A STUDY OF WATER USE AND DRY MATTER PRODUCTION OF LUCERNE UNDER IRRIGATION AND NATURAL RAINFALL

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INTRODUCTION

Probably more irrigation experiments have been conducted with lucerne than with any other crop. There have been extensive tests of the total water required for maximum crop production, the effects of various irrigation intervals, and the effects of various levels of water application per interval. However, it is not possible to generalise from most of the results obtained, because no simultaneous measurements of soil moisture were made. For example, there is little to be gained by irrigating at one -, two-, or three-week intervals if the soil can store ample readily available water from previous irrigations. The data all confirm that lucerne production is increased by yearly total water applications in excess of those needed for maximum yields of most other crops.

However, little work has been done on water use by lucerne during the intervals between cuttings. Most of the work so far done has been concerned with the total amount of water applied, or the total amount of water used at each cutting, i.e. the duration of studies was always more than a month. It may be anticipated that the study of water use for finer intervals will give a better understanding of the relation between crop growth and water relations.

None of the previous irrigation experiments have taken into consideration the amount of available water stored in the soil at the time when irrigation was commenced. Very little is known about the relation between water use, the amount of available water stored in the soil at the beginning of the period, irrigation, and rainfall.

The field experiment carried out was designed to give further information on the following questions:

(a) Is it possible to replenish the water used by lucerne by irrigation during Adelaide summer conditions?

(b) Does lucerne make more efficient use of water under irrigated than under natural rainfall conditions?

(c) What are the important factors controlling the water use under irrigated and natural rainfall conditions?

(d) What are the factors controlling the dry matter production under irrigated and natural rainfall conditions?

(e) Under irrigated conditions will lucerne be able to increase the pF of the soil water at the lower depths; if so to what extent?

(f) Under natural rainfall conditions, how long will lucerne take (from the outset of the experiment) to increase the pF of the soil water at the lower depths to permanent wilting percentage?

(g) What is the magnitude of the difference in soil temperature at various depths under irrigated and natural rainfall conditions?

(h) Is it possible to assess the changes in pF of the soil water at different depths under irrigated and natural rainfall conditions throughout the year?

(i) Is it possible to assess the validity of water loss data calculated from Penman's equations by comparison with actual values obtained?

(j) Does the growth of lucerne in the second year depend on its previous treatment?

In order to provide answers to these questions, an experiment was designed which included two main treatments:

(1) Soil moisture always maintained as far as possible at field capacity at all depths at all times. This will be referred to as "Irrigated".

(2) Under natural rainfall. This will be referred to as "Non-irrigated".

When starting the investigations reported herein, it was decided that valuable information could be obtained by an intensive study of the effects of soil moisture given to plots of limited areas rather than by less complete studies in larger plots. The advantages of the small plots are:

(i) That they may be selected for uniformity in depth and type of soil;
(ii) That water may be more evenly applied to them than to larger areas;
and (iii) That they permit more accurate records of dry matter production, soil moisture conditions and fluctuation.

LITERATURE REVIEW

Since the pioneer work of Briggs and Shantz (1913a) and their review (1913b) on the moisture relation of plants, a large number of papers dealing with soil moisture - plant relationships has appeared; these have recently been reviewed by Veihmeyer and Hendrickson (1950), by Richards and Wadleigh (1952), by Kelley (1954), and by Veihmeyer (1956). Only the most important papers, and those which have appeared since these extensive reviews, will be discussed here.

Soil moisture cannot be studied by itself without reference to other soil factors since it affects, and is affected by, all physical, chemical and biological processes of the soil. However, other factors will be mentioned only in so far as they are essential and relevant.

(a) Soil Moisture and Plant Growth

The movement of water takes place under the influence of gravity (drainage) and under a suction gradient (capillarity). The rate of movement is controlled by the size and continuity of the pores and by such factors as the suction gradient and the viscosity of the water. Richards and Wadleigh (1952) on the basis of experiments by Lewis (1937) infer that in the moisture range in which plant growth proceeds and in the absence of temperature gradients, the movement of water takes places primarily in the liquid phase, movement in the vapour phase compared with this process being negligible. Marshall and Gurr (1954), when measuring the movement of chlorides under isothermal conditions in soil packed in shallow cups from which water was allowed to evaporate, concluded that water can move in the liquid phase throughout the whole range in which it is available to plants. Russell (1950) states that water can only move through existing water-filled passages and that it cannot move across or down an air space. Viscous resistance to flow through narrow passages increases very rapidly as they narrow and the resistance may thus be considerable. Baver (1956, p.273) summarising various investigations, concludes that the downward movement of water by gravitational forces in natural soils is related to the amount and continuity of non-capillary pores (as determined by soil structure, texture, volume changes and biological changes), to the hydration of pores and to the resistance of entrapped air. The effect of pore size distribution on soil permeability has been studied by several investigators (for examples see Baver 1956, p.264).

It can be deduced from the various investigations of Veihmeyer and Hendrickson (Veihmeyer 1927; Veihmeyer and Hendrickson 1927a; Hendrickson and Veihmeyer 1929a, 1941) that a soil cannot be partially wetted. When a certain amount of water is applied to a volume of soil, that amount of water wets a certain depth of soil to its field capacity, and downward movement or distribution below this depth proceeds only slowly with time. To secure further penetration more water must be applied. The depth of penetration depends upon its water-holding capacity, its relative dryness before the water was applied and the amount of water added. This characteristic of the soil-wetting process was pointed out by Shantz in 1925 and an understanding of the mode of wetting of soils is clearly essential to experimental work on the relation of soil moisture to plant growth.

Thus it is not possible by surface application of water to bring the entire volume of soil, at all levels, to any desired moisture content such as 10, 20 or 30 per cent. Nor is it possible to maintain soil moisture at a theoretical amount such as an optimum, but only at field capacity.

As field capacity symbolises the maximum amount of water a well-drained soil can retain, and as the permanent wilting percentage represents the lowest limit to which moisture is reduced by growing crops, so the range of available water in a soil is bounded by these two limits. At one time it was thought that both of these can be calculated from the moisture equivalent but unfortunately this view has been shown to be incorrect; hence, both must be determined independently for every soil under consideration.

The term 'field capacity' has been defined by Veihmeyer and Hendrickson (1931) as the amount of water held in the soil after the excess gravitational water has drained away and after the rate of downward movement of water has materially decreased, which usually takes place within two or three days after a rain or irrigation in pervious soils of uniform structure and texture. However, it has also been recognised that the 'field capacity' is an arbitrary point on the time-drainage curve (Colman 1944; Israelson 1918; Veihmeyer and Hendrickson 1931, 1949) and that the rate of drainage from a particular profile at any time is influenced by a number of factors. Some soils which show the phenomenon of delayed drainage, such as some deep uniform moderately silty soils, cannot be said to have a field capacity at all, since drainage continues to remove appreciable quantities of water from them over periods of several months. This is supported by the statement of Richards (1949a) in which he suggests that some soils do not have a field capacity as they do not seem to have a definite moisture content at which moisture movement becomes negligible.

Veihmeyer and Hendrickson (1949) have suggested that it can be regarded as the starting point from which plants begin to use water from the soil in the normal functions of growth, although some water may be used while the soil is being irrigated and before the field capacity is reached. They have also proposed that a soil under a given set of conditions can be taken as having certain field capacity. They have reviewed the methods of measuring field capacity in the laboratory and in the field.

It has been pointed out by Richards (1949a) that the hydraulics of field capacity are not well understood. Baver (1956, p.286) has reported that various investigators have given various tensions at which water is held at field capacity and deduced that very little information is available regarding the tensions at which water is held at field capacity.

Various designations have been given to moisture content of the soil at the time when the soil cannot supply water at a sufficient rate to maintain turgor, and the plants growing on it permanently wilt. These include the wilting coefficient (Briggs and Shantz 1912), permanent wilting percentage (Hendrickson and Veihmeyer 1929a) and the first permanent wilting percentage (Furr and Reeve 1945). Since the term wilting coefficient generally indicates that it bears a definite relation to other soil properties and also that it is derived from indirect methods it would seem preferable to use the term permanent wilting percentage as suggested by Veihmeyer and Hendrickson in their various papers (1928, 1945, 1948, 1949 and 1950) to indicate that determinations were made by the direct methods. According to Baver (1956, p.284) most indirect methods are unreliable. Veihmeyer and Hendrickson (1948) have indicated that the reduction of moisture below permanent wilting percentage is very slight below the surface layer affected by evaporation, and that the moisture extraction curve is essentially horizontal after this moisture content is reached. However, they realised that the permanent wilting percentage is not an unique value, but is a small range of soil-moisture conditions within which permanent wilting takes place. They suggested that it is a satisfactory reference point from which the amount of readily available water and also the amount needed to raise the soil to its field capacity may be calculated. Detailed methods of determining the permanent wilting percentage have been fully discussed by Veihmeyer and Hendrickson (1945, 1949).

In fact the availability of the water between these limits is still a matter of controversy. One school of thought holds that water is equally and readily available over the entire range, so that irrigating the plants when there is available moisture in the soil is unnecessary. Another school believes that certain crop plants grow better when soil moisture is at field capacity and that adverse effects result as the water content of the soil decreases.

Most of the evidence put forward to support the first view has been produced by Veihmeyer and his associates (Conrad and Veihmeyer 1929;

Hendrickson and Veihmeyer 1929a, 1929b, 1934; Veihmeyer and Hendrickson 1927b, 1930, 1949). Their work was carried out with deciduous fruit trees with well developed root systems. The soil used in the investigations was mostly light sandy loam. They have shown that a moist soil has no optimum moisture content at which the trees grew best or at which the use of water was affected and suggested that optimum moisture conditions for growth may therefore be taken to cover a range of soil moisture from maximum field capacity to about the wilting coefficient. Hendrickson and Veihmeyer (1929a) extended this proposition to include the effect of moisture on all types of cultivated plants and went so far as to say that so long as the soil moisture fluctuated between the field capacity and the permanent wilting point, the grower could do nothing to influence the yields or growth by modifying the water relations between plant and soil. Summarising the various opinions and evidences in the discussion, Veihmeyer and Hendrickson (1955) concluded that "The results of investigation on the relation of plant growth to soil moisture show that the plants grow well throughout a wide range of soil moisture, but some investigators question whether they do so with equal facility throughout the entire range from field capacity to the permanent wilting percentage".

Other studies which throw some light on this aspect of the availability are the investigations of Beckett, Blaney and Taylor (1930); Cullinan and Weinberger (1932), Shaw and Swezey (1937), and Wadsworth (1934). Their conclusions are in accord with Veihmeyer's hypothesis.

