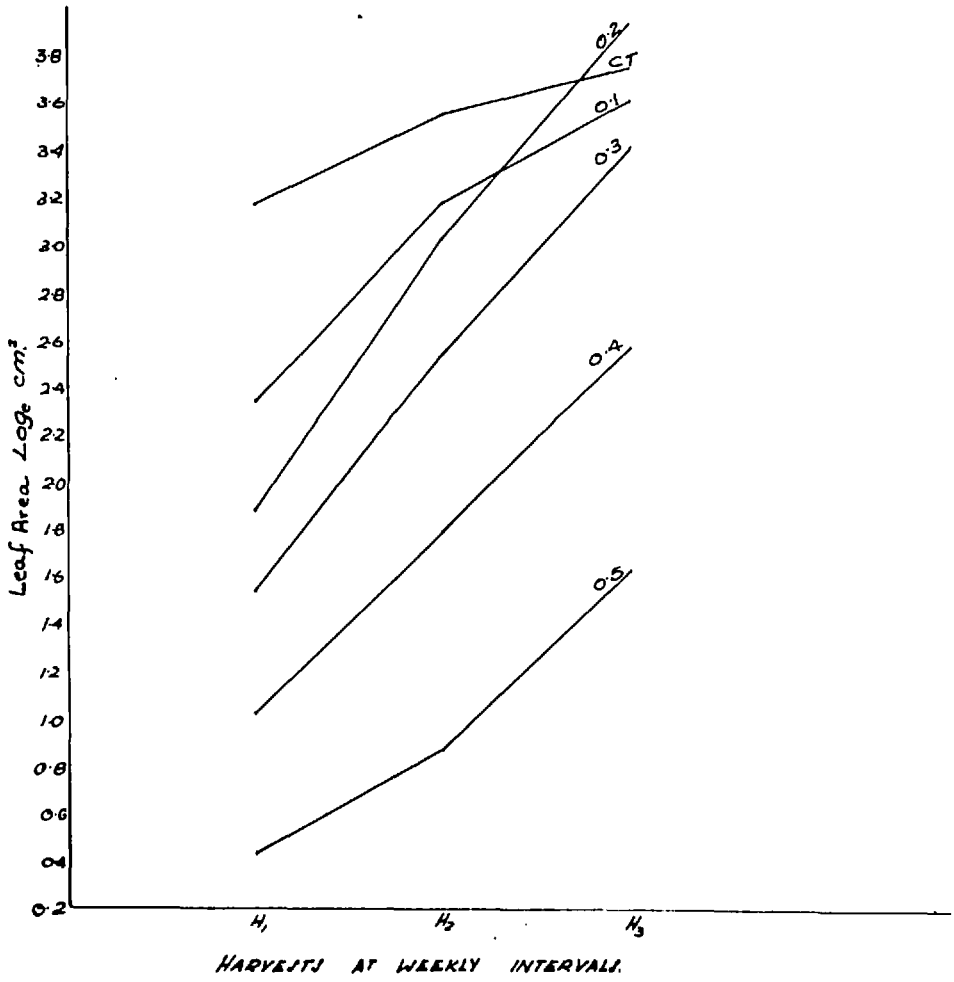


Fig. 25

	C T	0.1CCC	0.2CCC	0.3CCC	0.4CCC	0.5CCC
$\pm ts/\sqrt{n}$	±9.81	±5.61	±4.48	±6.09	±2.68	±2.39
d		2.11	3.44	4.65	12.65	16.86

area of control is more or less greater than the C.C.C. treated plants except at the 0.2 concentration the area of the C.C.C. treated plants is more than the Controls. However, the rate of increase of leaf area seems to be greater in the C.C.C. treated plants as compared to the controls particularly at the higher concentrations. With contrast to this the total dry weight of the controls was greater than the C.C.C. treated plants at all concentrations. The total dry weights of the plants seem to decrease with an increase in the concentration of C.C.C. The total dry weights of the controls and the C.C.C. treated plants at different harvests is given in Table 26 and graphically represented on page 161.

Fig. 26.

Table 26.

Mean Total Dry Weights of the Control and C.C.C. treated plants (in mgs.)

Harvest	CONTROL	0.1 CCC	0.2 CCC	0.3 CCC	0.4 CCC	0.5 CCC
1	417.4	325.8	193.2	119.8	111.3	81.2
2	609.2	506.6	317.6	184.0	137.6	108.6
3	782.2	641.4	486.4	287.4	186.2	139.4

EFFECT OF CCC SOIL DRENCH ON GROWTH.

TOTAL DRY WEIGHT AT SUCCESSIVE HARVESTS.

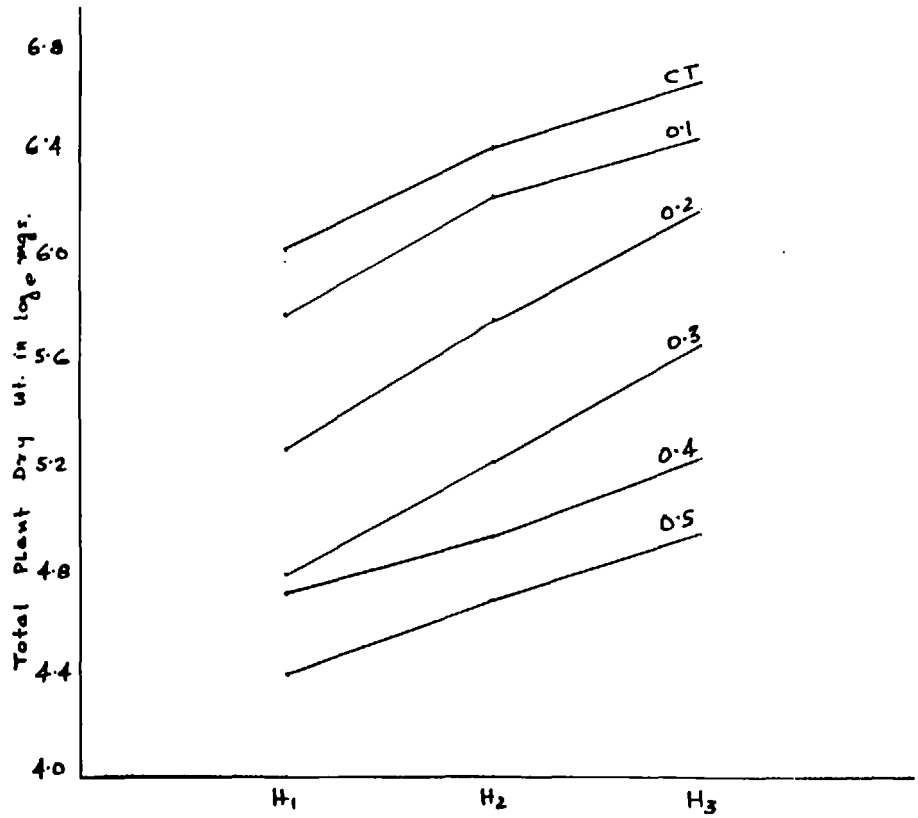


Fig. 26

	C T	0.1CCC	0.2CCC	0.3CCC	0.4CCC	0.5CCC
$\pm ts/\sqrt{n}$	±144.2	±109.42	±16.4	±23.25	±35.31	±39.9
d		3.35	8.8	14.59	17.32	18.52

The reduction in the total dry weight was chiefly due to the much reduced dry weight of the stem. However the leaf weight was less affected as compared to thestem.

Fig. 27 shows the $\frac{\text{Shoot}}{\text{Root}}$ ratios of the Controls and the C.C.C. treated plants. As is evident from Fig. 27 the $\frac{\text{Shoot}}{\text{Root}}$ ratios show that at lower concentrations of C.C.C. e.g. 0.1 and 0.2, more roots are produced as compared to shoots but at higher concentrations of C.C.C. more shoots are produced in proportion to roots.

The relative growth rates and the relative rates of leaf area increase of the Controls and the C.C.C. treated plants were calculated by means of Equation I and II (see pages 77, 78). These are given in Tables 27a, b.

Table 27a

Mean Relative Growth rates of Controls and C.C.C. treated plants mgs/mgs/week.

Harvest Interval	CONTROL	0.1 CCC	0.2 CCC	0.3 CCC	0.4 CCC	0.5 CCC
1 - 2	0.378	0.44	0.497	0.428	0.212	0.29
2 - 3	0.249	0.235	0.416	0.445	0.302	0.249

EFFECT OF C.C.C. (SOIL DRENCH) ON GROWTH

SHOOT / ROOT RATIO AT SUCCESSIVE HARVESTS.

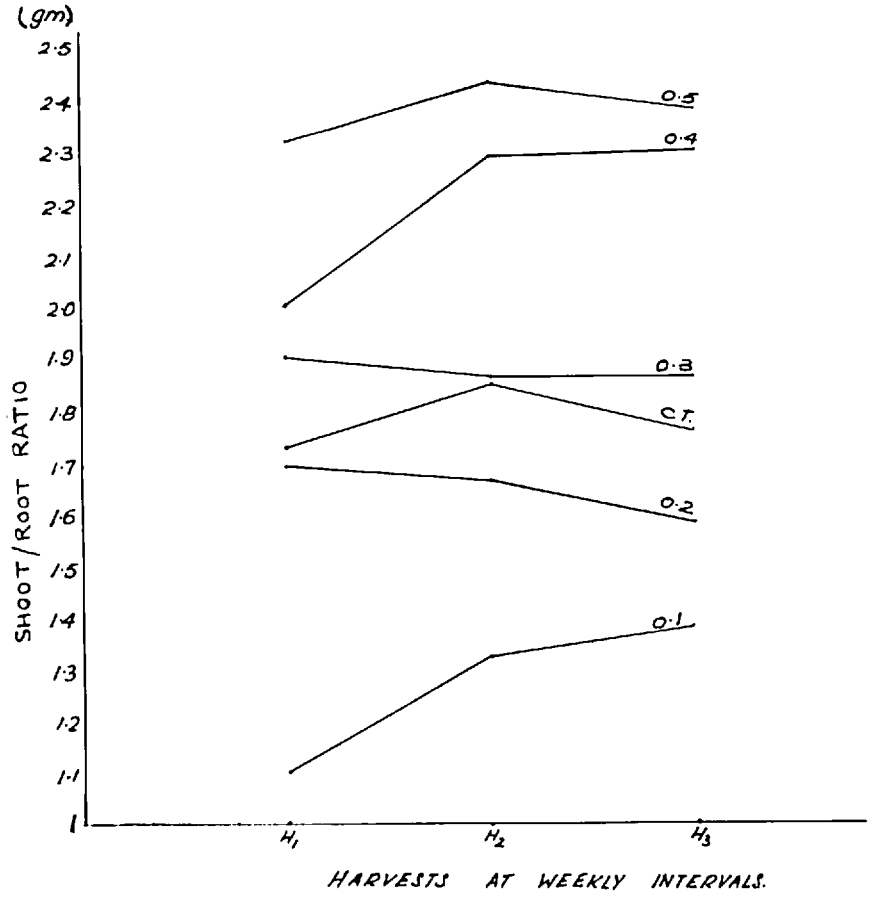


Fig. 27

	C T	0.1CCC	0.2CCC	0.3CCC	0.4CCC	0.5CCC
$\pm ts/\sqrt{n}$	±0.02	±0.26	±0.2	±0.38	±0.88	±0.45

Table 27b

Mean Relative Rates of leaf area increase of the Controls and C.C.C. treated plants $cm^2/cm^2/week$.