There is, however, another school of thought which holds that not all the water between field capacity and permanent wiling percentage is equally available to the plant and that the growth rate of various plants decreases as the soil becomes drier. Even with fruit trees Lewis et al. (Lewis, Work and Aldrich 1934, 1935; Work and Lewis 1936) studying the influence of moisture on the growth rate of pears found that the growth of fruit was reduced whenever the soil moisture in the major portion of the root zone fell below 70 per cent. of the available moisture.

Certain experiments carried out on annuals, herbaceous perennials and cereals are not in agreement with Veihmeyer's hypothesis. Heck (1934) found that the growth of sugarcane was retarded when the soil dried out to only slightly below field capacity. Similarly Stoeckeler and Aamodt (1940) found that seedlings in a forest nursery made best growth when the soil was approximately at field capacity. Haynes (1948) reported that in fertile, well aerated soils, growth of corn plants increased with increasing soil moisture "almost to saturation". West and Perkman (1953) reported that the rate of water extraction progressively decreases over the whole range from wetting by irrigation to the moisture content when the trees begin to show the sign of wilting. Other investigators (Ayers, Wadleigh and Magistad 1943; Davis 1940; Hunter, Kelley and Somers 1950; MacGillivray 1949; Martin 1940; Wadleigh and Ayers 1945; Wadleigh and Gauch 1948) have obtained results which are not in accord with Veihmeyer's hypothesis. It should be noted that many of their experiments were carried out in containers and may not have reproduced field conditions.

Russell (1950, p.377) citing the work of Oppenheimer and Elze on citrus fruit, suggested that Veihmeyer's assumption will fail on light soils even when the roots are evenly distributed. These investigators (1941) believe that there is no clearly defined limit between available and unavailable water and that a decrease in soil moisture undoubtedly exerts physiological effects even above the permanent wilting percentage. Russell (1950, p.377) has further pointed out that Veihmeyer's assumption will fail whenever the plant roots cannot ramify throughout the soil zone sufficiently uniformly to extract all the usable water fairly rapidly, for once the soil in the immediate neighbourhood of the plant root is in the wilting range, water can only move very slowly from moister soil through this zone. Thornthwaite (1954) from the data of Halstead confirms that as the soil becomes progressively drier the evaporation diminishes. He also gives the evidences from the soil moisture depletion for a sandy loam under four types of cover (grass, oakwood, pine forests and moist sand) that the transpiration rate is a continuously decreasing function of increasing soil dryness. Mather (1952) quoting the experiment of Thornthwaite indicates that water use does not vary greatly within a considerable range of soil moisture value as long as the soil moisture is maintained above field capacity.

Several investigators have put forward explanations of the different results. Lewis, Work and Aldrich (1935) and Work and Lewis (1936) suggest that the moisture percentage of the soil in contact with the feeding roots may be at or near the wilting percentage, while at the same time the moisture content a few millimetres away may be much higher. In this way the average content for a normal soil sample would be well above the wilting percentage at a time when the tree shows serious need of water. The variability of soil and root distribution under some conditions are so great that it is difficult to appraise from soil moisture-content the response fruit trees make to soil moisture availability. Furr and Taylor (1939) stated "At the times when apparent fruit growth first showed that water deficit had developed it was usually possible to find soil moisture contents varying from within the wilting range to near the field capacity. Even in locations where root distribution and soil moisture extraction were more uniform, variations in soils moisture contents were so great that the use of averages of soil-moisture percentages proved unreliable as a measure of the water supply of the trees". Wadleigh and Ayers (1945) and Wadleigh (1946) have indicated that "the hyperbolic nature of the relationship between soil moisture percentage and moisture tension accounts for the frequent finding that for all practical purposes, plants may not show changes in growth responses while reducing the moisture percentage of soil from field capacity to nearly the wilting percentage".

Kramer (1949) after a review of the subject came to the conclusion that for all practical purposes in many sandy soils water may be regarded as being equally available over most of the range from field capacity to permanent wilting percentage as a result of the hyperbolic nature of the moisture tension curve. (In many light soils, over half of the readily available water is held with a tension less than 1 atmosphere and nearly 90 per cent. with a tension of less than 5 atmospheres. But in heavy clay soils less than half of the readily available water is held with a tension of less than 1 atmosphere, and only 75 per cent. is held with a tension of less than 5 atmospheres. As most of the water in coarse-textured soil, such as light loam soils, is held with a tension of less than 1 atmosphere, water can be regarded as equally available for practical purposes, but in fine-textured soils, such as heavy clay, where less than half of the readily available water is held with a tension of less than 1 atmosphere, a considerable part of the water in the lower part of the range is less available than that in the upper part. In such soils, water becomes limiting to growth before the moisture content is reduced to the permanent wilting percentage. The difference in the moisture tension curves for these soils may account for the disagreement that has arisen as to whether or not water is equally available to plants over the entire range from field capacity to permanent wilting point).

Although the problem of optimum soil moisture for plant growth is by no means completely solved, many of the points of apparent disagreement are of little significance in irrigation agriculture. Generally the soil moisture tension does not exceed 1 atmosphere in many soils until most of the available water is removed. Since the transpiration rates are generally high, the last portions of available soil moisture cannot safely be relied on. Hence, with most crops on non-saline soils it is best to irrigate when the soil moisture tension in the root zone approaches 1 or 2 atmospheres.

Richards and Wadleigh (1952) in their extensive review on the subject examined the soil moisture extraction data of Hendrickson and Veihmeyer and suggested that these may not necessarily indicate that over the linear extraction range the soil moisture is equally available for the maintenance of plant turgor and growth. They stress the difficulty of obtaining reliable information from field tests of the relation of soil moisture stress and the growth rate of plants in view of the many factors that enter into field experiments, some of which are outside experimental control.

However, there is considerable evidence to suggest that the vegetative growth of the plants is much more sensitive to varying degrees of soil moisture in the available range than is the reproductive phase of development. Even Adams, Veihmeyer and Brown (1942) found that irrigating cotton (on both Panoche clay and fine sandy loam) caused significant differences in vegetative growth due to variations in the levels of soil moisture within the available range, but observed no differences in the yield of cotton per plant. This was noted on both dry and sandy soil. The results of Wadleigh, Gauch and Magistad (1946) show that, although a decrease in stress below the wilting percentage gave increase in fresh weight of guayule, the percentage of rubber produced decreased at tensions below about 5 atmospheres.

At this stage it should be indicated that although transpiration and growth are both to a large extent controlled by the amount of water in the soil there is a definite demarcation between the two processes. There is plenty of evidence to support the view that growth is checked a long while before any effect on transpiration is noticed. According to Kramer (1949) Lewis concluded that the growth of maize depends primarily on an adequate supply of water at the growing tip. This is limited most frequently by excessive transpiration, the restricted absorption caused by dry soil being second in importance as a limiting factor. So it can be safely concluded that the growth of some plants begins to decrease almost as soon as the soil water content falls below field capacity before any noticeable effect on transpiration is noticed.

When this information is considered in conjunction with that cited by Richards and Wadleigh (1952) it becomes evident that water held in the so-called range of available soil moisture is not equally available to the plant; the growth of the plant ceases as the soil moisture approaches wilting point.

(b) Measurement of Soil Moisture

Various attempts have been made to determine soil moisture without resorting to the laborious sampling, weighing, and drying techniques. Although the gravimetric method using a soil auger or king tube sampler is still considered by many a reliable method, the chief objection (in addition to it being time - and energy - consuming), is the destruction of the sampling location to the extent that the measurements of soil moisture can never be made more than once in the same place; at the same time it is misleading for studying soil moisture movements, changes, and trends. For example, if soil samples were collected at different dates from the same field and if the samples varied in soil texture any difference in moisture noted could equally well be due to differences in texture as to movement of soil moisture. Several attempts have been made to eliminate and substitute the drying process firstly by measuring the changes in specific gravity of pure methyl alcohol when the moist soil is allowed to disperse in it thoroughly (Bouyoucos 1931), and secondly by determining the amount of acetylene gas evolved when calcium carbide is mixed with the moist soil

(Sibrisky 1935). These methods are, however, insufficiently reliable for accurate soil moisture measurements.

These methods, mentioned above, which are quite impracticable to the average grower faced with making day-to-day decisions, suffer from the disadvantage that no standard scale of values is possible, since the amount of water held in given volumes of different soil types is not related to the force, or moisture tension, with which the soil particles are holding the soil water. With the object of overcoming these disadvantages, two methods of measuring moisture content <u>in situ</u> have been devised for general use under field conditions. These are (1) by electrical means, and (2) by tensiometer or techniques based upon the so-called suction force of soils or capillary tension.

There are several electrical methods that can be used for the measurement of the moisture content of the soil. These include electrode, absorbent block and dielectric methods.

Briggs (1899), Gardner (1898), McCorkle (1931) and Whitney, Gardner and Briggs (1897) were among the first to propose to measure the soil moisture <u>in situ</u> by means of electrical conductance or resistance. Since small changes in the salt content of the soil solution affected the conductivity more than the amount of water that was present, measuring soil moisture by means of electrical conductivity has never proved successful. Shaw and Baver (1939a, 1939b), Fletcher (1939), Bouyoucos and Mick (1940a, 1940b), Anderson and Edlefsen (1942a, 1942b), Anderson (1943), and Edlefsen and Anderson (1941) proposed the electrometric measurements of soil moisture in terms of thermal conductance, resistance, and capacitance. Although the thermal conductance method and the capacitance method both offer theoretical advantages, as pointed out by Kelley et al. (1946) and Wallihan (1945) and others, they have not been developed to the point of becoming commercially available. Hence, they have not received as much attention as the Bouyoucos and Mick's resistance method, which is readily available.

(i) Resistance Methods.- Bouyoucos and Mick (1940a) used two parallel electrodes embedded in small blocks of plaster of paris. These blocks, often known as gypsum blocks, are buried in the soil and, after the eqilibrium has been established between block and soil, the block will gain or lose moisture with the soil. Electrical resistance of the block between the electrodes varies with the moisture content and the temperature of the soil, since the salt content, compaction, texture, and density of the block are constant. Thus resistance provides an indirect measure of soil moisture when the block is calibrated for a particular soil. Changes in the salt content of the soil solution also affect the relationship of the moisture content to electrical resistance. However, the error caused by the concentration of salts in the soil solution, is said to be minimised by the buffering action of the dissolved calcium sulphate in the gypsum block (Bouyoucos 1951). Of the many substances that have been tested for their suitability as absorbent blocks, plaster of paris has been found to exert the greatest buffering action. Aitchison, Butler and Gurr (1951) recommended that the effect of salts may usually be ignored on those soils in which the total soluble salts does not exceed 0.1 per cent. Ewart and Baver (1950) while studying the effect of salt concentration on the effectiveness of the gypsum blocks for making soil moisture readings in situ concluded that the gypsum blocks are reliable for measuring soil moisture when the salinity of the irrigation water does not exceed 2000 parts per million of NaCl. A salt concentration less than the amount in the block has only slight effects on resistance. The main serious drawback is that the blocks are not very sensitive on the moist end of the moisture curve. The fact that they can be used only on the dry end of the plant growth moisture range is a definite limitation in their usefulness in the field.

Considerable work has been done to increase the range of sensitivity of the gypsum block particularly towards the wet range. Colman (1946) has introduced a soil unit resistance method for determining soil moisture in which fibreglass is used as the porous dielectric. Each unit contains a thermistor which measures the temperature. Colman and Hendix (1949) have indicated that it is more sensitive in the wetter range (from pF 0 to 3.6) and therefore covers the region in which the gypsum blocks are insensitive. The chief weakness of the method is its greater sensitivity to the presence of smaller amounts of electrolytes (Ewart and Baver 1950). Bouyoucos and Mick (1948) and Bouyoucos (1949) have experimented with a number of new units and recommended both nylon and fibreglass units as acceptable ones for the complete range from saturation to the wilting point. Although nylon and fibreglass units provide greater sensitivity in the higher ranges of soil moisture than gypsum blocks, the serious objection to their use in the field is the imperfect contact with soil alternately wet and dry. The response of the unit to moisture changes in the soil is often erratic and unreliable under such conditions. The desirable features of the gypsum block as a buffer and a contact medium with the soil and glass fibre as an absorbing medium were combined in a modified fibreglass technique by Youker and Dreibelbis (1951). The unit so designed is claimed to measure soil moisture under field conditions from saturation to wilting. Bouyoucos (1954a) has modified his method by casting a complete nylon unit inside a plaster of paris block. This unit measures the moisture in the soil from near the saturation to a point above an air-dry condition.

A considerable drawback in the use of the gypsum blocks is their lack of durability in the wet condition, since under these conditions the blocks may dissolve and disintegrate in one season, a considerable handicap in investigations designed for long-term studies. An improvement in the durability of the block was made when Bouyoucos (1953) introduced the gypsum block impregnated with alcohol-soluble nylon resin. Bouyoucos (1954b) has introduced a new type of electrode adopted for gypsum blocks and has claimed to be sensitive to change in soil moisture content at a tension ranging from about 260 to 330 cm of water. Closs and Jones (1955) have described the construction of small cylindrical gypsum blocks which can be used near the surface of the soil. Croney, Coleman and Currer (1951) have introduced a new type of concentric electrode moisture gauge of small dimensions which is claimed to have the advantage of rapid response. The increased use of gypsum blocks for following soil moisture changes and scheduling irrigation has led Ahmed and Marsh (1955) to introduce new types of gypsum blocks cast in tubes at 6 inch intervals. It is claimed that the blocks-in-tubes idea permits:-

(i) Quick installation of a complete "string" of blocks, uniformly spaced throughout the root zone.

(ii) Intimate contact between the blocks and undisturbed soil and roots.

(iii) Elimination of back-fill, potential channels, compaction or looseness.

(iv) Easy removal at end of season for longer life.

(v) A shape in which concentric electrodes become a possibility.

Further work is necessary to substantiate these claims.

Cummings and Chandler (1940), Kelley _et al._ (1946) and Slater and Bryant (1946) have made extensive field tests to compare the operating efficiencies of tensiometers, sorption plugs, electrical resistance units and electro-thermal units under field conditions. The general conclusion seems to be that the resistance method (only Bouyoucos blocks were included) offer the most practical approach to soil moisture measurements _in situ_.

It has been shown by various investigators that the gypsum blocks can safely be used to measure the soil moisture tension in their sensitive zone (Aitchison and Butler 1951; Cummings and Chandler 1940; Haise and Kelley 1946; and Kelley _et al._ 1946). They function best in those soils that have moisture-tension curves with gradual slopes, that is on those soils that release moisture over a wide range of tensions (Baver 1956, p.297).

With the knowledge gained so far in the electrical resistance methods for measuring soil moisture it can be safely concluded that the nylon units are more sensitive at tensions less than 2 atmospheres and fibreglass units operate satisfactorily over the entire range of plant available moisture, but gypsum blocks function most effectively between 1 and 15 atmospheres.

(ii) Tensiometers.- The principle of capillary tension has been used by many investigators to measure moisture changes in the soil. The contributions of various workers to the development and use of tensiometers have been reviewed by Richards (1949a).

According to Richards (1949a) tensiometers have a unique advantage over other moisture-measuring devices now available because they measure a property of soil water which is directly related to the work plants must do against surface force action to extract water from the soil. It is said that, for some purposes, the calibration of tensiometer readings against soil moisture content is unnecessary.

Since the range of tensiometers, i.e. zero tension to near one atmosphere, includes over half of the available moisture from field capacity to permanent wilting percentage for the fine-textured soils and nearly 90 per cent. for sandy soils, the tensiometer can serve a most useful purpose in following changes in soil moisture.

As none of the resistance units are as sensitive as the tensiometer within the one atmosphere tension range, the best way in which to measure the soil moisture tension *in situ* would be the combination of the tensiometers and the gypsum blocks. The two will supplement each other, one covering the higher levels of water content, and the other the lower levels.

(c) Methods of Soil Moisture Control

Irrigation is the practice of supplementing that part of the actual precipitation which is available for crop production and to supply water to crops in the right amount, and when needed. The amount of water used in irrigation varies from place to place and from time to time as the natural precipitation varies. Knowledge of seasonal water requirement of different crops, the means by which to determine the time of water application, the process of effective and economical use of water by the plant, are some of the requirements for effective irrigation, which should be adjusted to the soil type, its texture, depth of the rooting of the crops, the types and age of crop, the weather and so on. Irrigation may be accomplished generally by flooding, by means of furrows, by sprinkling or by applying water underneath the land surface by subirrigation and thus causing the ground water to rise. One of the main requisites of good irrigation is the distribution of the water in the field as evenly as possible.

It has already been noted in an earlier context that it is impracticable to attempt to maintain the moisture content of soil continuously at any value other than saturation, field capacity, or permanent wilting percentage. So instead of attempting to maintain a definite amount of moisture in the soil, the moisture content has to be allowed to fluctuate through a definite range. Any attempt to wet the soil in the field (Veihmeyer 1927) or in a container (Hendrickson and Veihmeyer 1941) to less than field capacity will simply result in part being wetted to field capacity while the remainder is left unwatered. The most practical method of studying the effects of limited water supply on plant growth is to allow the plants to dry the soil to some moisture content well below the field capacity or even approaching the permanent wilting percentage, before adding water to bring it back to the field capacity.

Several attempts have been made to control the soil moisture under field conditions and to determine the time to irrigate the crops. In many attempts the regulation of time of irrigation was by such capricious methods as the feel or appearance of the soil or by the appearance of the crops. These methods have never proved to be entirely satisfactory and much experimental work has been carried out on the control of soil moisture, using resistance blocks and tensiometers to indicate the moisture status of the soil. Tensiometers have not, however, been used in this investigation and are not considered further.

(i) Gypsum Blocks.- Several investigators have used Bouyoucos type blocks to determine the irrigation interval and to control the soil moisture under field conditions. The blocks are installed at various depths, depending upon the type of information required. The soil is then allowed to dry out to a predetermined level of soil moisture tension or resistance as indicated by the resistance readings of the block. Soil moisture tension readings are obtained from the calibration curve, and sufficient water is added to bring the entire depth to the field capacity. Since the sensitivity of the gypsum blocks startsfrom about 1 atmosphere, the soil moisture tension will range from 1 atmosphere to 15 atmospheres above which is not available for ordinary growth of the plant.

The gypsum blocks have been used quite successfully for determining the irrigation interval and controlling the soil moisture under field conditions. (Ewart 1954; Hunter and Burtch 1955; Rouse, Willhite and Miller 1955). Use of gypsum blocks, as an economic and efficient instrument to determine when and how much to irrigate, can be illustrated from the four different irrigation treatments that were carried out on tomatoes and sweetcorn by Schleusener, Peikert and Carolus (1949). The highest yield in both crops were reported to have been obtained from the treatment in which the total irrigation of 4 inches was given according to the block readings. Others receiving three or four times as much water based on empirical methods did not yield so well. Unfortunately the authors do not give the resistance readings at which they irrigated but mention only that water was given when the blocks showed the available moisture in the soil was less than 50 per cent.

To eliminate the possible danger of over-irrigating or under-irrigating Bouyoucos (1950) introduced a practical soil moisture meter, calibrated to read directly in percentage of available moisture in the soil. This is claimed to be a simple, quick and practical method of measuring the available moisture content of soils and also indicates when and how it is necessary to irrigate and also the depth of penetration of water. He recommends that for all practical purposes, the meter can be used to measure the approximate percentage of available moisture in almost all soils.

In most soils fertilisers do not affect the performance of the gypsum blocks (Bouyoucos 1951). The effect of salt concentration was found to be most pronounced in the highest level of water content and is practically negligible in the lower level of water content. Bouyoucos considers that even if the soil contains reasonable amounts of salts or fertilisers, the method will give satisfactory information below 95 per cent. of available water content on the moisture scale. He stressed that errors in the method due to fertilisers are only temporary, for during the growing season the plant nutrients are being used up rapidly by the plants, or are being leached out, and do not accumulate in the soil. He concludes that his study indicates that the irrigation moisture meter is reasonably accurate from field capacity to the wilting percentage for practically all soils with medium to low salt content.

A more precise approach to irrigation was suggested by Bouyoucos (1952) which includes a new electric automatic irrigation system, which is at present mainly in use for watering in greenhouses. The nylon unit used in the apparatus is the centre of this unit which actuates the controller to turn the water on and off according to the need of the soil for water. The scale on the meter is calibrated to read from 0 to 100 per cent. of available water. He (1956) has developed a new alternating current type of moisture meter which measures not only the percentage of available water but also the corresponding resistance in ohms.

Gypsum blocks have been used extensively for determining the irrigation interval for irrigating sugarcane on large acreages in Hawaii (Ewart 1951; see also Baver 1956, p.316). This is reported to have saved a number of irrigations, and has resulted because water was applied only when readings indicated their need, and not because a fixed interval of a number of days had elapsed. Baver (1956, p.317) quoting the work of Ewart (1951) seems to indicate that irrigating the soil at a tension equivalent to a resistance block reading of 5000 ohms saved about 27.8 acre-inches of water and at the same time yields of sugarcane were slightly superior to previous record yields from the same field. Plaster of paris blocks are being used successively to define depths of wetting, rate of removal, irrigation interval control in experiments, irrigation control in different soil types on a field scale, and the location of dry spots (Hawaiian Sugar Pl. Ass. 1952, p.20).