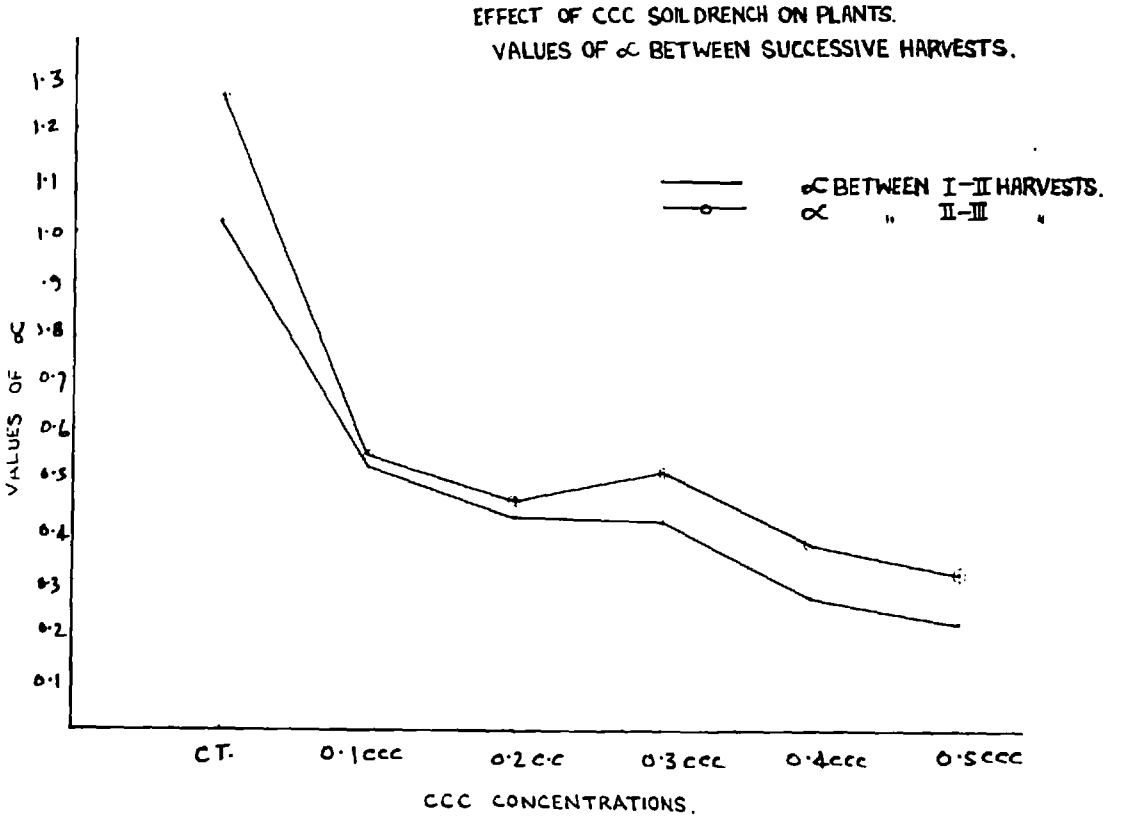
Harvest Interval	CONTROL	0.1 CCC	0.2 CCC	0.3 CCC	0.4 CCC	0.5 CCC
1 - 2	0.368	0.832	1.138	1.001	0.762	1.306
2 - 3	0.195	0.428	0.902	0.855	0.780	0.753

The ratio of mean relative growth rate to mean relative rate of leaf area increase i.e. $\alpha \left(\frac{\bar{R}}{RL}\right)$ was determined. This is given in Table 28 and is graphically represented on page.165Fig. 28.

Table 28.

Values of α between successive harvests of the Controls and C.C.C. treated plants

Harvest Interval	CONTROL	0.1 CCC	0.2 CCC	0.3 CCC	0.4 CCC	0.5 CCC
1 - 2	1.02	0.53	0.43	0.42	0.27	0.22
2 - 3	1.277	0.55	0.46	0.52	0.38	0.33


EFFECT OF CCC SOIL DRENCH ON PLANTS.
VALUES OF ∝ BETWEEN SUCCESSIVE HARVESTS.
∝ BETWEEN I–II HARVESTS.
∝ " II–III "
VALUES OF ∝
1·3
1·2
1·1
1·0
·9
·8
0·7
0·6
0·5
0·4
0·3
0·2
0·1
CT.
0·1ccc
0·2c·c
0·3ccc
0·4ccc
0·5ccc
CCC CONCENTRATIONS.

.Fig. 28.

It can be seen that the Controls have the higher values of α as compared to the C.C.C. treated plants in other words the rate of increase in leaf area was less among the controls as compared to the C.C.C. treated plants. Whereas, the values of α are very much less among the C.C.C. treated plants which shows that the leaf area increase was very high.

Effect of C.C.C. (Soil Drench) on Anatomy

The anatomy of the Controls and the plants with 0.2 and 0.4% C.C.C. applied as a soil drench was examined. Transverse sections of the stems, leaves and roots were cut by the same procedure as mentioned on page 46.

The following anatomical features of the stems, leaves and roots were studied.

Stem: The number of bundles was counted. The area of xylem, phloem, sclerenchyma and cortex was determined as mentioned on page 50 and expressed as a percentage of stem x section area. The cortex/stele ratio was determined as mentioned on page 50.

Leaf: The area of the xylem, phloem, sclerenchyma and cortex was determined and expressed as a percentage of mid rib cross section area. The cortex/stele ratio was determined as mentioned on page 50. The total number of xylem vessels and the number of vessels over 14μ diameter in the central bundle was counted. The diameter of the ten largest vessels was measured. The number of palisade layers and the degree of compactness of the spongy tissue was compared.

Root: The areas of the cross sections of the roots

were determined. The area of the vascular tissue internal to the pericycle and the area of the cortex was determined. These areas were expressed as a percentage of the root cross section area. The ratio of the cortex/vas. region was calculated. The magnifications are given on page 97.

The anatomical features of the stem of Controls and the C.C.C. plants at 0.2% and 0.4% concentrations are given in Table 29 and shown in Fig. 29 on page 170.

Table 29

Anatomical Features of the stem of controls and C.C.C. plants at 0.2 and 0.4% concentrations

Plant Type	stem x section area cm^2	Number of vascular bundles	Areas of xylem, phloem and sclerenchyma as % of stem x section area				cortex/ stele ratio
			xylem cm^2	phloem cm^2	Sclerenchyma cm^2	cortex cm^2	
Control	1438.4	12	0.432	0.455	0.479	34.6	2.13
0.2 CCC	1059.37	13	0.460	0.475	0.517	27.4	1.47
0.4 CCC	727.9	13	0.576	0.6	0.68	27.7	1.14

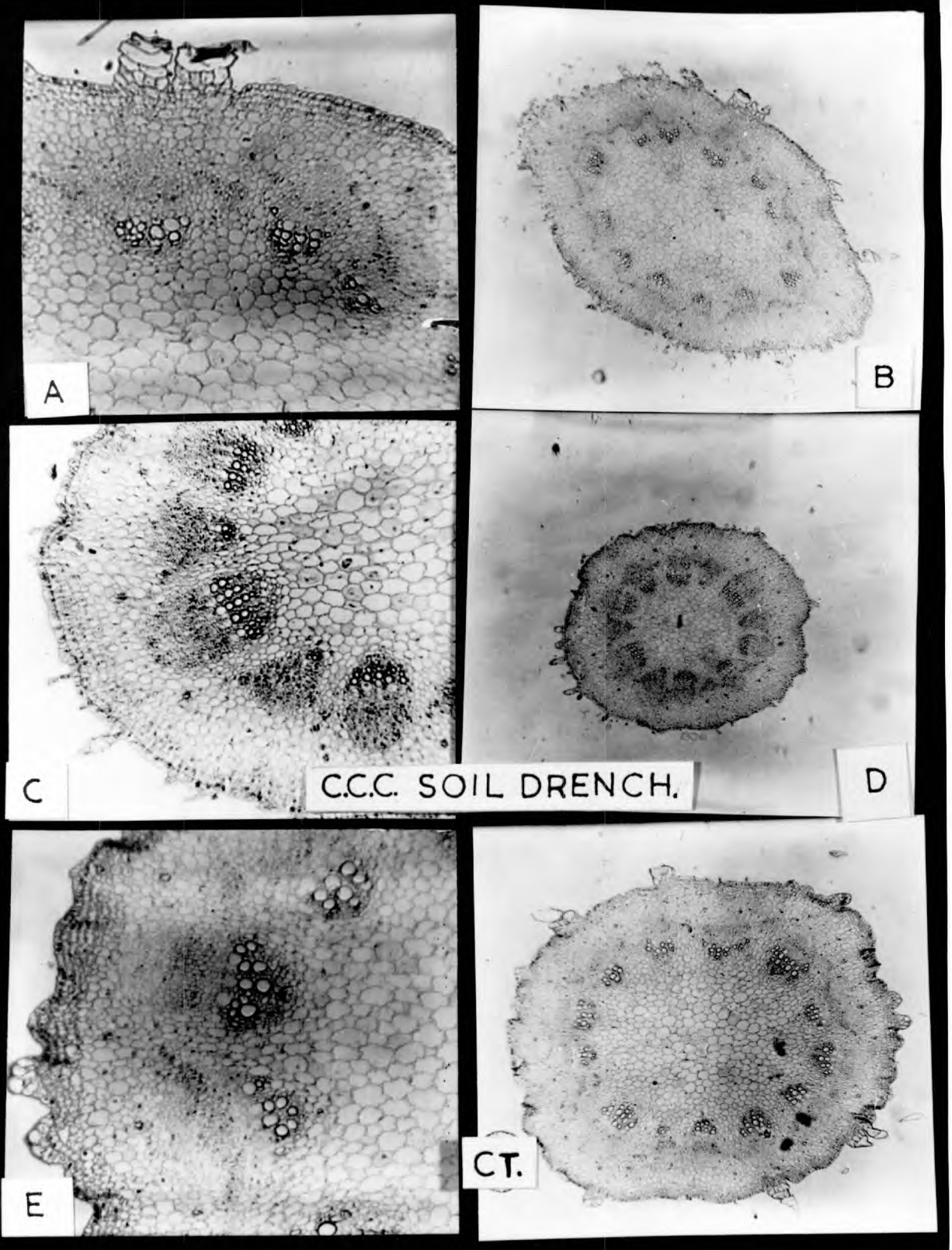


FIG. 29 T.S. STEM.

Fig. 29

showing the transverse section of stem

A = Portion of T.S. of 0.2C.C.C. under x 10

B = T.S. of 0.2C.C.C. under x 2

C = Portion of T.S. of 0.4 C.C.C. under x 10

D = T.S. of 0.4 C.C.C. under x 2

E = Portion of T.S. of C. T. under x 10

F = T.S. of C.T. under x 2

Table 29 shows the anatomical features of the stem of controls and plants treated with 0.2 and 0.4% of C.C.C. applied as soil drench. It seems quite evident from the Table 29 that the application of C.C.C. (soil drench) produces more xylem, phloem and sclerenchyma in relation to stem cross section area as compared to the Controls. It also indicates that the higher the concentration of C.C.C. the greater the area of the vascular bundles. The number of vascular bundles was also found to be 13 - also greater among the C.C.C. treated plants as compared to 12 in Controls.

The area of the cortex is greater among the controls as compared to C.C.C. plants, but the cortex/stele ratio of the C.C.C. treated plants was found to be much smaller than controls, indicating a greater development of the stele as compared to the cortex with contrast to the control plants where the cortex/stele ratio is higher.

Table 30 a

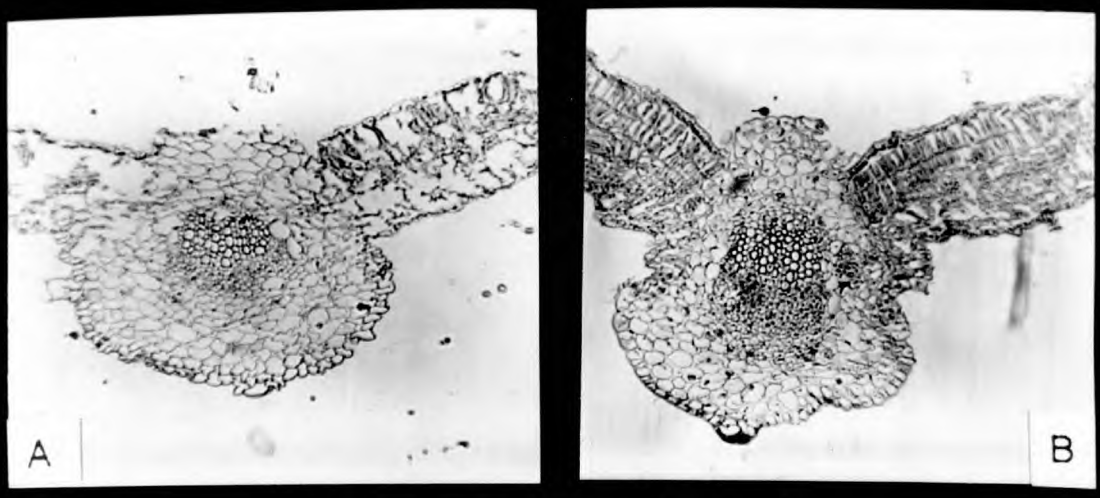
Anatomical features of the Leaves of Controls and C.C.C. treated plants

Plant Type	No. of vessels in central bundle	No. of xylem vessels over 14μ diameter	No. of Palisade layers	degree of compactness of spongy tissue
Control	60	38	1 - 2	not very compact
0.2 CCC	83	41	2 - 3	compact than control
0.4 CCC	101	48	3 - 4	compact than 0.2 CCC

Table 30b

Anatomical features of the Leaves of Controls and C.C.C. treated plants

Plant Type	Mid rib x section area cm^2	Areas of xylem, phloem, sclerenchyma and cortex as % of stem x section area				cortex/ stele
		xylem cm^2	phloem cm^2	sclerenchyma cm^2	cortex cm^2	
Control	83.6	7.89	5.98	6.1	16.67	4.01
0.2 CCC	55.5	9.9	9.0	8.6	15.3	2.62
0.4 CCC	56.0	11.6	10.7	10.0	18.1	2.08



C.C.C. SOIL DRENCH.