Butler (1951) using the resistance pattern diagram of gypsum blocks calculated the amount of water stored and has also demonstrated that gypsum block technique can be used to study the soil moisture regime under a simple crop rotation. As gypsum blocks are not sensitive at approximately field capacity or wetter, his results indicate that they are more reliable when the soil is undergoing uniform drying and under these circumstances the interpretation of resistance in terms of both soil moisture tension and soil water content is possible.

Gypsum blocks have been used to measure the seasonal changes in the soil moisture tension throughout the depth of the soil profile (blocks were installed up to 6 feet) and to mark the arrival of wetting and drying fronts for three successive years (Aitchison and Holmes 1953). It is suggested that the gypsum block moisture meter may be used to determine a datum for calculation of total available water in the soil. It has been shown that the gypsum block can be used to measure the soil moisture changes and changes in soil moisture tension during three successive seasons in the crop rotation (Butler and Prescott 1955). These authors indicated that evapo-transpiration loss from wheat and pasture in relation to available moisture can be estimated by this technique.

It can be safely concluded that the gypsum block, within the limits of its sensitive range, is probably the most reliable and moderately inexpensive device available at present for use in the control of the soil moisture economically and efficiently *in situ* in non-saline soils.

EXPERIMENTAL METHODS

(a) Site and Previous History of the Field

An area of approximately ½ acre was selected north-west of the laboratories of the Waite Institute on the gentle alluvial-colluvial slopes of Pre-Cambrian origin (Litchfield 1951). The ground surface has a slope from south-east to north-west; the outer corner of the plot C (Fig. 1) was at the highest level in the experimental area and was taken as a reference point. The diagonal slope from plot C to the outer corner of plot L was 9 feet, i.e. about 5 per cent. The slope from south to north was less than a foot, while the slope from east to west was about 2 feet. It was appreciated that the slope of the ground would render irrigation treatments more difficult, but no other site was available.

During 1951-52 the field was fallow. Spaced plants of *Medicago tribuloides* were grown in 1953 and the area was cultivated after plants had been harvested.

(b) Description of the Soils

The soils of the area are representative of soil conditions over a major part of the Institute being dominated by red brown earth of the Urrbrae series. There is an occurrence of a pattern of soils with waterworn stones and gravels associated with hydromorphic affinities. These stones are found at variable depths in the profile from 1 to 6 feet. The soil is classified (Litchfield 1951) as a slightly hydromorphic red podzolic soil. The following characteristics were noted while sinking the blocks, and by reference to Litchfield's paper

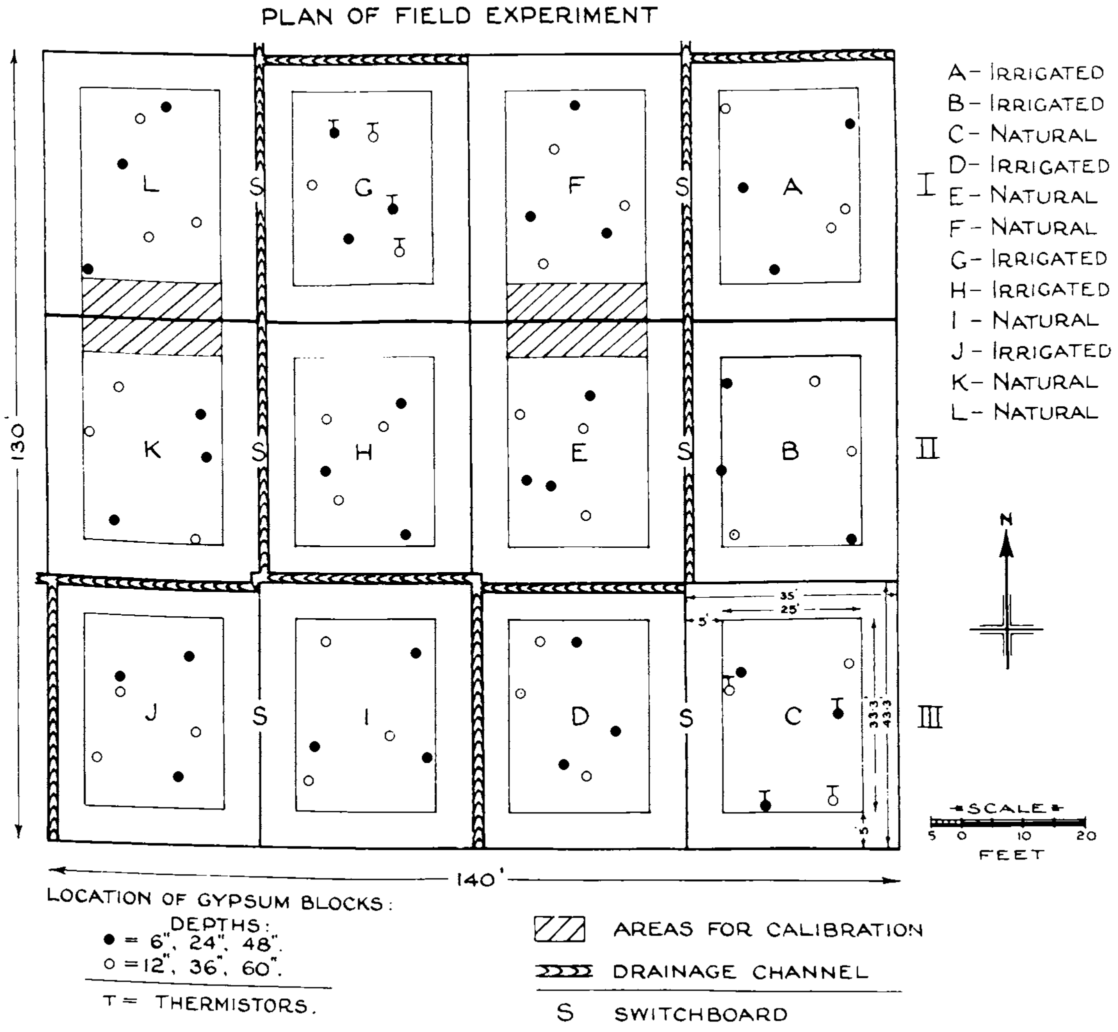

Fig. 1. Plan of field experiment.

Depth (in.)	Texture	Clay (%)	Colour
0 - 4	Loam	18.0	Brown
4 - 9	Loam	21.8	Light red brown
9 - 18	Clay	47.9	Brown red slightly stony
18 - 27	Clay	61.1	Red brown stony
27 - 36	Clay	60.2	Red brown stony
36 - 45	Clay	41.2	Yellow red stony
45 - 54	Clay	37.6	Yellow red or yellow brown-stony

(c) Gypsum Blocks

For the present investigation the Bouyoucos type of gypsum block (Bouyoucos and Mick 1940) was used. All blocks used were of standard shape with two parallel electrodes 2 inches long and $\frac{3}{4}$ inch apart.

Two groups of these blocks of this pattern were used. These comprised:

(a) 300 blocks with appropriate length of leads were obtained from National Instrument Co. Pty. Ltd., Sydney. These will be referred to as 'New Blocks'.

(b) 100 blocks which were already in the possession of the Institute. They were approximately one year old but had not been used. These will be referred to as 'Old Blocks'.

(d) Design of Experiments

An area of 0.42 acre of 140 x 130 feet was divided into three equal blocks. Each block was further divided into four equal plots of size 43.3 x 35.0 feet (approximately 0.034 acre) each having two treatments. A strip 5 feet wide on either side of the plot and 5 feet all around the field was left for border effect. In order to prevent the water running off to non-irrigated plots, a drainage channel of 12 inches wide and 6 inches deep was dug on the borders of irrigated and non-irrigated plots. The yield and other morphological observations were therefore taken from the sampling area of 33.3 x 25.0 feet (approximately 0.019 acre). The actual lay-out followed in this work is shown to scale in Fig. 1.

(e) Calibration Plots

The border areas between the plots E and F, and K and L, each 25 x 10 feet, were utilised for calibrating the gypsum blocks under field conditions (Fig. 2). Each plot has 18 blocks, 3 blocks in each of 6 holes.

(f) Soil-Moisture Tension Measurements

It was decided to measure soil moisture tension down to five feet. The depths selected were 6, 12, 24, 36, 48 and 60 inches. The location of holes for the instalment of blocks within each plot were chosen by dividing the plot into six equal parts and a location allocated by random positioning in each part. The depths 6, 24 and 48 inches were allocated to three holes at random and the depths 12, 36 and 60 inches were allocated to the remaining three holes. This method of arrangement of vertical distances between blocks was adopted in order to determine whether or not the depth of penetration of water was uniform throughout the profile.

Since the average plough depth is approximately 3½ to 4 inches, it was decided that the minimum depth at which a block could safely be installed was 6 inches. The average block resistance readings of 6, 12, 24, 36, 48 and 60 inches were assumed to represent the values on any one occasion of between 0-9, 9-18, 18-30, 30-42, 42-54 and 54-66 inches respectively. It will be seen that the total number of gypsum blocks