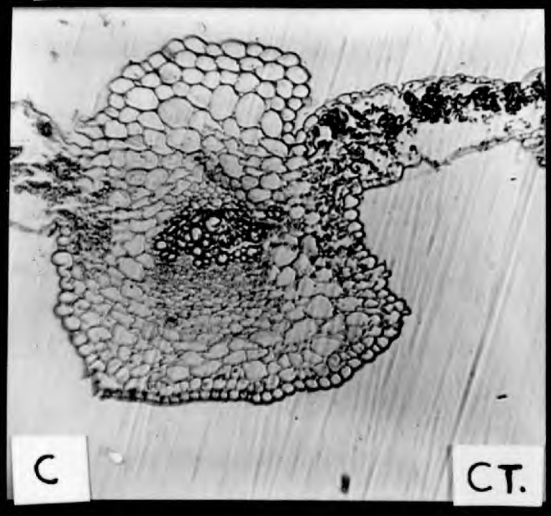


FIG. 30 T.S. LEAF

Fig. 30

showing the transverse sections of leaf

A = Portion of 0.2 C.C.C. under x 10

B = Portion of 0.4 C.C.C. under x 10

C = Portion of C.T. under x 10

Fig. 30 & tables 30 a and b show the anatomical features of the leaves of the controls and the C.C.C. plants at 0.2 and 0.4% concentrations.

Table 30 b shows that the area of the xylem, phloem and sclerenchyma in the central bundle have increased as compared to controls, as a result of C.C.C. application. As seen in the stem the relative areas of xylem, phloem and sclerenchyma increase as the concentration of C.C.C. increases. The number of vessels in the central bundle of the mid rib was also increased with increasing concentrations of C.C.C. The number of palisade layers and the degree of compactness of the spongy tissue also increases with C.C.C. applications. The number of vessels over 14μ diameter was also greater in C.C.C. soil drench plants. As in the stem the cortex/stele ratio of the C.C.C. treated plants is smaller as compared to the controls.

Table 31 shows the diameter of ten largest xylem vessels of the Controls and the C.C.C. plants.

Table 31

Diameter of ten largest xylem vessels in the vascular bundle of the controls and C.C.C. plants (in μ).

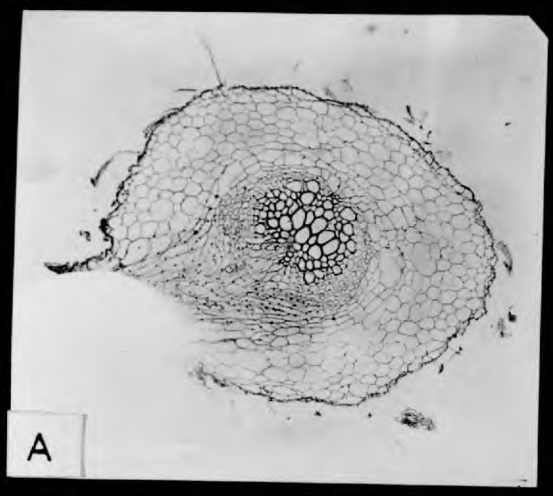
CONTROLS	0.2 C.C.C.	0.4 C.C.C.
33.3 x 25.9	25.9 x 22.2	18.5 x 18.5
29.6 x 25.9	18.5 x 18.5	25.9 x 18.5
25.9 x 18.5	25.9 x 22.2	22.2 x 18.5
25.9 x 18.5	22.2 x 18.5	25.9 x 25.9
37.0 x 25.9	22.2 x 18.5	18.5 x 18.5
40.7 x 29.6	25.9 x 14.8	22.2 x 18.5
33.3 x 25.9	22.2 x 22.2	22.2 x 18.5
29.6 x 29.6	25.9 x 18.5	18.5 x 18.5
29.6 x 22.2	22.2 x 18.5	18.5 x 18.5
25.9 x 18.5	25.9 x 18.5	22.2 x 18.5

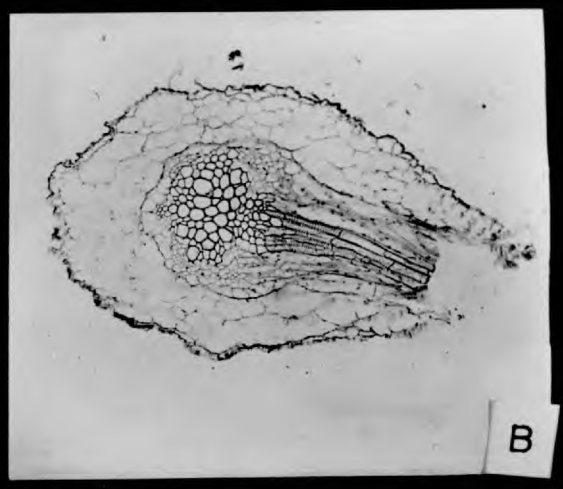
Table 31 shows that the diameter of the vessels is bigger in the Controls as compared to the C.C.C. plants. It also shows that with the application of C.C.C. as soil drench the vessels become smaller as the concentration of C.C.C. increases. The number of vessels, on the other hand, increasesas the size decreases.

Table 32 showing anatomical features of the roots of Control and C.C.C. plants.

Plant Type	Areas of vas. and cortical region as % of root x section area		$\frac{\text{cortex}}{\text{vas.reg.}}$ ratio	Total root x section area cm^2
	vas.region cm^2	cortical reg. cm^2		
Control	26.8	73.1	2.7	4.1
0.2 CCC	29.0	70.9	2.4	6.54
0.4 CCC	34.4	65.5	1.9	4.35

It seems evident from Table 32 that the area of vascular region in the roots of C.C.C. plants is greater as compared to the Controls. With increasing concentration of C.C.C. (soil drench) the area of the vascular region increases and the area of the cortex decreases. That is to say, the ratio of





C.C.C. SOIL DRENCH.

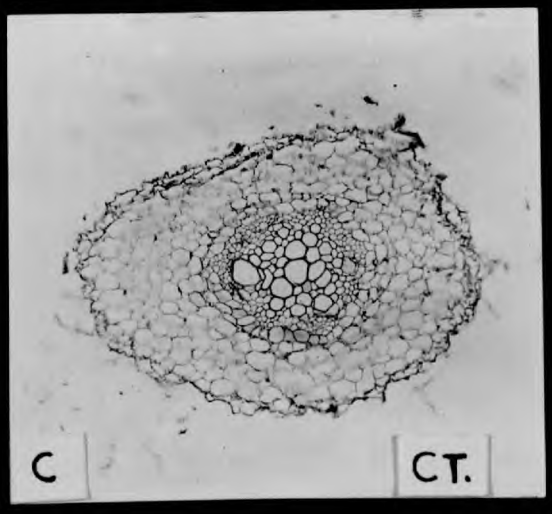


FIG. 31 T.S. ROOT

Fig. 31 Page 178

showing the transverse sections of root.

A = T. S. of 0.2 C.C.C.

B = T.S. of 0.4 C.C.C.

C = T.S. of C.T.

$\frac{\text{cortex}}{\text{vas.reg.}}$ decreases with an increase in the concentration of C.C.C. applied as soil drench. By studying the anatomical features of the stems, leaves and roots of the Controls and the C.C.C. plants the following conclusions can be drawn. In the vascular bundles of the stem and leaf mid rib the areas of the xylem, phloem and sclerenchyma are increased with an increasing concentration of C.C.C. The application of C.C.C. tends to induce xeromorphic characters in the leaves by developing greater number of xylem vessels, palisade layers and by increasing the degree of compactness of the spongy tissue. However, with increasing concentrations of C.C.C. the diameter of the vessels becomes smaller. An increase in the vascular region of the roots was also observed among the C.C.C. treated plants as compared to the Controls.

Effect of C.C.C. on water balance

The water balance of the C.C.C. treated plants with C.C.C. applied as soil drench and Controls was studied. The technique used for the determination of relative turgidities was the same as described on page 44.

The percentage increase in water content of the discs of C.C.C. and Controls is shown in Table 33.

Table 33

Percentage increase in water content of the discs of controls and C.C.C. treated plants

	TIME IN HOURS				
	$2\frac{1}{2}$ hr.	5 hr.	$7\frac{1}{2}$ hr.	10 hr.	25 hr.
Control	38.7	54.5	61.7	66.2	74.7
.1 CCC	64.6	84.0	94.4	102.6	119.4
.2 CCC	111.0	144.9	161.4	172.4	200.0
.3 CCC	124.3	161.7	183.9	200.8	254.3
.4 CCC	136.6	176.6	201.6	220.0	283.3

It can be clearly seen from Table 33 and Fig. 33 th the rate of uptake of water by the discs increases with an increase in the concentration of the C.C.C. The absorption of water is less in the leaf discs of the Controls as compared with the leaf discs of the C.C.C. treated plants. The water absorbed by the leaf discs of C.C.C. treated plants at 0.4 concentration of C.C.C. after 25 hrs., was about four times more as compared to the Controls, and more than twice as compared to the 0.1 C.C.C. The increased absorption of water at higher concentration is reflected by the relative turgidities of these plants.

The relative turgidities of the controls and C.C.C. treated plants are given in Table 34.

Table 34.

	Control	0.1	0.2	0.3	0.4
R.T.	94.2	89.6	85.3	83.9	81.0

It can be seen from Table 34 that the relative turgidity of the Controls is higher as compared to the C.C.C. treated plants. The increase in the concentration of the C.C.C. causes a successive decrease in the relative turgidities of the plants.

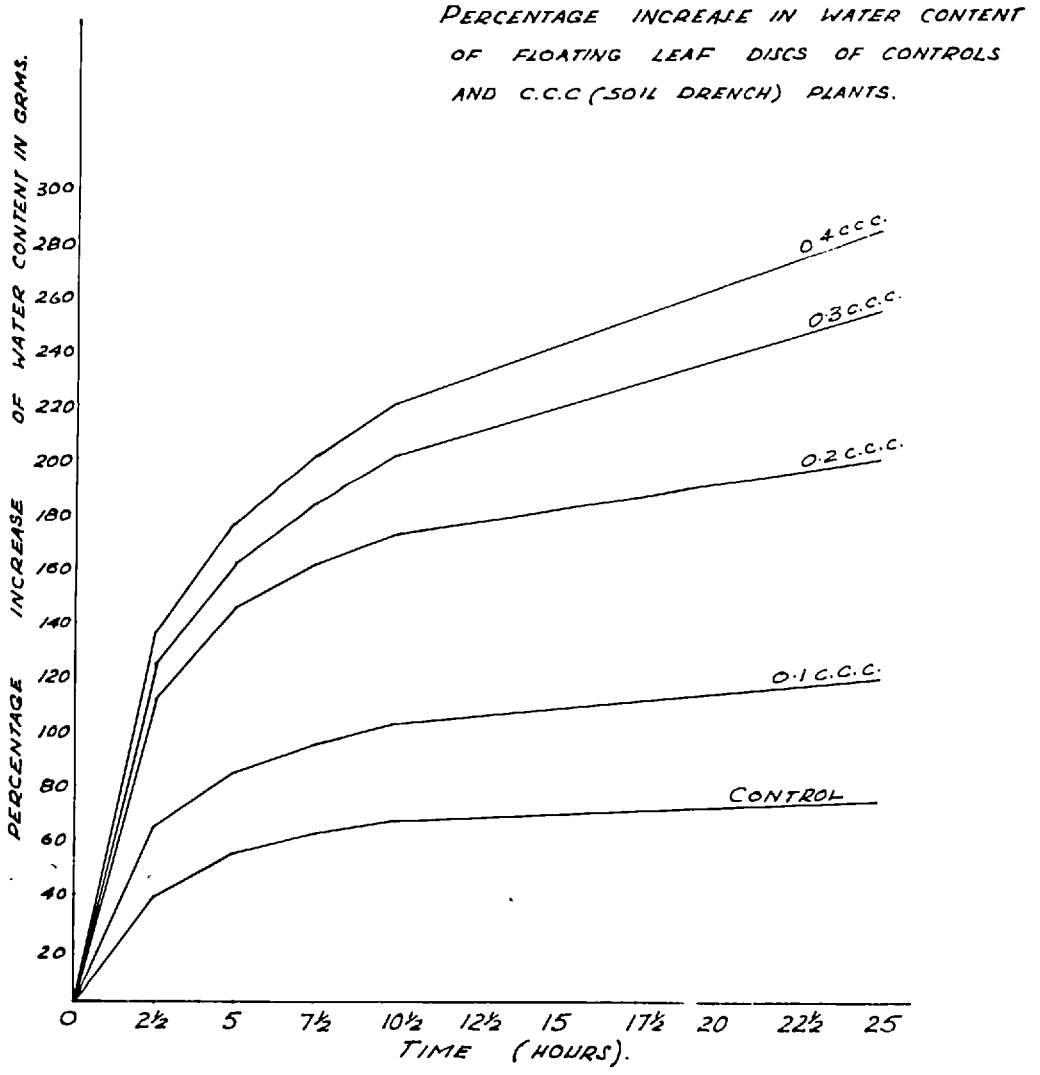


Fig. 33

The relative turgidity for Controls was calculated after $7\frac{1}{2}$ hrs.
" " " " 0.1 CCC " " " $10\frac{1}{2}$ hrs.
" " " " 0.2 " " " " $10\frac{1}{2}$ hrs.
" " " " 0.3 " " " " $10\frac{1}{2}$ hrs.
" " " " 0.4 " " " " $10\frac{1}{2}$ hrs.

Effect of Soil Drought on C.C.C. treated Plants

This experiment was done in order to compare the drought tolerance power of the C.C.C. treated plants in comparison to the Controls. Seeds were sown and transplanted as mentioned in Chapter II on Page 38 . Transplantation was done in 250 ml. beakers without holes at the bottom. The soil (mixture of sand and peat) used in the beakers was of equal quantity in each beaker. The weight of the beakers was also determined. A single plant was transplanted in each beaker. The plants were divided into 4 sets. One set was untreated (Controls), second set was sprayed once a week with aqueous solution of C.C.C., third set was sprayed with C.C.C. twice a week and the fourth set received 0.3% C.C.C. as soil drench. For the concentration of C.C.C. and method of its application see pages 41 &.42. The plants were grown at 100% soil moisture regime (see page 41) by weighing the beakers on alternate days and keeping the weight constant. The plants were kept at 100% soil moisture regime until three pairs of leaves had appeared. After this the supply of water was stopped until the beakers reached predetermined weights in

all the four sets of plants. These weights corresponded to the soil moisture regimes maintained during the latter part of the experiment. The soil moisture regimes to which the plants were kept after drying were 30%, 15% and 10%. But as it will be shown later on, that as soon as the supply of the water was stopped the plants started wilting especially the Controls and the C.C.C. soil drench plants. Whilst the C.C.C. treated plants responded in a better way by growing normally for a longer period than the Controls and the C.C.C. soil drench plants. The condition of the plants noted at different times is as follows:-

Soil Drench Plants

10% died within 3 days after last watering

15% " " 7 " " " "

30% " " 10 " " " "

Controls

10% died within 7 days after last watering

15% " " 10 " " " "

30% " " 12 " " " "

C.C.C. 1 spray

10% died within 7 days after last watering

15% " " 14 " " " "

30% some still normal and some in wilting condition

C.C.C. 2 spray

10% died within 10 days after last watering

15% " " 14 days (but some still in wilting condition)

30% most of the plants seemed to be normal.

From the above mentioned observations it can be said that the C.C.C. treated plants (sprayed) in conditions of drought are more resistant than the Controls and the C.C.C. soil drench plants. As it can be seen that the 30%, 15% and 10% soil moisture regime plants died within 10 days in soil drench C.C.C. plants while among the controls they survived for 12 days. In the C.C.C. (sprayed) plants the plants still behaved normally up to 14 days when few plants had started showing signs of wilting. The condition of the plants seem to be slightly better among the 2 sprayed plants as compared to those sprayed once a week.

Effect of Wind Exposure on C.C.C. treated Plants

The effect of exposure to wind on the relative turgidities of the C.C.C. treated plants and the controls was studied. Seeds were sown and transplanted in 250 ml. beakers as described on page 38. The plants were divided into three sets, one set was kept as controls, the second set was sprayed with C.C.C. once a week and the third set was sprayed with C.C.C. twice a week. All the three sets of plants were grown in the greenhouse and kept at full field capacity throughout the period of the experiment. Twenty four days after transplantation the plants of the three sets were exposed to wind for different time intervals and their relative turgidities were determined together with the plants which were not exposed to the wind. The relative turgidities were determined of the following wind treatments.

Controls

i) No wind treatment

ii) Exposed to wind for $\frac{1}{4}$ hr.

) " " " " $\frac{1}{2}$ hr.

C.C.C. plants (sprayed once a week)

i) No wind treatment

ii) Exposed to wind for $\frac{1}{2}$ hr.

iii) " " " " 1 hr.

C.C.C. plants (sprayed twice a week)

i) No wind treatment

ii) Exposed to wind for $\frac{1}{2}$ hr.

iii) " " " " 1 hr.

The plants of the three sets were exposed to wind as mentioned above and their relative turgidities were determined in the same way as mentioned for previous experiments (see page 44).

The absorption of water by the leaf discs of the Controls, 1 spray C.C.C. plants and 2 spray C.C.C. plants and their relative turgidities with and without wind treatments are given in Tables 35 a, b and c.

Table 35a

Percentage Increase of Water Content in Controls (in gms.)

Wind Treatment	TIME IN HOURS					Relative Turgidity
	3 hr.	6 hr.	9 hr.	12 hr.	24 hr.	
No wind Exposure	229.3	353.9	393.0	405.0	441.0	73.6
¼hr. wind Exposure	282.0	364.0	405.0	442.0	515.0	68.4
½hr. wind Exposure	217.8	332.6	406.9	464.9	531.8	66.3

Table 35b

Percentage Increase of Water Content in 1 spray C.C.C. plants (in gms.)

Wind Treatment	TIME IN HOURS					Relative Turgidity
	3 hr.	6 hr.	9 hr.	12 hr.	24 hr.	
No wind Exposure	192.2	218.1	228.1	237.3	260.9	80.9
½hr. wind Exposure	209.3	286.1	308.7	324.7	357.8	77.2
1hr. wind Exposure	204.6	291.4	360.9	398.9	442.0	76.8

Table 35 c

Percentage Increase of Water Content in 2 spray C.C.C. plants (in gms.)

Wind Treatment	TIME IN HOURS					Relative Turgidity
	3 hr.	6 hr.	9 hr.	12 hr.	24 hr.	
No wind Exposure	103.5	131.6	152.6	173.9	221.9	86.8
½hr. wind Exposure	112.3	163.8	175.7	184.8	209.4	83.2
1hr. wind Exposure	246.0	276.6	296.4	313.9	349.6	78.3

It can be seen from Tables 35a, b, and c that the absorption of water by the leaf discs increases with the time of exposure to wind, in all three sets of plants. However, after exposure to wind there was a much increased absorption of water by the leaf discs of the Controls as compared to the C.C.C. treated plants, especially the plants receiving 2 sprays of C.C.C. in a week. (See Figs. 34, 35 & 36).

The relative turgidities of these plants were determined as mentioned on page 44 . The relative turgidities of the three sets of plants exposed to wind for different time intervals are given in

Tables 35 a, b and c. It can be seen from the Tables 35 a, b and c that the relative turgidities of the Controls and the C.C.C. treated plants decrease with an increase in the time of exposure to wind. The decrease in relative turgidity is more evident among the controls as compared to the C.C.C. treated plants and the two spray C.C.C. plants show a smaller decrease compared to the one spray.

Exposure to wind upsets the water balance of the leaves in that the rate of loss is greater than the rate of uptake. In the C.C.C. treated plants there is probably a greater rate of uptake compared to the controls and at the same time a smaller rate of loss. These two factors in combination account for the fact that the relative turgidity is less affected by wind over time in the C.C.C. treated plants.

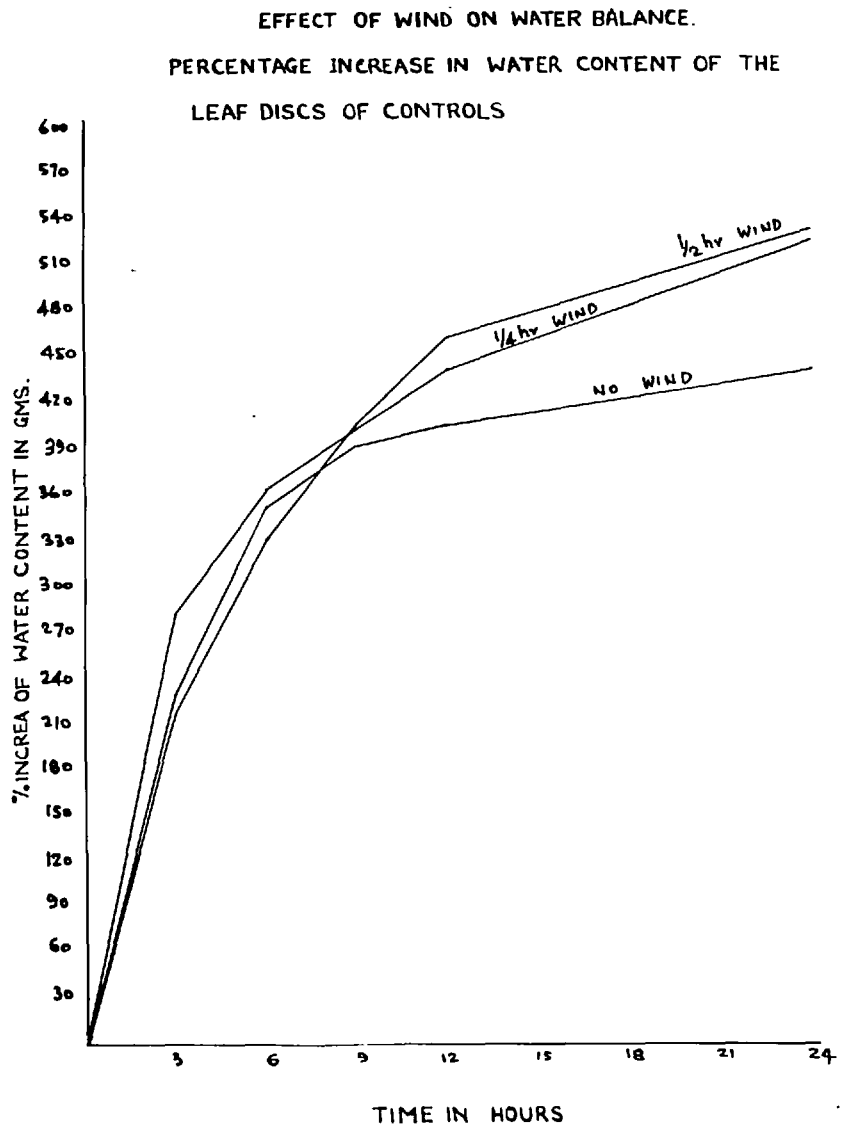


Fig. 34
The relative turgidity of Controls was calculated after 9 hrs.
" " " " " with $\frac{1}{4}$ hr. wind treatment was calculated after 12 hrs.
The relative turgidity of Controls with $\frac{1}{2}$ hr. wind treatment was calculated after 12 hrs.