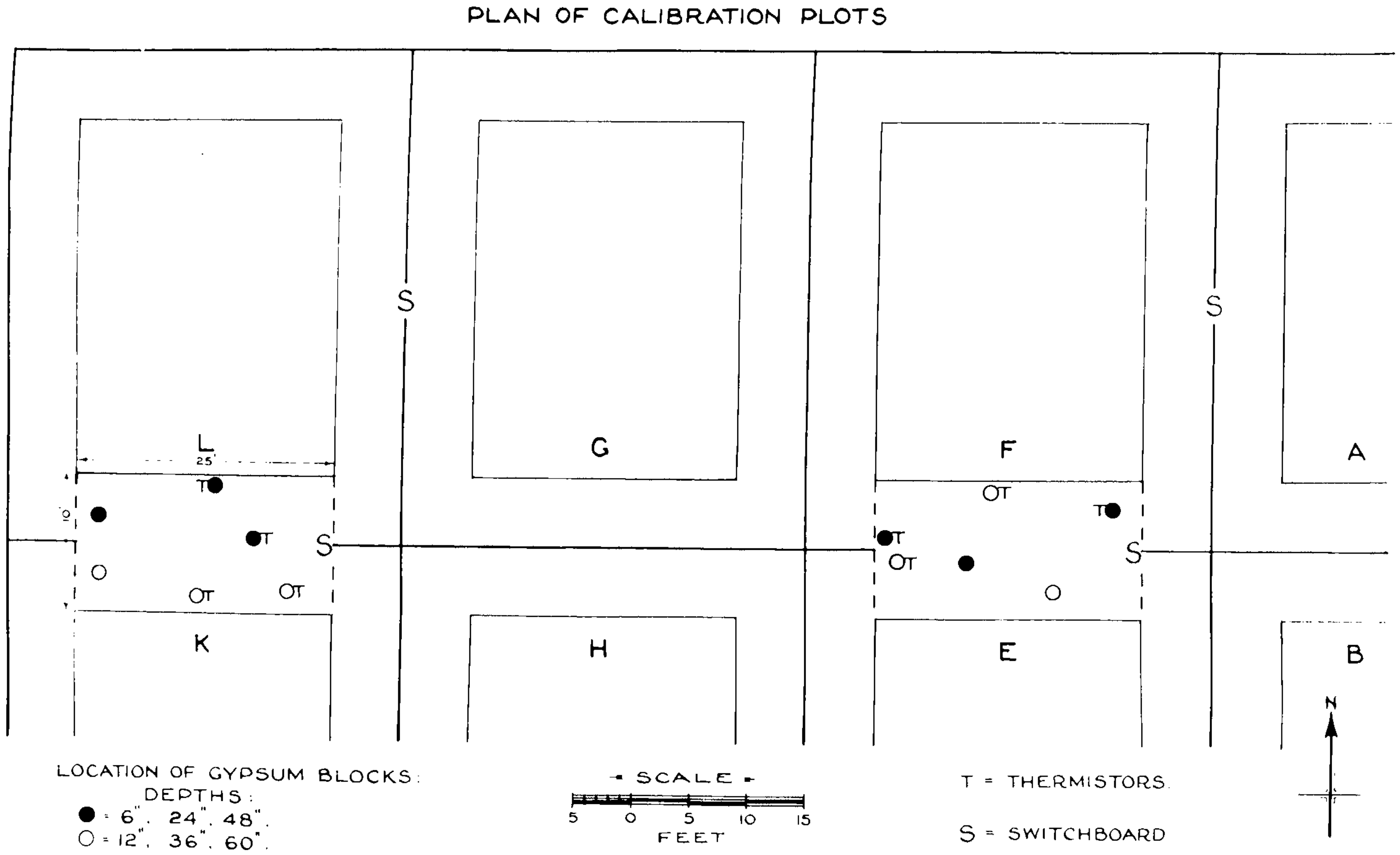

Fig. 2. Plan of calibration plots.

required for this study was 216. Duplicated thermistors for measuring soil temperature at these depths were taken to be sufficient for correction of block readings and thermistors were therefore placed in plot C (non-irrigated) and plot G (irrigated).

(g) Installations

One of the main advantages of the electric resistance method over gravimetric methods is that after installation the readings can be taken as frequently as desired without destroying the sampling area. It is necessary, however, for the blocks to be placed in close contact with the soil with the minimum disturbance of soil and vegetation. In order to eliminate as far as possible the uneven germination and variable stand of lucerne due to the trampling of the soil surface near the holes and trenches, and to avoid breaking the growing roots of lucerne, it was considered advisable to install the blocks and thermistors before any cultural and sowing operations were done. This procedure also has the advantage of allowing the growing roots of lucerne to dry out the soil around the blocks evenly.

(i) Pre-installation Operations.- The field was first ploughed to a depth of 3½-4 inches on 21st April 1954, and was subsequently harrowed. The experimental area and the positions of holes were marked out.

(ii) Importance of Proper Installations.- Clearly the success of the experiment depended largely on the careful installation of the blocks. The best time for installing them is, if possible, when the soil is moist, not dry and hard. The packing of the soil around the block and thus optimum contact between block and soil can be more easily obtained in moist soil than when the soil is dry or is in a very wet plastic condition.

Unless the excavated soil is replaced to its original density the resistance readings may not be representative of the soil as a whole. If this is not done an artificial channel may be created through which water can travel rapidly to the units, so that after a rain or irrigation soil moisture samples at a given depth are still dry, whereas the resistance of the corresponding unit has dropped significantly. This problem is especially serious when a natural soil has a layer of low permeability and under such circumstances it is difficult to duplicate when refilling. On the other hand, if the excavated soil is not packed to the same density in its appropriate horizon there is every possibility that heavy unnatural root growth adjacent to the units may result in immoderate transpiration drains. A consideration of the literature suggests that the importance of such effects has never been fully examined.

(iii) Uniformity Tests of Gypsum Blocks.- Bouyoucos and Mick (1947) suggested a simple uniformity test for the rectangular (Bouyoucos) type blocks. The blocks were immersed in distilled water for 24 hours, allowing them to become completely saturated. The resistance of each block was then measured. Tanner, Abrams and Zubriski (1948) modified this technique by wetting the blocks in a vacuum desiccator and found that it gave more accurate results. Aitchison, Butler and Gurr (1951) found that differences of resistance detected with this technique persisted in the same order throughout the whole moisture range. They hold that a tolerance of ± 5 per cent. was acceptable. Similarly, the blocks used by Pereira (1951) had a saturated resistance which lay within 5 per cent. of the mean of 50 blocks.

In the present investigation the grouping of gypsum blocks followed strictly the methods used by Aitchison, Butler and Gurr (1951). The mean resistance of the new gypsum blocks when suspended in air immediately after removal from the water was found to be approximately 550 ohms and blocks with resistance between 530 and 570 ohms were accepted. In this way 250 'new' blocks were selected. Similarly the old blocks with the resistance between 960 and 1040 ohms were selected; the mean resistance being approximately 1000 ohms. Fifty blocks were thus selected.

(iv) Identification Tags.- The blocks and thermistors were provided with aluminium tags bearing the name of the plot, depth and serial number for ease of identification.

(v) Method.- In this experiment the installation procedure followed that of Aitchison, Butler and Gurr (1951). The blocks were placed perpendicular to the ground surface with the middle of the block at the appropriate depth. After installing the blocks the leads were led downwards before being brought to the surface in order to prevent water movement along the wires to the blocks. All the six leads from one hole were brought up to about 6 inches below the surface; they were then taken in trenches 6 inches deep (photograph 1) to the switchboard pole. All blocks were installed similarly in plots and a tag at the end of the wire near the pole made it possible to identify the wire. The leads were soldered to the switchboard after completing the instalment of blocks in all the plots (photograph 2). Soil was replaced to its original horizon and repacked as far as possible to its original density. A small sample

Photograph 1. View of trenches dug to take the wires to the switchboard. In the background is the pole for the switchboard. The positions of holes are marked by pegs.

Photograph 2. Reverse side of the switchboard.

of excavated material from each depth was taken for determination of the permanent wilting percentage and for such other analysis that might be required. Little difficulty was experienced when installing the blocks at 6 and 12 inches but at 24, 36, 48 and 60 inches the soil was found to be in a plastic state. Under these circumstances the soil was moulded around the block in the form of a 3 to 4 inch diameter ball as suggested by Aitchison, Butler and Gurr (1951).

(vi) Thermistor Mountings and Installations.- Mounting technique of thermistors was the same as outlined by Aitchison (1952b). It was suggested (Aitchison 1953) that the time lag of this type of mounting is unimportant in the determination of soil temperature. With the slow rates of change of temperature occurring in the soil it may be assumed that the delay in response of thermistors was entirely negligible. As suggested by Aitchison, Butler and Gurr (1951) duplicate thermistors irrespective of block numbers at each depth were used. Hence each two plots had 12. The installation of thermistors was carried out as for blocks. A cold setting P.V.C. paint was used in the field for insulation purposes (Aitchison 1952b).

(h) Switchboard

Triple-contact phone jacks (only two contacts used) mounted on 6 feet high and 4 x 4 inch wooden posts were used for switchboard. On each side of a pole, a bank consisting of 20 jacks was used for each plot, two jacks being left unused. Where thermistors were used, there were 30 jacks (18 for blocks and 12 for thermistors). The triple contact phone plug (only two contacts were used) was used (photograph 3) for connecting the

Photograph 3. Front view of switchboard and the triple-contact phone jack used to connect the bridge with the block or thermistor. Roman numerals are the terminals of thermistors and Arabic are for the blocks.

meter to the block or thermistor. The 3/16 inch diameter plug and jack was found simple and easy to operate. Since there were no moving parts such as are found in multiple-pole switches and a uniform contact was made each time a plug was inserted, they proved to be fast and reliable. No confusion of leads could occur as only one operation was required to make two contacts. About 10 minutes were required to take the reading of 18 blocks. The whole switchboard was covered with weather-proof containers.

(i) Calibration

The resistance of the gypsum blocks gives only an indirect measure of soil moisture or soil moisture tension, and the most important step in the use of gypsum block is the determination of an accurate calibration factor for converting electrical resistance of the blocks to soil moisture content or soil moisture tension. The resistance of the gypsum blocks (when temperature and other variables are constant) is determined directly by the moisture content of the blocks and indirectly by the moisture content of the soil. When the moisture content of the block is in equilibrium with that in the soil surrounding the block, the force with which the water in the block is held will be the same as the force with which it is held in the surrounding soil. Thus the resistance and the moisture content of the block will remain the same as long as the force with which the water is held is the same and this will be independent of soil type.

The moisture tension in the soil varies with the moisture content of a given soil in a given physical condition, the soil particle size, and the packing of the soil. Since in any chosen position in the soil the structure will tend to remain constant during the season, the variation in soil moisture tension shown by the block resistance will correspond to changes in the moisture content. It may be added that there is a unique advantage in expressing the block resistance in terms of soil moisture tension rather than soil moisture percentage, since it measures a property of soil water which is directly related to the work plants must expend to extract water against surface force action from the soil. Soil moisture tension is, moreover, independent of texture, structure or composition of the soil. For this reason it is clear that regardless of soil type, tensions are directly comparable with each other. A particular tension in any type of soil indicates the same degree of water availability to the plant without reference to the nature of the soil. Consequently there is no necessity to calibrate for each horizon of soil when only pF* is under consideration.

(i) Gypsum Blocks.- Several investigators have calibrated the block resistance in terms of soil moisture tension (Aitchison and Butler 1951; Closs 1954; Cummings and Chandler 1940; Haise and Kelley 1946; and Taylor 1955). Aitchison and Butler (1951) suggested that the shape of an average resistance tension curve may be taken as representative of the shape of the curve for each individual block and concluded that over most of the sensitive range of the blocks this curve approximates to a straight line and further, that within this range all blocks of a particular type have a characteristic constant relation between pF and log R† (i.e. a constant characteristic

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* The terms pF is used throughout the text to denote the logarithm of the tensions (expressed in cm of water) of the soil water. This is not strictly in accordance with Schofield's (1935) definition, since it does not include the effect of soluble salts.