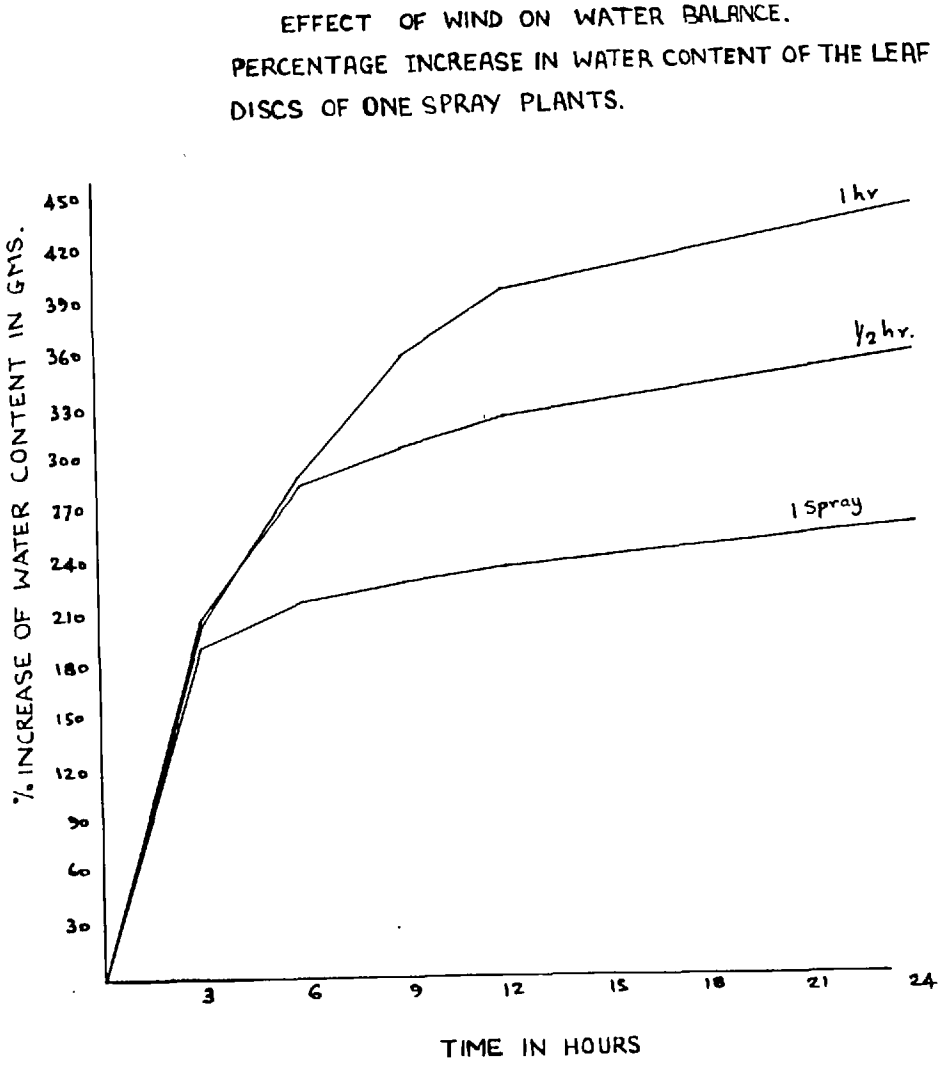


Fig. 35
The relative turgidity for 1 spray (no wind) was calculated after 6 hrs. The relative turgidity for 1 spray with $\frac{1}{2}$ hr. wind treatment was calculated after 6 hrs. The relative turgidity for 1 spray with 1 hr. wind treatment was calculated after 9 hrs.

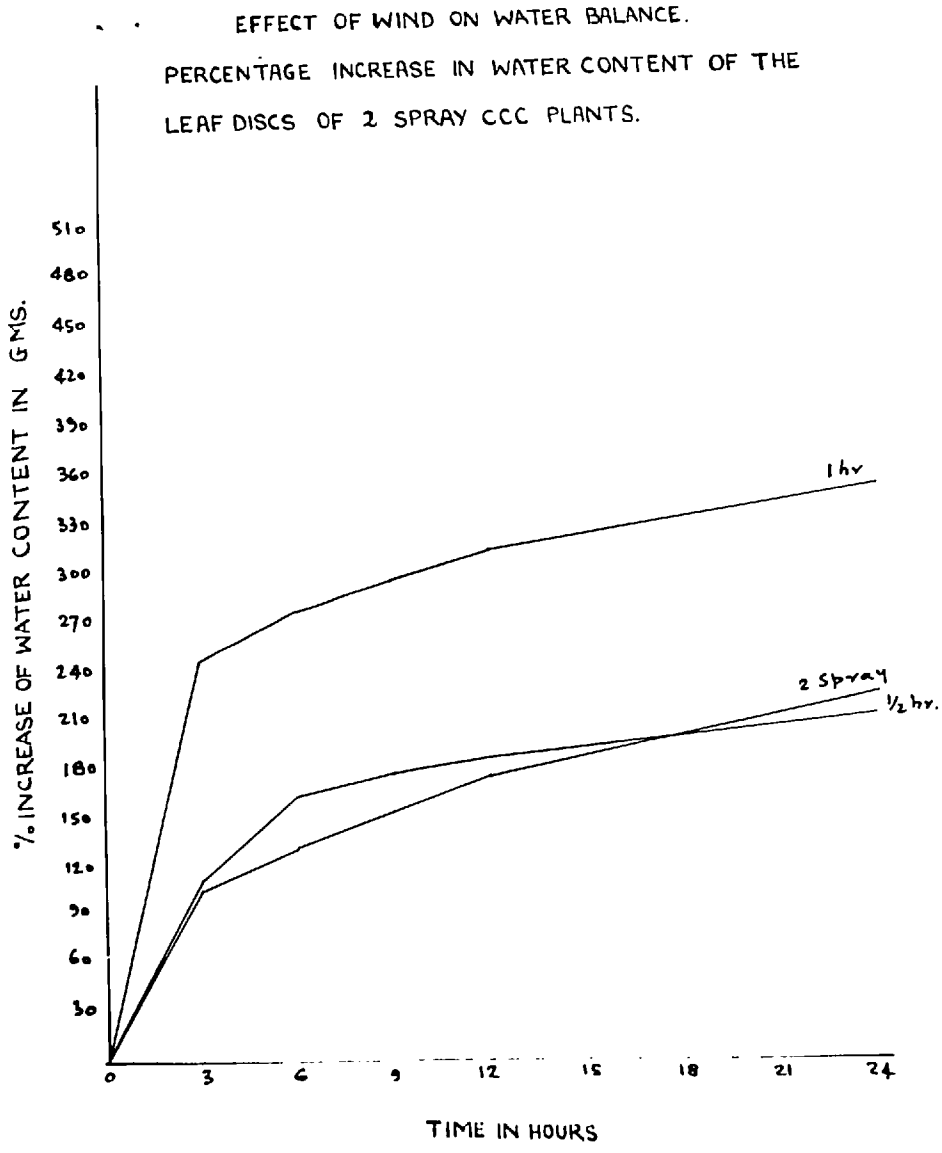


Fig. 36
The relative turgidity of 2 spray C.C.C. plants was calculated after 6 hrs. The relative turgidity of the 2 spray C.C.C. plants with $\frac{1}{2}$ hr. wind treatment was calculated after 3 hrs. The relative turgidity of the 2 spray C.C.C. plants with 1 hr. wind treatment was calculated after 3 hrs.

DISCUSSION

The effect of drought on plants presents a complex problem to which plants respond with many protective adaptations. Drought resistance was first reviewed in comprehensive manner by Maximov (1935). Recently Levitt (1951, 1956), Richards and Wadleigh (1952), Kursanov (1956) and Iljin (1957) have made useful contributions. Detailed discussion of this subject is presented in the reviews of Richards and Wadleigh (loc. cit.), Russel (1959), Stocker (1960)& Henckel (1964). During drought the plant suffers from dehydration of its cells and tissues as well as from considerable overheating. Hence the ability of a plant to resist drought depends upon its capacity to withstand dehydration and overheating. It has been generally observed that drought affects plants in several ways, various ecological groups or even individual species show different types of response. There is no universal mechanism of adaptation of plants to drought but it has been generally observed that all drought resistant plants have much in common. In order to understand the problem, it is necessary to study the process of adaptations to drought.

Since drought resistance is an important process affecting plants of many regions it is of importance to investigate the nature of higher or lower drought resistance. It is also important to devise methods of drought-hardening. Drought resistance is defined by Henckel (1964) as "Drought-resistant plants are those which in the process of ontogenesis are able to adapt to the effect of drought and which can normally grow, develop and reproduce under drought conditions because of a number of properties acquired in the process of evolution under the influence of environmental conditions and natural selection." This definition shows that such changes when brought about under experimental conditions can produce both drought resistant and high yielding plants.

According to the reviews of Richards and Wadleigh; Russel (loc. cit.) drought injury is believed to result from metabolic and mechanical effects that accompany tissue hydration and overheating. Structural changes in the protoplasm resulting from mechanical stress induced by the loss of water are believed to be a major cause of drought injury (see Stocker, 1960). Drought hardy plants usually have smaller cells when desiccated, these suffer a much less proportionate reduction in volume and are thus less

liable to damage. Although there are variations between species, it is generally accepted that increased osmotic values are characteristic of plants having superior drought-hardiness. Plants show large differences in drought tolerance. Such differences reflect the ability of the plant (1) to avoid internal water stress by effectively balancing water intake and water loss or (2) to adjust physiologically to such stress.

As described in Chapter 1 (Introdution) on page 18 numerous workers have shown that water deficiency accelerates the differentiation of mechanical elements and tissues as well as xylem and causes a decrease in cell size. It has also bee shown (see page 18) that plants in response to drought show anatomical and morphological modifications and acquire xeromorphic characters, including a more extensive and denser network of veins and ribs, smaller epidermal and stomatal cells. The number of stomata per unit leaf area is also greater.

The present investigation was a study of the changes in growth behaviour, differentiation, anatomy and morphology resulting from changes in leaf water balance. The effects of drought created by increased transpiration (plants exposed to wind) and inadequate absorption (decreasing soil moisture regime) were studied in the case of Gibberellic acid, C.C.C. treated and control (untreated) plants of Helianthus annuus. These are summarised and discussed below. From the study of wind and decreasing soil moisture regime on the anatomy and growth it was clear that in the process of differentiation, control (conditioned and determined by external environment) was exercised in producing the ultimate plant structure. Three sets of plants were grown at decreasing soil moisture regimes (100%, 55%, 30%, 15% and 10%). One set was sprayed with an aqueous solution of 1000 p.p.m. C.C.C. once a week, the second set was sprayed with an aqueous solution of 100 p.p.m. gibberellic acid once a week and the third set was treated as controls.

In understanding the pattern and mode of growth of the plants the usual parameters of growth analyses were employed. These parameters provided indices for the general growth of the plants in terms

of the total dry weight gain and relative growth rate (RGR). However, in such studies where the behaviour of the plants in response to C.C.C. and gibberellic acid at varying moisture regimes is involved, morphogenetic behaviour, differentiation and yield had to be taken into consideration and for this the value of α as used by Whitehead and Myerscough (1962) appears to be a useful parameter. This ratio has important attributes which indicate the potentiality of plant as a morphogenetic entity. The important observations made with respect to RGR and dry weight at successive harvests were that at decreasing soil moisture regime in both the treatments and controls, there was a decrease in values of RGR. A comparative account of all the three sets of plants indicates that at all moisture regimes the performance of the C.C.C. treated plants was better than the Gibberellic acid treated and controls (See Fig.5p.84). It can be seen that with the decreasing moisture regime C.C.C. exercised a marked effect on the plant as a unit in terms of dry weight gain.

Several experiments have been carried out to test the effects of C.C.C. on 'dwarfing' or 'shaping' of plants by application of suitable concentrations of C.C.C. used as soil drench or foliar spray; for details

see Tolbert (1960), Wittwer and Tolbert (1960); Halevy and Kessler (1963); Lockhart (1962); Stuart (1962); Kofranek, Sciaroni, Byrne (1962), Mayr and Presoly (1961). As a matter of fact the present experiments in design and purpose differ from those of the earlier workers. Interaction between concentration of C.C.C. and increasing moisture stress is important from several points of view.

Dwarfing of plants may have important applications in agriculture or horticulture where 'shaping' of plants or control of lodging is the chief aim. The current experiments have indicated that the efficiency of plant in terms of dry weight gain and drought resistance is markedly increased. This discloses important principles on the behaviour of plants in terms of their general performance and water balance economy.

In the case of gibberellic treated plants as can be seen from Figs. 1, 2 & 3 the behaviour of plants is different from the C.C.C. treated plants. In general aspects the plants in size and general morphology look much bigger.

The three sets of plants referred to above were also assessed in terms of α using the same primary data. This as a ratio has important implications

as explained above. It could be seen that at all soil moisture regimes the values of α for C.C.C. treated plants were greater than those for gibberellic treated plants and controls. This means that C.C.C. exercises an important influence on plants not only in terms of dry weight gain but it also confers certain advantageous adaptations to the plants leading to greater gain in dry weight. It can also be inferred that the higher values of α indicate that photosynthetic capacity of the leaf per unit area is markedly increased because of the greater leaf thickness. This acquisition accompanied with balanced morphogenesis confers several adaptative and survival advantages to the plants. That it also has a far reaching effect in producing anatomical changes can be seen from Chapter III on page 95.