† The term log R is used throughout the text to denote the logarithm of the block resistance in ohms.

sensitivity). This is sustained by Taylor (1955) who also suggested that uniform block resistance will permit the use of a single calibration curve. Hence there is no need to calibrate each block so long as the blocks are selected from the same batch. Moreover, it has been claimed (Aitchison and Butler 1951) that the differences of block resistance persist in the same order throughout the whole sensitive range of blocks.

The calibration of gypsum blocks for this investigation was carried out as outlined by Aitchcison and Butler (1951) using the pressure membrane technique developed by Richards (1941). Twelve blocks were used (6 new and 6 old). The relation between mean block resistance (log R) and the corresponding pF is shown in Fig. 3. The resistance of 6 individual blocks when they were at equilibrium at a particular value of pF have been plotted for both types of block indicating the range of variation in resistance among the blocks themselves. In plain plaster blocks and in the concentric plugs the standard errors of about 12 and 15 per cent. (Taylor 1955) were low enough to permit the use of a single calibration curve. It has been further suggested by Taylor that the standard error for the difference between blocks, if selected as suggested by Tanner, Abrams and Zubriski (1948) would be less than 12 per cent. All the blocks used were selected from the same group, and the standard error of resistance was $1\frac{1}{4}$ per cent. for new blocks and $1\frac{3}{4}$ per cent. for old blocks which was thought not to be great enough to affect the calibration curve. The drying curve was used since the investigation was mostly concerned with soil under these conditions.

It is clear from Fig. 3 that both sets of blocks are sensitive throughout the range of pF 2.9 to 4.2 (and higher). The old blocks do not,

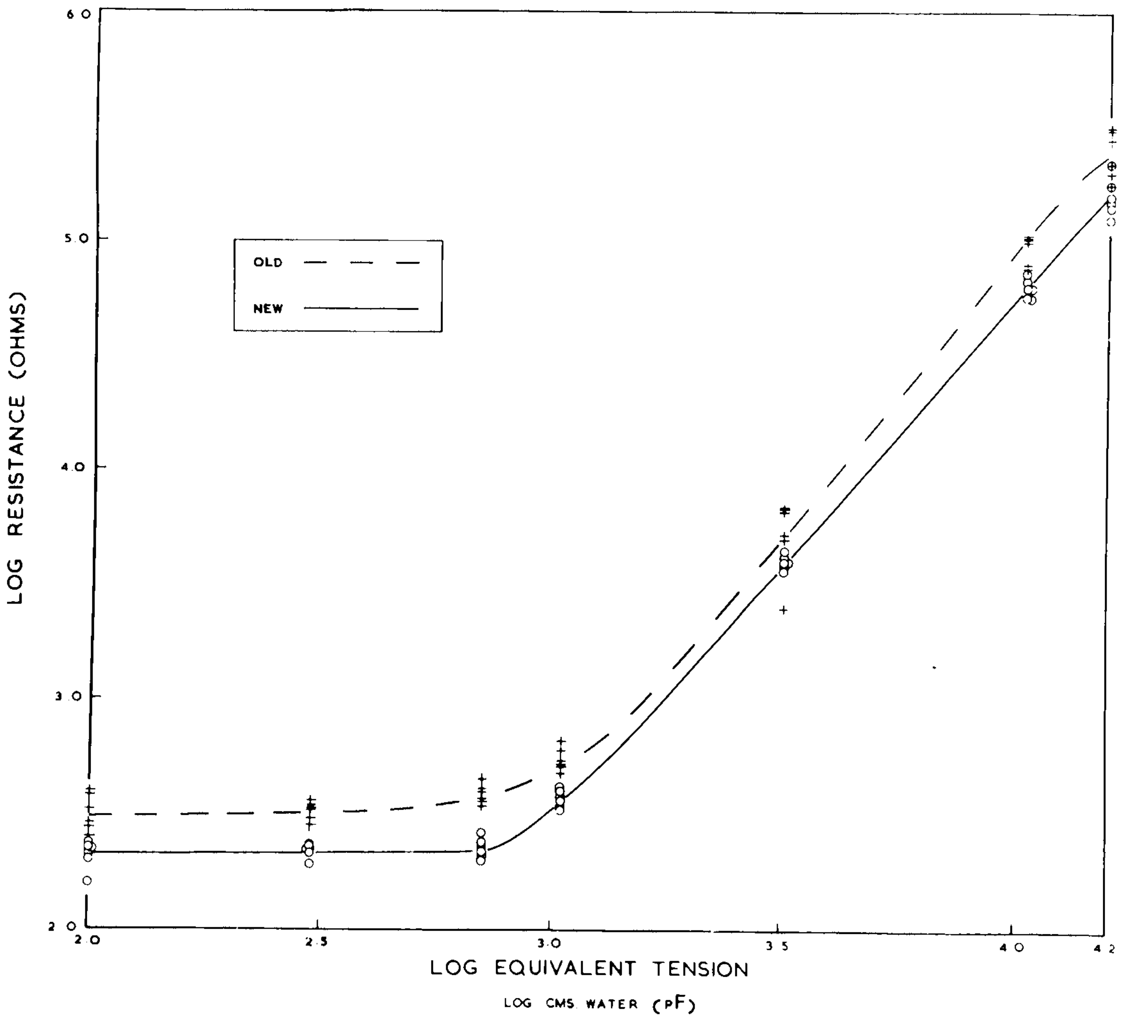

Fig. 3. Resistance-tension relationships for gypsum blocks (old and new)

however, seem to be as sensitive as the new blocks, particularly at values around pF 2.9 and 3.0. It was thought that this would not have any serious effect on the final results as only six of these blocks were used (three each in two plots). These two calibration curves have been used throughout this study to convert the temperature corrected block resistance (log R) to pF.

(ii) Thermistor Calibration.- Aitchison (1953), and Richards and Campbell (1948) have indicated that it is necessary to calibrate every thermistor separately and this was accordingly done. The measuring bridge and the thermistors used in the present investigation are the same type as described by Aitchison (1952a,1953). Calibration was made in a thermos flask containing water at the desired temperature, the cork of the thermos flask having two small holes through which the thermometer and the leads from the thermistors were inserted. The thermos flask was mounted on a small shaking platform, and a standard thermometer graduated to 0.1°C was used. Before taking the readings, 5 minutes were allowed for thermistors to come to equilibrium with the temperature of the water. Fig. 4 shows the relation between dial readings of the bridge and temperature for three thermistors. All the curves, of which only three are shown, indicated that an approximate linear relationship exists between dial readings and temperatures. Aitchison (1953) has shown that the relation between potentiometer setting and thermistor temperature is linear and accepts the relationship between thermistor resistance and temperature as

$$R_T = aT^{-c} \exp{(b/T)} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; (1)$$

where a, b, and C are constants,

and T = degrees Kelvin,

R_T = thermistor resistance.

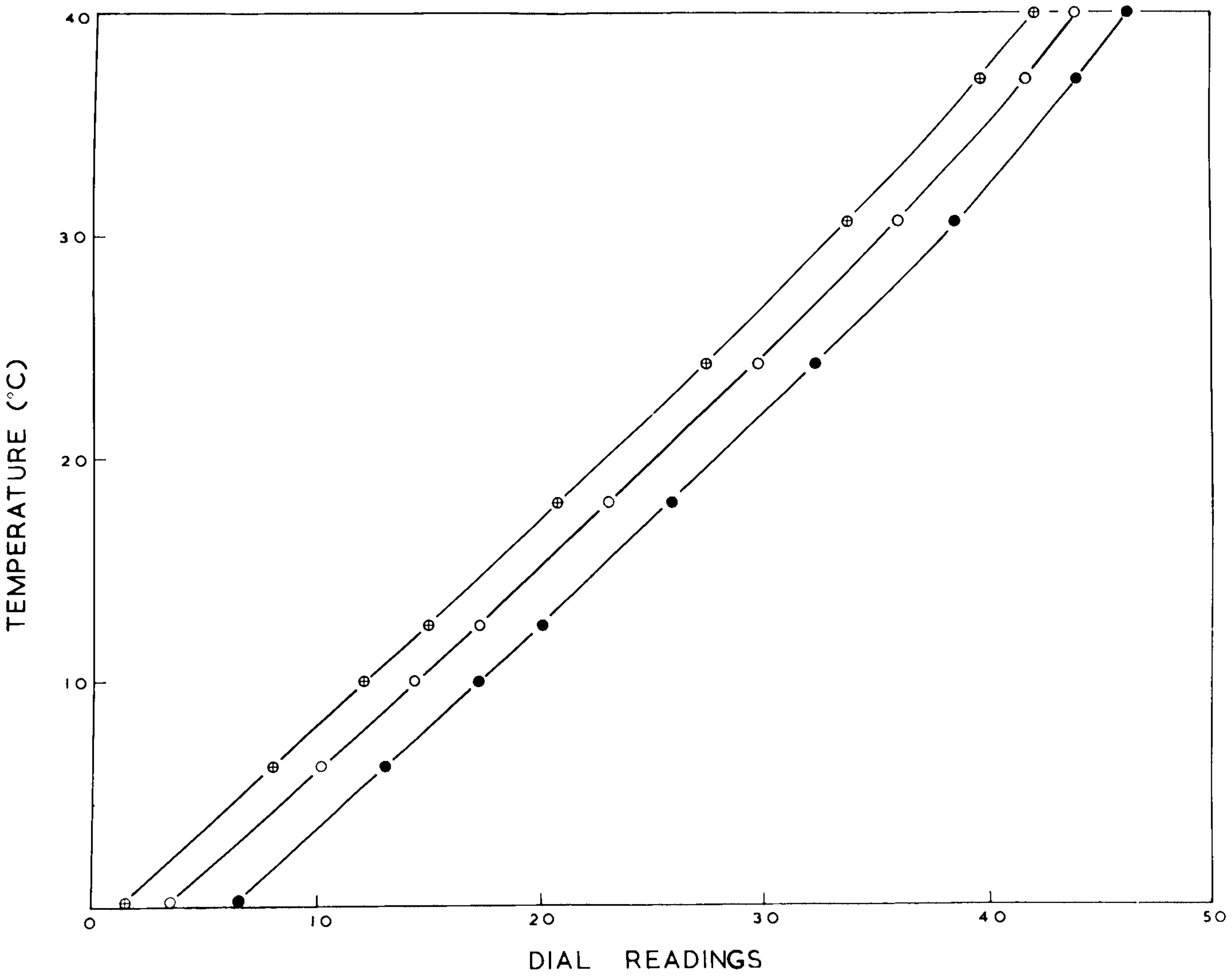

Fig. 4. Calibration of 3 randomly selected thermistors using soil moisture and temperature bridge.