It can be seen from Table 54 (see appendix) for the specific leaf area that this is a useful parameter for studying the comparative anatomy and to some extent morphogenetic condition of the plant (see Evans and Hughes, 1961). Higher value of this parameter (referring only to the dry weight) indicates leaf area per unit weight. Its value at varying soil moisture regimes for C.C.C. treated plants is lower than that of control and gibberellic treated plants at the

corresponding soil moisture regimes.

So far the Shoot/Root ratio is concerned it provides useful values for comparing the relative proportion by weight of shoot. This value is lowest for all soil moisture regimes for C.C.C. treated plants (See Fig. 6 on page 85). This indicates that root production as compared to the shoot is more in this treatment. This has got a special significance when dealing with the comparative study of the effect of C.C.C. against increasing moisture stress. The values of Shoot/Root ratios of controls and gibberellic treated plants can be seen from Fig. 6 on page 85.

It can be seen that the next increasing value is that of the controls while the gibberellic treated plants have the highest values for Shoot/Root ratios.

An experiment was carried out to compare the effect of C.C.C. applied as foliar spray to that applied as soil drench. The concentrations used for the application of C.C.C. as soil drench were 0.1, 0.2, 0.3, 0.4, 0.5%. At all concentrations the value of α was significantly smaller than that of foliar spray or control, see Fig. 28 Table 28. It was clear from this that the effects of C.C.C. applied as soil drench

were different from that applied as foliar spray. As pointed out earlier, the values of α in the foliar spray (at 100% S.M.R.) range from (1.04 - 2.86), whereas that for soil drench range from 0.53 - 0.55, 0.43 - 0.46, 0.42 - 0.52, 0.27 - 0.38, 0.22 - 0.33 at 0.1, 0.2, 0.3, 0.4, 0.5 concentrations respectively. This evidently means that at the increasing concentrations there was a tendency to produce more leaf area as compared to total dry weight. These results are in coincidence with Humphries (1963). These plants tried to adjust themselves by "compensating mechanism" (sensu Whitehead, 1962). The plants in general appearance looked stunted and chlorotic. As regards the Shoot/Root ratio it was observed that with increasing concentration of C.C.C. the value of this ratio had a tendency to increase (see Tables 63-67 on pages 245-249) from which it could be concluded that root weight as compared to shoot was restricted. All these plants were grown at full field capacity (100% moisture regime). Plants were grown in wind tunnel at a speed of 33 m.p.h. for five weeks. Primary data were recorded and from this the values of α for successive harvests were determined. The values of α range from 0.98 - 1.7 (wind) 1.0 - 2.2 (CT) which means that there was a

greater increase in leaf area as compared to total dry weight in the wind treated plants as compared to the controls, see Fig. 20 on page 141. As regards the Shoot/Root ratio the values for wind treated plants were lower than those for controls, indicating that root production as compared to shoot was greater in the wind treated plants, see Fig. 19 on page 140.

As expected there was a general tendency towards shortening of the height of the plant at decreasing soil moisture regimes in C.C.C.., gibberellic treated and the controls. The height of the plants between 100% and 10% moisture regime for controls was about 3:1, that for gibberellic treated was 2.5:1 and for C.C.C. 2:1 see Fig. 3a on page 70. This clearly indicated that plants treated with C.C.C. had the capacity to resist moisture stresses better than control and gibberellic treated plants.

So far the height of wind treated plants was concerned the reduction in the height of the plants was in the ratio 2:1 as compared with control, Table. 16 on page 134. In the C.C.C. soil drench plants the general tendency was towards dwarfing with increasing concentration of C.C.C., see Table 25 on page 158.

The general anatomy of stem of C.C.C. and Gibberellic treated plants as compared to control showed important points of differences in the extent of development of mechanical tissues especially the xylem elements, see Fig. 9 Table 7 . The number of vascular bundles at the 100% and 30% moisture regimes was the same. C.C.C. treated plants showed the highest degree of development of xylem and other mechanical tissues. The ratio between the xylem area of C.C.C. plants and control at 100% moisture regime was 2:1. There was no marked difference between the gibberellic treated plants and the controls. This means that gibberellic acid as compared to C.C.C. is not effective in bringing about useful anatomical changes. The same thing can be said about C.C.C. and Gibberellic acid at the 30% moisture regime.

It was found that the cortex/stele ratio at 100% and 30% soil moisture regimes was also lowest (1.71, 1.55) among the C.C.C. treated plants as compared to control (2.33, 2.18) and gibberellic treated plants (2.8, 2.69) showing that the stelar development was greater as compared to cortex.

In the anatomical studies of leaf it could be seen from Table 8 on page 103 that C.C.C. plants at

100% and 30% moisture regimes as compared to gibberellic treated and control plants had increased vascularization and the cortex/stele ratio was also found to be lower. Whereas the cortex/stele ratio at 30% soil moisture regime in the control and gibberellic treated plants was more or less the same whereas at 100% soil moisture regime this ratio was slightly lower among the gibberellic treated plants. The number of palisade layers, degree of compatness of spongy tissue, number of xylem vessels, area of the vascular tissues was greater in the C.C.C. plants as compared to controls and gibberellic treated plants. The number of stomata of the controls, C.C.C. and gibberellic treated plants were counted at the 100%, soil moisture regime shown in Table 15 on page 129. It was found that the stomata of C.C.C. were smaller and more in number, those of gibberellic treated plants were larger and less in number while those of controls were intermediate. All of these changes are of a kind that make the plants more xeromorphic in nature. The anatomy of the C.C.C. roots showed the same tendency to produce more vascular tissues as compared to control and gibberellic treated plants. The cortex/stele ratio at 30% soil moisture regime was also found to be much

lower in the C.C.C. treated roots (1.4) as compared to the controls (3.33) and the gibberellic treated roots (2.5). The anatomy of stem and leaf of wind treated plants compared favourably to C.C.C. treated plants. This indicated that the anatomical attributes of wind treated plants are adaptive to the same extent as that of C.C.C. treated plants. These results in comparative anatomy are in coincidence with that of Whitehead and Luti (1962) for full details see Tables 21 and 22. Figs. 21 and 22.

The anatomical features of the leaf, stem and root of plants treated with C.C.C. as soil drench showed the degree and kind of anatomical changes similar to C.C.C. spray plants. As pointed out before (see Introduction) the relative turgidity of the plant is a very important factor in studying the water relations of plants. It was found that the relative turgidities of the gibberellic acid, C.C.C. treated and control plants showed a general tendency to decrease with the decrease in the soil moisture regime. The relative turgidity of the wind treated plants was also lower than that of the controls. In the plants where C.C.C. was used as a soil drench the relative turgidities of the plants decreased with an increase in the concentration

of C.C.C.. Untreated (control) plants were placed in the wind tunnel in a wind of 40 m.p.h. and left for varying periods of time, at intervals the relative turgidity of these plants was determined. The experiment was repeated using plants treated with C.C.C. and grown under normal conditions in the greenhouse. When these were placed in the wind tunnel it was found that the rate of reduction of relative turgidity was decreased, in other words these plants were losing water at a slower rate than the control plants. This is a clear demonstration of pre-adaptation, i.e. the plants have been grown under mesophytic conditions yet are capable of withstanding conditions which are highly xerophytic.

This would suggest that the effect of wind is to a very great extent the same as the effect of drought arising from lack of available water in the soil. Thereare no marked differences in the plants developing under the two different treatments. The combination of the morphological and anatomical changes would appear to account for the greater resistance to desiccation of both the wind and C.C.C. treated plants. So far as the C.C.C. soil drench plants are concerned it was found that these plants had virtually no greater ability to withstand exposure to drought.

It can be concluded a) that C.C.C. can produce plants whose anatomical and morphological developments under mesophytic conditions pre-adapts them to conditions of moisture stress. b) the same degree of resistance can be developed phenotypically by the plants grown under the imposed conditions of moisture stress, i.e. both in wind tunnel and with lower soil moisture. c) the controls grown under mesophytic conditions similar to (a) above do not possess either the anatomical or morphological features of (a) and (b) and in addition failed to survive the extreme conditions which were not fatal to (a) and (b).

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APPENDIX

Table 36

MEAN INTERNODE LENGTH IN CMS. AT SUCCESSIVE HARVESTS - CONTROL

MOISTURE REGIME	Harvests	1st Int.	2nd Int.	3rd Int.	4th Int.	5th Int.
100%	H_1	1.2	-	-	-	-
	H_1^2	3.0	0.25	-	-	-
	H_2^3	9.1	0.7	0.1	-	-
	H_3^4	13.1	5.5	0.3	0.2	-
	H_4^5	13.5	14.5	2.6	0.33	0.15
55%	H_1	0.75	-	-	-	-
	H_1^2	2.5	0.1	-	-	-
	H_2^3	8.5	0.25	-	-	-
	H_3^4	9.2	4.2	0.2	-	-
	H_4^5	10.2	5.1	2.2	0.4	-
30%	H_1	0.25	-	-	-	-
	H_1^2	0.53	-	-	-	-
	H_2^3	3.1	0.2	-	-	-
	H_3^4	5.0	1.6	0.1	-	-
	H_4^5	8.2	3.8	0.6	0.2	-
15%	H_1	0.2	-	-	-	-
	H_1^2	0.7	-	-	-	-
	H_2^3	2.0	-	-	-	-
	H_3^4	2.6	0.6	-	-	-
	H_4^5	4.4	2.0	0.2	—	-
10%	H_1	0.05	-	-	-	-
	H_1^2	0.23	-	-	-	-
	H_2^3	0.3	-	-	-	-
	H_3^4	0.8	-	-	-	-
	H_4^5	1.1	1.3	-	-	-

Table 37

MEAN INTERNODE LENGTH IN CMS. AT SUCCESSIVE HARVESTS - GIBBERELLIC TREATED PLANTS

MOISTURE REGIME	HARVESTS	1st INT	2nd INT	3rd INT	4th INT	5th INT	6th INT
100%	H_1	0.7	-	-	-	-	-
	H_2	3.8	1.3	-	-	-	-
	H_3	13.6	3.4	0.5	-	-	-
	H_4	14.3	11.7	1.3	0.33	-	-
	H_5	17.8	16.2	9.7	1.8	0.6	0.3
55%	H_1	0.6	-	-	-	-	-
	H_2	3.1	0.1	-	-	-	-
	H_3	10.1	3.3	0.5	-	-	-
	H_4	10.6	7.7	1.3	0.17	-	-
	H_5	11.5	8.7	5.8	1.2	0.23	-
30%	H_1	0.4	-	-	-	-	-
	H_2	2.8	0.1	-	-	-	-
	H_3	9.7	1.5	-	-	-	-
	H_4	10.3	5.0	0.45	-	-	-
	H_5	10.6	5.1	4.4	0.8	-	-
15%	H_1	0.25	-	-	-	-	-
	H_2	2.6	-	-	-	-	-
	H_3	7.5	0.9	-	-	-	-
	H_4	9.5	4.3	0.4	-	-	-
	H_5	-	-	-	-	-	-
10%	H_1	0.1	-	-	-	-	-
	H_2	2.3	-	-	-	-	-
	H_3	4.4	0.5	-	-	-	-
	H_4	8.7	4.2	0.3	-	-	-
	H_5	-	-	-	-	-	-

Table 38

MEAN INTERNODE LENGTH IN CMS. AT SUCCESSIVE HARVESTS - C.C.C. TREATED PLANTS

MOISTURE REGIME	HARVESTS	1st Int.	2nd Int.	3rd Int.	4th Int.
100%	H_1	0.3	-	-	-
	H_2	4.6	0.2	-	-
	H_3	8.0	1.1	0.25	-
	H_4	10.4	5.3	0.33	-
	H_5	13.0	10.6	1.2	0.2
55%	H_1	0.1	-	-	-
	H_2	3.7	0.13	-	-
	H_3	8.5	0.7	0.2	-
	H_4	8.7	3.2	0.3	-
	H_5	9.7	3.8	0.35	-
30%	H_1	0.1	-	-	-
	H_2	2.5	0.08	-	-
	H_3	5.2	0.3	-	-
	H_4	7.0	1.3	0.14	-
	H_5	7.5	5.1	0.3	-
15%	H_1	0.09	-	-	-
	H_2	1.8	0.05	-	-
	H_3	4.1	0.3	-	-
	H_4	6.1	2.0	0.1	-
	H_5	6.5	3.1	0.4	-
10%	H_1	0.09	-	-	-
	H_2	1.5	-	-	-
	H_3	3.7	0.2	-	-
	H_4	4.6	1.1	0.1	-
	H_5	6.2	1.4	0.15	-

Table 39

Means of Controls at 100% S.M.R.

Harvests	Leaf Area cm^2	$\log_e$ leaf area	D.Wt. Leaves mgs.	D.Wt. Stem mgs.	D.Wt. Shoot mgs.	D.Wt. Root mgs.	Total D.W. mgs.	$\log_e$ D.Wt.	Shoot / Root mgs.
I	20.6	3.025	50.1	26.5	76.7	31.0	107.7	4.679	2.4741
II	32.1	3.468	80.6	46.2	126.9	42.0	168.9	5.129	2.560
III	44.0	3.784	98.8	98.6	197.4	67.0	264.4	5.577	2.946
IV	57.6	4.053	124.4	171.5	295.9	114.6	410.5	6.017	2.582
V	72.2	4.279	144.4	305.7	450.2	177.7	627.9	6.442	2.533

Table 40

Means of Controls at 55% S.M.R.

Harvests	Leaf Area cm^2	log_e leaf area	D.Wt. Leaves mgs.	D.Wt. Stem mgs.	D.Wt. Shoot mgs.	D.Wt. Root mgs.	Total D.Wt. mgs.	log_e D.Wt.	Shoot / Root mgs.
I	16.0	2.772	34.5	24.4	58.9	22.6	81.6	4.401	2.07
II	21.7	3.077	45.2	26.0	71.2	29.2	100.5	4.609	2.438
III	31.53	3.45	70.9	61.7	132.6	37.0	169.6	5.133	3.482
IV	39.7	3.681	94.7	78.6	173.3	63.9	237.2	5.468	2.71
V	55.2	4.01	176.7	126.2	303.0	93.7	396.7	5.983	3.234

Table 41

Means of Controls at 30% S.M.R.

Harvests	Leaf Area cm^2	$\log_e$ leaf area	D.Wt. Leaves mgs.	D.Wt. Stem mgs.	D.Wt. Shoot mgs.	D.Wt. Root mgs.	Total D.Wt. mgs.	$\log_e$ D.Wt.	Shoot / Root mgs.
I	13.0	2.564	30.7	21.6	52.7	21.6	74.3	4.308	2.4398
II	16.1	2.778	43.4	20.1	63.6	24.8	88.4	4.481	2.564
III	19.3	2.96	60.9	23.0	84.0	29.7	113.7	4.733	2.829
IV	23.0	3.135	84.4	29.8	114.3	35.2	146.2	4.984	3.249
V	31.2	3.44	109.1	72.8	182.0	62.9	244.9	5.5	2.894

Table 42

Means of Controls at 15% S.M.R.

Harvests	Leaf Area cm^2	$\log_e$ leaf area	D.Wt. Leaves mgs.	D.Wt. Stem mgs.	D.Wt. Shoot mgs.	D.Wt. Root mgs.	Total D.Wt. mgs.	$\log_e$ D.Wt.	Shoot / Root mgs.
I	8.2	2.104	27.2	18.2	45.4	16.0	61.4	4.118	2.838
II	6.9	1.931	33.8	16.2	50.0	14.1	66.1	4.191	2.817
III	1.1	0.095	38.2	15.4	53.6	14.8	68.5	4.226	3.621
IV	1.2	0.182	47.1	22.8	69.9	17.9	87.9	4.476	3.905
V	8.2	2.104	76.5	25.8	102.3	30.5	132.8	4.888	3.354

Table 43

Means of Controls at 10% S.M.R.

Harvests	Leaf Area cm^2	$\log_e$ leaf area	D.Wt. Leaves mgs.	D.Wt. Stem mgs.	D.Wt. Shoot mgs.	D.Wt. Root mgs.	Total D.Wt. mgs.	$\log_e$ D.Wt.	Shoot / Root mgs.
I	7.3	1.987	22.1	12.4	34.5	10.1	44.6	3.798	3.416
II	7.4	2.001	22.8	11.9	34.9	13.8	48.7	3.885	2.529
III	2.7	0.993	22.5	13.4	35.9	17.9	53.8	3.985	2.006
IV	4.5	1.504	23.4	12.8	36.2	20.0	56.2	4.028	1.806
V	4.8	1.568	30.2	22.0	52.2	20.2	72.4	4.282	2.584

Table 44

Means of Gibberellic treated Plants at 100% S.M.R.

Harvests	Leaf Area cm^2	$\log_e$ leaf area	D.Wt. Leaves mgs.	D.Wt. Stem mgs.	D.Wt. Shoot mgs.	D.Wt. Root mgs.	Total D.Wt. mgs.	$\log_e$ D.Wt.	Shoot / Root mgs.
I	12.50	2.525	36.2	20.7	57.0	18.5	75.5	4.324	3.0810
II	23.56	3.159	65.3	51.5	116.8	24.2	141.1	4.949	4.8264
III	40.36	3.697	94.4	137.1	231.6	51.8	283.4	5.646	4.47
IV	54.76	4.0	129.4	260.0	389.4	117.1	506.6	6.227	3.3253
V	61.5	4.119	146.1	361.2	507.3	140.8	648.1	6.474	3.612

Table 45

Means of Gibberellic treated Plants at 55% S.M.R.

Harvests	Leaf Area cm^2	$\log_e$ leaf area	D.Wt. Leaves mgs.	D.Wt. Stem mgs.	D.Wt. Shoot mgs.	D.Wt. Root mgs.	Total D.Wt. mgs.	$\log_e$ D.Wt.	Shoot / Root mgs.
I	9.5	2.251	22.8	16.6	39.4	15.0	54.5	3.998	2.6266
II	17.1	2.839	39.6	40.9	80.5	18.6	99.2	4.597	4.3279
III	28.3	3.342	78.0	71.9	150.0	37.7	187.7	5.234	3.9787
IV	31.0	3.433	80.6	86.5	167.2	49.4	216.6	5.378	3.3846
V	44.0	3.784	161.0	123.0	284.0	117.3	401.4	5.994	2.4211

Table 46

Means of Gibberellic treated plants at 30% S.M.R.

Harvests	Leaf Area cm^2	$\log_e$ leaf area	D.Wt. Leaves mgs.	D.Wt. Stem mgs.	D.Wt. Shoot mgs.	D.Wt. Root mgs.	Total D.Wt. mgs.	$\log_e$ D.Wt.	$\frac{\text{Shoot}}{\text{Root}}$ mgs.
I	8.53	2.219	30.2	19.0	49.3	13.8	63.1	4.144	3.5724
II	13.6	2.61	40.2	27.3	67.5	24.8	92.4	4.526	2.7217
III	16.7	2.815	52.4	44.6	97.0	27.7	121.8	4.802	3.5018
IV	19.2	2.954	65.4	51.2	116.6	39.0	155.6	5.047	2.9897
V	25.2	3.226	97.4	94.0	191.4	68.0	259.4	5.558	2.8147

Table 47

Means of Gibberellic treated plants at 15% S.M.R.

Harvests	Leaf Area cm^2	$\log_e$ leaf area	D.Wt. Leaves mgs.	D.Wt. Stem mgs.	D.Wt. Shoot mgs.	D.Wt. Root mgs.	Total D.Wt. mgs.	$\log_e$ D.Wt.	Shoot / Root mgs.
I	8.1	2.092	31.2	22.4	53.6	17.3	70.9	4.261	3.091
II	9.3	2.230	34.9	26.8	61.7	19.4	81.1	4.395	3.18
III	2.3	0.8329	37.8	29.6	67.5	20.9	88.4	4.481	3.734
IV	9.3	2.230	46.8	42.8	89.7	23.2	112.9	4.726	3.867
V									

Table 48

Means of Gibberellic treated plants at 10% S.M.R.

Harvests	Leaf Area cm^2	$\log_e$ leaf area	D. Wt. Leaves mgs.	D.Wt. Stem mgs.	D.Wt. Shoot mgs.	D.Wt. Root mgs.	Total D.Wt. mgs.	$\log_e$ D.Wt.	Shoot / Root mgs.
I	3.3	1.193	18.8	10.6	29.4	10.7	40.1	3.691	2.7476
II	2.81	1.033	36.2	17.7	54.0	17.9	71.9	4.275	3.0167
III	2.45	0.896	35.4	23.8	59.2	18.8	78.1	4.357	3.1489
IV	7.1	1.960	44.6	40.3	84.9	22.6	109.5	4.696	3.7566
V									

Table 49

Means of C.C.C. treated Plants at 100% S.M.R.

Harvests	Leaf Area cm^2	log_e leaf area	D.Wt. Leaves mgs.	D.Wt. Stem mgs.	D.Wt. Shoot mgs.	D.Wt. Root mgs.	Total D.Wt. mgs.	log_e D.Wt.	Shoot / Root mgs.
I	12.26	2.506	43.0	23.1	66.1	24.3	90.5	4.505	2.7201
II	29.8	3.394	100.6	55.2	155.8	72.5	228.4	5.431	2.1489
III	42.2	3.742	156.5	118.8	275.3	160.5	435.8	6.077	1.7152
IV	52.0	3.951	186.2	306.0	492.2	196.2	688.4	6.534	2.5086
V	54.0	3.988	190.6	359.7	550.3	216.8	767.1	6.642	2.5359

Table 50

Means of C.C.C. at 55% S.M.R.

Harvests	Leaf Area cm^2	log_e leaf area	D.Wt. Leaves mgs.	D. Wt. Stem mgs.	D.Wt. Shoot mgs.	D.Wt. Root mgs.	Total D.Wt. mgs.	log_e D.Wt.	Shoot / Root mgs.
I	11.6	2.451	28.2	20.6	48.8	21.8	70.6	4.257	2.238
II	26.8	3.288	68.8	35.7	104.5	56.5	161.0	5.081	1.850
III	40.9	3.711	120.2	102.6	222.9	108.4	331.3	5.80	2.056
IV	47.6	3.862	152.2	147.4	299.6	154.7	454.3	6.118	1.936
V	56.0	4.025	159.0	187.8	346.8	203.6	550.4	6.310	1.703

Table 51

Means of C.C.C. at 30% S.M.R.

Harvests	Leaf Area cm^2	$\log_e$ leaf area	D.Wt. Leaves mgs.	D.Wt. Stem mgs.	D.Wt. Shoot mgs.	D.Wt. Root mgs.	Total D.Wt. mgs.	$\log_e$ D.Wt.	Shoot / Root mgs.
I	12.8	2.549	32.2	17.0	49.2	18.0	67.2	4.207	2.734
II	19.8	2.985	50.5	22.2	72.7	27.6	100.3	4.608	2.634
III	24.9	3.214	68.0	30.8	98.8	49.2	148.0	4.997	2.008
IV	35.2	3.561	97.8	63.0	160.8	121.8	282.7	5.644	1.32
V	37.5	3.624	112.1	78.3	190.4	137.2	327.6	5.791	1.381

Table 52

Means of C.C.C. at 15% S.M.R.

Harvests	Leaf area cm^2	$\log_e$ leaf area	D.Wt. Leaves mgs.	D.Wt. Stem mgs.	D.Wt. Shoot mgs.	D.Wt. Root mgs.	Total D.Wt. mgs.	$\log_e$ D.Wt.	Shoot / Root mgs.
I	7.3	1.988	27.6	15.4	43.0	20.4	63.4	4.150	1.674
II	12.1	2.493	44.3	22.5	66.8	31.8	98.6	4.591	2.010
III	15.6	2.747	70.6	23.8	94.4	49.4	143.8	4.968	1.911
IV	18.8	2.934	93.6	46.5	140.1	60.8	200.6	5.301	2.303
V	20.2	3.005	112.2	51.6	163.8	71.2	235.0	5.459	2.301

Table 53

Means of C.C.C. at 10% S.M.R.