He states that the expression -

$$R_T = a \exp (b/T \quad . . . . (2)$$

is usually used as an approximation since the constant c is usually small and may be ignored for a small range of T. However, Aitchison points out that a moderate degree of variability between thermistor temperature and potentiometer setting may be expected for most of these semi-conductors, with the result that the values a and b in equation (2) may not accurately be the same for each thermistor. He suggests that this is the reason for the variability of the slope of the curve and for the considerable displacement between the curves. However, these curves indicate that the relationship between the two are adequate for the degree of precision required for the correction of block readings. For the present investigation 50 thermistors were calibrated to the range of 0 to 40°C.

(j) pF-Moisture Content Relationship

After establishing the relationship between log R and pF, it is necessary to find the relationship of pF and soil moisture content for an undisturbed soil. This has to be done for a number of depths since certain soil characteristics are not constant throughout the profile.

The curve showing the relation between pF and moisture content varies widely between soil media of different textural characteristics (Haines 1930; Rogers 1935; Richards and Lambs 1937). Furthermore, the soil holds more water at a given tension when water is being withdrawn than when it is being added, so that at a constant temperature the pF of the soil water at a given moisture content depends upon whether the moisture content is increasing or decreasing. In view of the difference between the shape and position of the wetting and drying curves (Haines 1930; Richards 1938), Russell (1950, p.349) contended that there is no unique pF-moisture content curve for a soil. The hysteresis effect has been observed, studied and measured by many workers (Richards 1949a). Here as noted earlier, the drying curve has been adopted because the soil was in this part of the cycle when most of the measurements were made.

(i) Laboratory Calibration.- In the present study a pressure membrane apparatus as developed by Richards (1941, 1947, 1949a, 1949b) was used. Controlled air pressure for the apparatus was obtained by the use of a water column for pressure up to 300 cm of water, and by a two stage regulator valve for high pressures up to 15 atmospheres. The whole of the apparatus was maintained at a constant temperature of 20°C.

Samples from depths of 6, 12, 24, 36, 48 and 60 inches were taken from an undisturbed site (plot A), put in the pressure membrane apparatus and allowed to wet very slowly for 6 hours. The thickness of soil samples used were approximately 1 cm. The soil water was then subjected to various tensions. At equilibrium, tensions were noted and moisture percentage of soil on dry weight basis was determined. Three samples for each depth were subjected to each tension, so that altogether 104 samples were handled. The soil for all depths was subjected to a series of six pF steps in order of 2.00, 2.48, 3.02, 3.50, 4.02 and 4.20 and the results are plotted in Fig. 5.

(ii) Field Calibration.- Since the relationship of pF to soil moisture content for any soil is dependent upon a number of factors such as size of particles, degree of compaction and amount of water present, direct

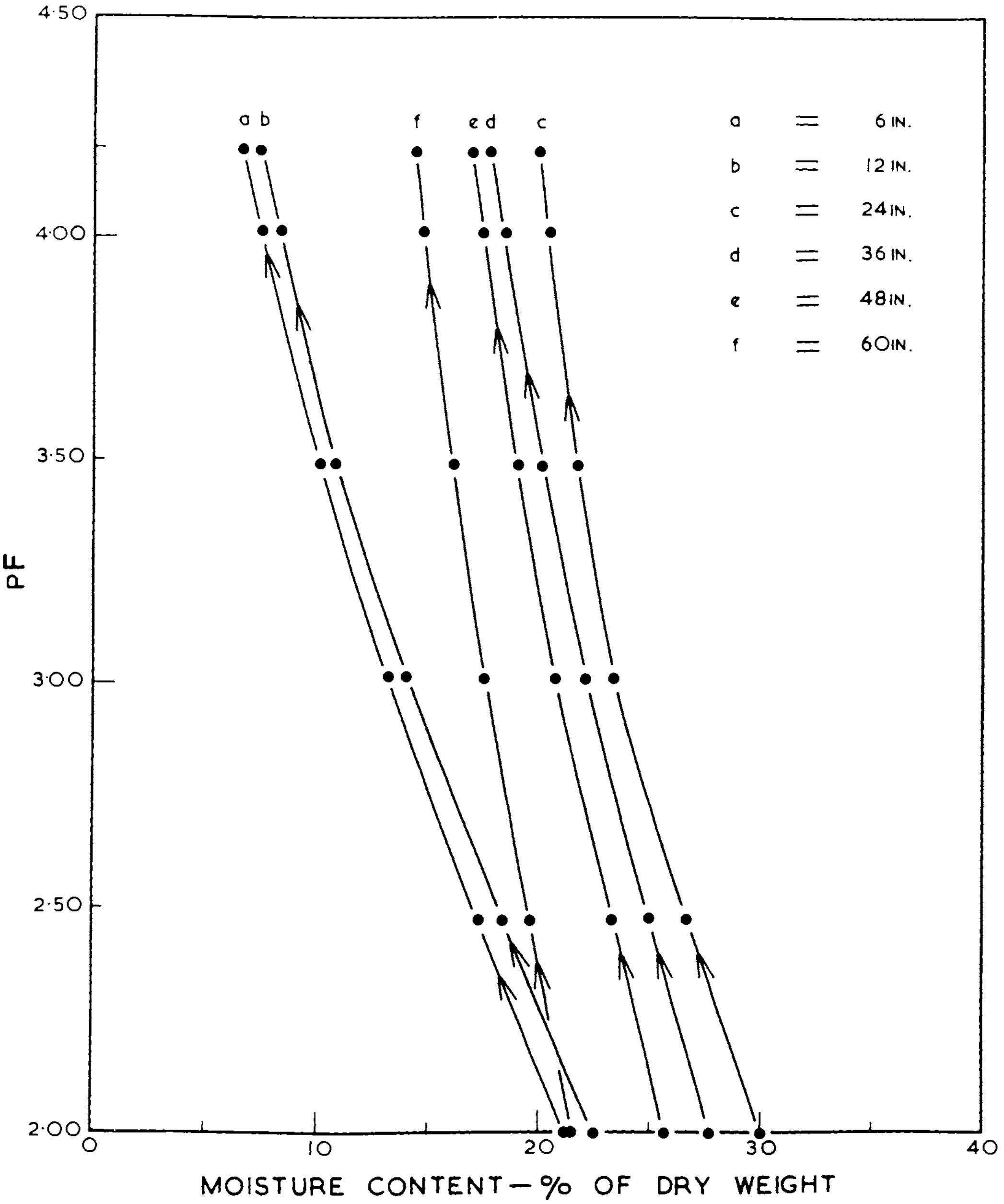

Fig. 5. pF - moisture content curves of soils (6 depths)

calibration under field conditions was also attempted. It was, however, anticipated that there might be a considerable disparity between the physical behaviour of a disturbed laboratory sample and the undisturbed material, particularly in heavy textured soils or lighter textured soils of low water stability.

Due to the large variation between samples in soil moisture content ascribable to structure and texture (Aitchison, Butler and Gurr 1951), a large number of samples are required to establish a reliable field calibration. It was suggested that due to differences in the soil structure the water content of a soil horizon may vary widely from one place to another in the same horizon even when the energy status of the soil moisture remains constant over the same distance.

The first requisite of field calibration is to take the soil sample close enough to the block to represent the same moisture condition, yet not close enough to disturb the natural soil and moisture relations at the block. The area should be large enough to provide for repeated samplings.

Soil moisture samples were taken from the calibration plots only on selected occasions when uniform soil moisture tension or pF conditions were shown by all replicate blocks at that depth, as suggested by Aitchison, Butler and Gurr (1951). Under the conditions of the present experiment soil samples were taken when at a particular depth the three blocks gave similar resistance values. Soil samples were taken with 4 inch augers from 6, 12, 24, 36, 48 and 60 inches depth, corresponding to the depth of blocks. Samples were placed in 4 oz. metal cream tins with tight lids and taken to the laboratory for determination of moisture content. On the average six samples for each depth at each occasion were taken on each of three occasions.

Fig. 6 shows the relationship between the resistance of the block (new and old respectively) and moisture content for all the depths. Each moisture content value is plotted from the abscissa against corresponding resistance (log R) measured on the ordinate. The pF scale is also given on the other side of the graph for comparison. It should be stressed that the points shown were those obtained from the direct field sampling, while the curve drawn is that obtained from pF-moisture content, and pF-log R curves. The points obtained at the 6 and 12 inch depths agree fairly well with the laboratory curves, while at other depths the agreement is less satisfactory. The agreement at the surface may have been due to better aeration of the laboratory samples and the surface soil in the field. Under these conditions, carbon dioxide can diffuse readily to the atmospheres. At lower depths, diffusion is restricted and the carbon dioxide level increases, thus bringing more salts (the bicarbonates) into solution (Russell 1952) and consequently lowering resistance at given moisture contents. This would probably explain the greater discrepancy of the laboratory curves with increase of soil depth. Field conditions of aeration at lower depths would be difficult to duplicate in laboratory samples. The hysteresis between wetting and drying of the soil may also explain part of the overall difference between the laboratory and field curves. Laboratory curves are drying curves throughout while field curves are based on soil samplings interspaced by rain and depletion periods, and thus may have been a combination of drying and wetting curves. Other probable causes for the discrepancy are moisture gradients in the