Harvests	Leaf area cm^2	$\log_e$ leaf area	D.Wt. Leaves mgs.	D. Wt. Stem mgs.	D.Wt. Shoot mgs.	D.Wt. Root mgs.	Total D. Wt. mgs.	$\log_e$ D.Wt.	Shoot / Root mgs.
I	6.5	1.872	23.1	15.6	38.7	26.0	64.8	4.171	1.559
II	10.1	2.312	40.6	20.6	61.2	32.4	93.6	4.539	1.899
III	13.3	2.589	64.2	25.7	88.8	46.9	135.8	4.911	1.893
IV	15.9	2.767	91.4	38.4	129.8	53.9	183.7	5.213	2.409
V	17.2	2.845	107.0	44.5	151.5	62.8	214.3	5.367	2.412

Table 54 a

Specific Leaf Area of the Controls

Harvest	MOISTURE REGIME				
	100%	55%	30%	15%	10%
1	411.18	463.76	423.45	301.47	342.01
2	398.26	480.08	370.97	263.31	359.64
3	445.34	444.71	316.91	238.22	386.67
4	463.02	419.22	272.51	222.93	380.34
5	500.00	312.39	285.98	172.54	331.13

Table 54b

Specific Leaf Area of the Gibberellic treated plants

Harvest	MOISTURE REGIME				
	100%	55%	30%	15%	10%
1	345.3	416.66	282.45	259.61	175.53
2	360.79	431.81	338.3	266.47	77.62
3	427.54	362.82	318.7	60.84	69.2
4	423.18	384.61	293.57	198.71	159.19
5	420.94	273.29	258.72		

Table 54c

Specific Leaf Area of the C.C.C. treated plants

Harvest	MOISTURE REGIME				
	100%	55%	30%	15%	10%
1	285.11	411.34	397.51	264.49	281.38
2	296.22	389.53	392.07	273.13	248.76
3	269.65	340.26	366.17	220.96	207.16
4	279.27	312.74	359.91	170.94	114.11
5	283.32	352.83	334.52	131.46	112.14

Table 55

Increase in fresh weight of floating leaf discs of controls (in gms.)

MOISTURE REGIME	TIME IN HOURS					
	0 Hr.	3 Hr.	6 Hr.	9 Hr.	12 Hr.	24 Hr.
100%	0.2654	0.2946	0.3060	0.3103	0.3118	0.3132
55%	0.2960	0.3202	0.3356	0.3395	0.3432	0.3470
30%	0.3088	0.3272	0.3454	0.3512	0.3540	0.3612
15%	0.3116	0.3448	0.3626	0.3698	0.3758	0.3820
10%	0.2884	0.3204	0.3416	0.3506	0.3590	0.3640

No. of Discs - 20

Temp. 59.9°F.

Rel. Humidity - 77.8%

Table 56

Increase in fresh weight of floating leaf discs of Gibberellic treated Plants (in gms).

MOISTURE REGIME	TIME IN HOURS					
	0 Hr.	3 Hr.	6 Hr.	9 Hr.	12 Hr.	24 Hr.
100%	0.2638	0.2903	0.2903	0.2950	0.3008	0.3104
55%	0.2786	0.3174	0.3248	0.3312	0.3351	0.3433
30%	0.2394	0.2750	0.2834	0.2909	0.2986	0.3102
15%	0.2640	0.3044	0.3164	0.3264	0.3374	0.3584
10%	0.2556	0.3040	0.3190	0.3304	0.3434	0.3656

No. of discs - 20

Temp. 63.8°F.

Rel. Humidity 75.4%

Table 57

Increase in fresh weight of floating leaf discs C.C.C. treated plants (in gms.)

MOISTURE REGIME	TIME IN HOURS					
	0 Hr.	3 Hr.	6 Hr.	9 Hr.	12 Hr.	24 Hr.
100 %	0.3186	0.3380	0.3498	0.3588	0.3645	0.3783
55%	0.3216	0.3486	0.3652	0.3712	0.3764	0.3905
30%	0.3142	0.3475	0.3614	0.3711	0.3790	0.3914
15%	0.3520	0.3968	0.4126	0.4216	0.4278	0.4328
10%	0.3144	0.3702	0.3866	0.3956	0.4028	0.4072

No. of discs : 20

Temp. 58.8°F.

Rel. Humidity 76.3%

Table 58

Dry weight of 20 leaf discs of (a) Controls, (b) Gibberellic and (c) C.C.C. treated plants (in gms.)

	(a)	(b)	(c)
100%	0.0276	0.0252	0.0322
55%	0.250	0.0272	0.0326
30%	0.0274	0.0252	0.0274
15%	0.0260	0.0244	0.0276
10%	0.0230	0.0236	0.0296

Table 59

Means of Controls (in wind tunnel) in mgs.

Harvests	Leaf Area	loge leaf area	D.Wt. leaves	D.Wt. stem	D.Wt. shoot	D.Wt. root	Total D.Wt.	Loge Total D.Wt.	Shoot/Root
H_1	21.15	3.05160	56.9	22.9	79.8	61.7	141.5	4.95228	1.275
H_2	42.0	3.73767	113.7	60.7	174.4	126.5	300.9	5.70674	1.35
H_3	63.05	4.14392	191.9	160.9	302.8	266.8	619.7	6.42925	1.32
H_4	82.9	4.41763	283.4	422.8	710.3	449.0	1154.3	7.05094	1.55

Table 60

Means of wind treated plants (in mgs.)

Harvests	Leaf Area	loge leaf Area	D.Wt. leaves	D.Wt. stem	D.Wt. shoot	D.Wt. root	Total D.Wt.	Loge Total D.Wt.	Shoot / Root
H_1	9.1	2.26176	35.1	19.6	54.7	54.6	109.4	4.69509	0.77
H_2	13.34	2.59079	50.3	27.4	77.7	73.8	151.5	5.02057	1.01
H_3	16.5	2.80336	69.2	37.7	106.9	97.7	203.2	5.31419	1.1
H_4	22.1	3.09558	111.2	64.0	175.2	163.9	339.2	5.82661	1.07

Table 61

Increase in Fresh weight of leaf discs of controls and wind treated plants (in gms.)

	TIME IN HOURS						Dry wt. of Discs (in gms.)
	≠0 Hr.	3 Hrs.	6 Hrs.	9 Hrs.	12 Hrs.	24 Hrs.	
CONTROL (IN WIND TUNNEL)	.2702	.3034	.3048	.3060	.3072	.3104	.0304
WIND	.3090	.3440	.3546	.3574	.3594	.3604	.0298

No. of Discs = 20

≠ = Initial Fresh Weight.

Table 62

Means of Controls with C.C.C. Soil Drench Plants (in mgs)

Harvests	Leaf Area	$\log_e$ leaf area	D.Wt. Leaves	D.Wt. Stem	D. Wt. Shoot	D. Wt. Root	Total D.Wt.	$\log_e$ total D. Wt.	Shoot / Root
H_1	24.0	3.17805	142.2	122.8	265.0	152.4	417.4	6.03405	1.73
H_2	34.7	3.54674	175.2	221.0	396.2	213.0	609.2	6.41215	1.85
H_3	42.2	3.74242	192.4	307.4	499.8	282.4	782.2	6.66211	1.76

Table 63

Means of 0.1 C.C.C. (Soil Drench) Plants in mgs.

Harvests	Leaf Area	$\log_e$ Leaf Area	D.Wt. Leaves	D.Wt. Stem	D.Wt. Shoot	D.Wt. Root	Total D.Wt.	$\log_e$ Total D.Wt.	Shoot / Root
H_1	10.4	2.34181	118.8	53.2	172.0	153.8	325.8	5.78629	1.1
H_2	23.9	3.17288	166.6	122.0	288.6	218.0	506.6	6.22773	1.32
H_3	36.7	3.60278	203.2	169.2	372.4	269.0	641.4	6.46365	1.38

Table 64

Means of 0.2 C.C.C. (Soil Drench) Plants in mgs.

Harvests	Leaf Area	$\log_e$ Leaf Area	D.Wt. Leaves	D.Wt. Stem	D.Wt. Shoot	D.Wt. Root	Total D.Wt.	$\log_e$ Total D. Wt.	Shoot / Root
H_1	6.6	1.88707	84.2	37.4	121.6	71.6	193.2	5.26374	1.69
H_2	20.6	3.02529	127.2	71.4	198.6	119.0	317.6	5.76082	1.66
H_3	50.8	3.92790	180.2	117.0	297.2	189.2	486.4	6.18704	1.57

Table 65

Means of 0.3 C.C.C. (Soil Drench) Plants in mgs.

Harvests	Leaf Area	loge Leaf Area	D.Wt. Leaves	D.Wt. Stem	D.Wt. Shoot	D.Wt. Root	Total D.Wt.	loge Total D.Wt.	Shoot / Root
H_1	4.7	1.54756	51.2	27.8	79.0	40.8	119.8	4.78596	1.9
H_2	12.8	2.54945	73.6	46.8	120.4	63.6	184.0	5.21494	1.86
H_3	30.1	3.40453	125.8	61.2	187.0	100.4	287.4	5.66090	1.86

Table 66

Means of 0.4 C.C.C. (Soil Drench) Plants in mgs.

Harvests	Leaf Area	$\log_e$ Leaf Area	D.Wt. Leaves	D.Wt. Stem	D.Wt. Shoot	D.Wt. Root	Total D. Wt.	$\log_e$ Total D.Wt.	$\frac{\text{Shoot}}{\text{Root}}$
H_1	2.8	1.02962	48.9	25.4	74.3	37.0	111.3	4.71212	2.0
H_2	6.0	1.79176	64.2	31.6	95.8	41.8	137.6	4.92437	2.29
H_3	13.1	2.57261	91.8	38.0	129.8	56.4	186.2	5.22682	2.3

Table 67

Means of 0.5 C.C.C. (Soil Drench) Plants in mgs.

Harvests	Leaf Area	$\log_e$ Leaf Area	D.Wt. Leaves	D.Wt. Stem	D.Wt. Shoot	D.Wt. Root	Total D.Wt.	$\log_e$ Total D.Wt.	$\frac{\text{Shoot}}{\text{Root}}$
H_1	0.65	0.43078	38.2	18.6	56.8	24.4	81.2	4.39692	2.32
H_2	2.4	0.87547	51.8	25.2	77.0	31.6	108.6	4.68774	2.43
H_3	5.1	1.62924	68.4	29.8	98.2	41.2	139.4	4.93740	2.38

Table 68

Increase in Fresh weight of leaf discs of controls and C.C.C. soil drench plants (in gms.)

	TIME IN HOURS						Dry wt. of Discs (in gms.)
	≠0 Hr.	2½ Hrs.	5 Hrs.	7½ Hrs.	10½ Hrs.	25 Hrs.	
CONTROL	.2452	.2538	.2573	.2589	.2599	.2618	.0222
0.1 CCC	.2258	.2408	.2453	.2477	.2495	.2535	.0232
0.2 CCC	.2404	.2646	.2720	.2756	.2780	.2840	.0218
0.3 CCC	.2644	.2930	.3016	.3067	.3106	.3229	.0230
0.4 CCC	.2552	.2880	.2976	.3036	.3080	.3232	.0240

No of discs = 20

≠ = Initial Fresh weight.

Table 69

Increase in fresh weight of leaf discs of the control with wind treatment (in gms.)

WIND TREATMENT	TIME IN HOURS						Dry wt. of discs (in gms.)
	≠0 Hr.	3 Hrs.	6 Hrs.	9 Hrs.	12 Hrs.	24 Hrs.	
NO WIND	.3696	.4404	.4788	.4908	.4944	.5176	.0308
¼Hr. WIND	.3600	.4556	.4836	.4976	.5100	.5350	.0340
½Hr. WIND	.3564	.4326	.4728	.4988	.5191	.5425	.0350

no. of discs = 20

≠ = Initial fresh weight.

Table 70

Increase in fresh weight of leaf discs of 1 spray C.C.C. plants with wind treatment (in gms.)

WIND TREATMENT	TIME IN HOURS						Dry wt. of discs (in gms.)
	0 Hr.	3 Hrs.	6 Hrs.	9 Hrs.	12 Hrs.	24 Hrs.	
NO WIND	.3974	.4716	.4816	.4857	.4890	.4981	.0386
½Hr. WIND	.4548	.5436	.5760	.5856	.5924	.6064	.0424
1 Hr. WIND	.4512	.5224	.5526	.5768	.5900	.6050	.0348

No. of discs = 20

$\neq$ = Initial fresh weight.

Table 71

Increase in fresh weight of leaf discs of 2 spray C.C.C. plants with wind treatment (in gms.)

WIND TREATMENT	TIME IN HOURS						Dry wt. of Discs (in gms.)
	≠0 Hr.	3 Hrs.	6 Hrs.	9 Hrs.	12 Hrs.	24 Hrs.	
NO WIND	.3690	.4086	.4192	.4276	.4358	.4542	.0384
½Hr. WIND	.3516	.4136	.4420	.4486	.4536	.4672	.0452
1Hr. WIND	.3616	.4512	.4624	.4696	.4760	.48904	.0364

No. of discs = 20

≠ = Initial Fresh weight.