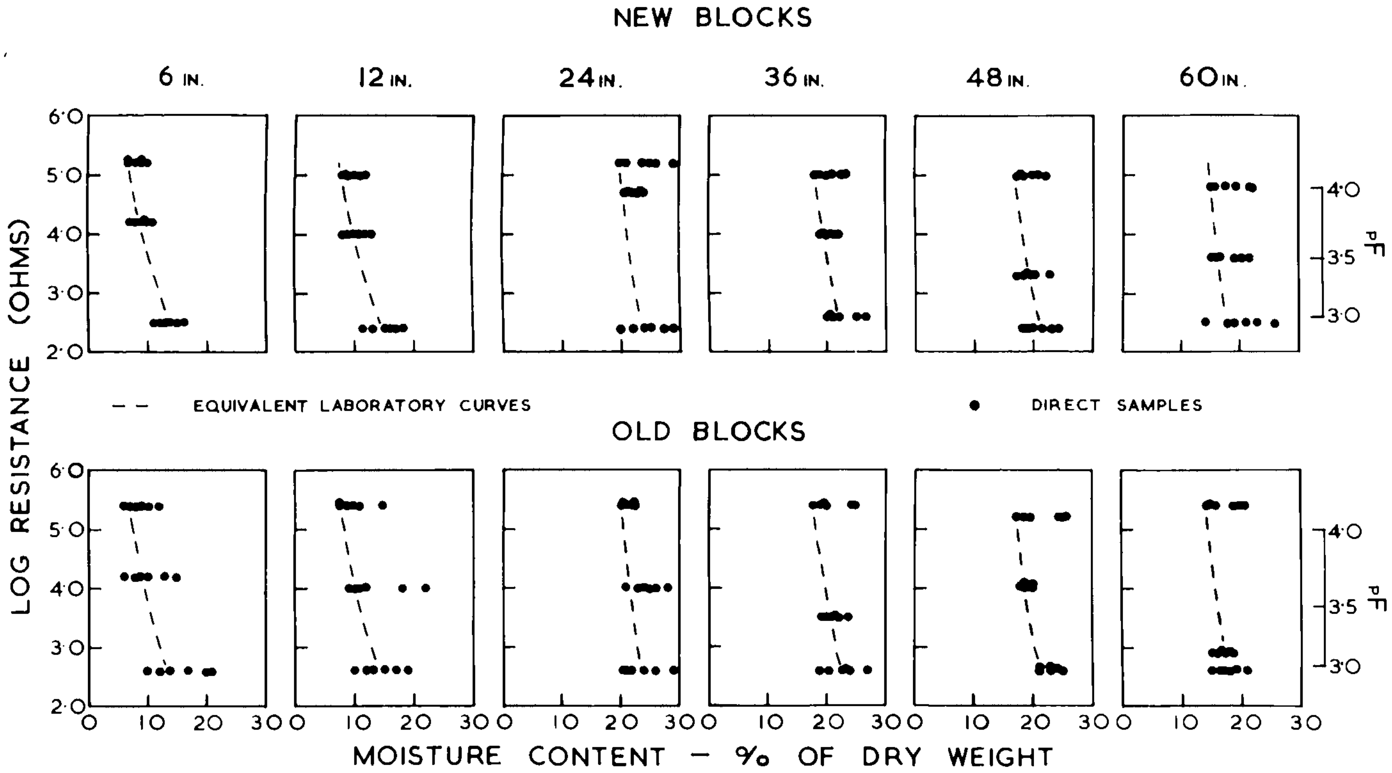

Fig. 6. Resistance - moisture content relationship (old and new blocks) obtained for different depths. The pF is also shown.

laboratory samples at higher resistances and the greater swelling of the unconfined laboratory soil samples.

(k) Soil Moisture Constants

The moisture content over the range from field capacity to permanent wilting percentage gives the most useful information concerning the availability of water in a given soil. The determination of this range requires the measurement of two arbitrary values, the field capacity and the permanent wilting percentage.

(i) Field Capacity.- To obtain information on this point, the soil samples were taken from the plots of lucerne after winter rainfall. Four quadrats, each of 10 x 5 feet were randomly selected in four different plots. The lucerne was cut in these quadrats and the soil surface covered with plastic sheets and then with corrugated iron sheets to prevent evaporation. After 72 hours samples were taken from depths down to 60 inches. Samples were taken from these four quadrats on four different occasions. Thus the results given in Table 1 are the mean of 16 replicates for each depth. The samples subjected to 100 cm tension of water (pF = 2.00) have already been discussed. Results are given in Table 1.

Mean water content estimated at pF 2.00 has been used throughout this investigation as corresponding to field capacity for different depths.

(ii) Permanent Wilting Percentage.- Since the permanent wilting percentage is more or less stable for a given soil and since it indicates the lower limit of soil moisture available for plant growth, it is probably the most important of all soil constants.

Table 1

Field Capacity* and Water Content *
at pF 2.00

Depth (in.)	Mean water content at pF 2.00	Field Sampling
6	21.19	21.27
12	22.45	21.70
24	30.02	29.28
36	27.69	27.43
48	25.71	24.81
60	21.52	20.40

* Expressed as percentages of oven-dry soil

There are three ways of determining permanent wilting percentage. They are:

(a) Direct field sampling during the growing season.

(b) By growing indicator plants in sealed containers, and

(c) By the pressure membrane technique

(a) Field Sampling - This method was tried in non-irrigated plots but it failed to give satisfactory results, probably for the following reasons:-

(i) To find out whether moisture extraction is complete or nearly so, several points are necessary and the plants must remain wilted for at least some days. This may have serious effects on the growth of the plant. This will be more or less impossible to achieve in the present experiment since lucerne is deep rooted and at the same time it is unlikely that no rain will fall during the period necessary.

(ii) Although this method gives accurate results and is reproducible in succeeding years, it has the disadvantage that it cannot be obtained during the growing season, since it is not advisable to allow the plants to suffer from water shortage while they are still growing. The lucerne takes approximately 10 or 12 weeks to flower, and under the present experiment it was not possible to wait so long.

(iii) With the deep rooted crop like lucerne, samples from the top 1 and 2 feet of soil may show that it has reached the low extraction level while below this layer samples were still high in water content. Under these conditions quite a considerable time will be required for the plants to extract the available water throughout all depths. Samples that were taken in late April show that there is still some available water at a depth of 60 inches showing that while the sampling method may be quite feasible for the top 2 feet of soil, it does not seem to be practicable under the present conditions.

(iv) Considerable variation in the amount of water content in the top 2 feet was noted, probably due to layers or pockets of soil of different texture at irregular depths below the surface and uneven root distribution. At the same time the soils in many places are so compact and stony that the roots may not have been able to penetrate them, with the result that the moisture content of these soils may remain about the same throughout the season. It is felt that this may be one of the important reasons why this method failed to give satisfactory and accurate results. The uneven distribution of stony layers at the same depth and at different depths had been noted when the gypsum blocks were sunk into the soil.

(v) Since a lucerne plant may have more than 20 leaves it is very difficult to judge when it has reached the wilting stage or gone beyond permanent wilting under field conditions.

(b) Indicator Plants. - Having failed to obtain a satisfactory determination of the wilting percentage by direct field observations a further attempt was made by growing sunflower plants, using the composite soil samples obtained during the installation of blocks.

The technique used in this method for determining permanent wilting percentage has been described by Marshall and Williams (1942). Samples of soil (about 600 g passed through 2 mm sieve) were placed in small honey tins. Two replicates were used for each depth for each plot. Thus 144 pots were used (2 replicates x 6 depths x 12 plots), so that there were 24 replicates for each depth in this experiment. Corrections were made for the weight of the plant roots (assumed to be one half the weight of the tops) and for the water content of the roots (assumed to be 80 per cent.). Results are given in Table 2.

(c) Pressure-membrane Technique.- Richards (1952) has pointed out that the moisture retained in a sample of soil that has been air-dried, fragmented, placed on the pressure membrane, wetted and brought to hydraulic equilibrium with the membrane at a pressure of 15 atmospheres, appears to be closely related to the lower limit of water available in the field for crop growth. He contends that this physical determination has certain definite advantages over the sunflower plant method for estimating the wilting point of soil. The same composite sample as had been used in the sunflower method was again used in the pressure membrane apparatus. This method has already been discussed in the determination of pF-moisture content curve. Results of the determination of permanent wilting percentage by sunflower method and by pressure-membrane technique are given in Table 2.

Table 2

Permanent Wilting Percentage* and Water Content * at pF 4.20

Depth (in.)	Mean water content at pF 4.20	P.W.P.
6	6.63	6.80
12	7.40	7.70
24	19.88	19.72
36	17.74	17.92
48	16.90	16.42
60	14.39	14.01

* Expressed as percentage of oven-dry soil

Mean water content at pF 4.20 has been used throughout this investigation to represent the amount of water present at permanent wilting percentage at different depths.

(1) <u>Measurement and Recording of Resistance Data</u>

All resistances were measured at 1000 c./s. seconds with a portable resistance bridge as described by Aitchison, Butler and Gurr (1951). Readings were taken every Tuesday starting at about 9 a.m. and about three hours were required to complete the readings on all plots. Since the block resistance readings were used to indicate the pF of the soil, no attempt has been made to plot the resistance-time graphs; furthermore, it was realised that the graph of changes of pF against time will probably yield more information and give a better picture than resistance-time graphs. Readings were taken on paper ruled as shown in Appendix A, to allow space for the correction for temperature, for the conversion of temperature corrected block resistance readings to pF and then to various conversions leading up to the amount of water stored or used.

(m) Measurement and Recording of Temperature Data

The same bridge was used for taking temperature readings. Whenever block readings were taken, the resistance (dial readings) of thermistors were also taken. The time of reading was arranged in such a way that the soil temperature (in wet and dry plots) was always read between 9.30 a.m. and 10 a.m. The dial readings of the thermistors were then converted to temperature (°C) using individual calibration curve as mentioned earlier.

(n) Temperature Correction

The resistance readings of gypsum blocks were corrected for temperature errors, using the nomogram given by Aitchison, Butler and Gurr (1951).

(o) Conversion of log R to pF

The corrected log R of each block was then converted to pF using the calibration curve obtained in the pressure membrane apparatus.

Considerable difficulties were, however, experienced in expressing the results in terms of pF for every depth, plot and treatment due to insensitivity of the blocks at tensions below pF 2.90. It was frequently found that in the same plot at the same depth one block was at pF 2.90 or higher and the other two at less than pF 2.90, or vice versa. It also becomes necessary where several blocks are operating as replicates to consider how best their individual behaviour can be represented to show, as accurately as possible, the nature of changes taking place. Since the pF indicates the logarithm of the cm of water tension, the use of the arithmetic mean of the height in cm of water column or logarithmic mean of pF would lead to misinterpretation, particularly where greater variation in pF occurs and where greater pF variation represents small variation in water content at tensions approaching 4.20.

In view of these difficulties it was initially proposed to adopt the median values of 18 pF readings (i.e. 3 blocks in 6 replicated plots) for a given depth to give the value of pF on each occasion. One serious drawback of this method of presentation is that it tends to overlook the variability between and within replicates. It was therefore decided to calculate the median value for each plot and then to obtain the median of the values thus determined; this final median value was thus the value for that particular treatment. The advantage of the median is that it does not weigh on unusual extreme results too heavily.

A complete record of pF readings over the whole period, the median values for each plot and for each treatment are given in Appendix B_1, B_2.

Fig. 7 shows the combined graph of the median of 6 plots for irrigated and non-irrigated treatments for 6 inch depth, and Fig. 8 shows

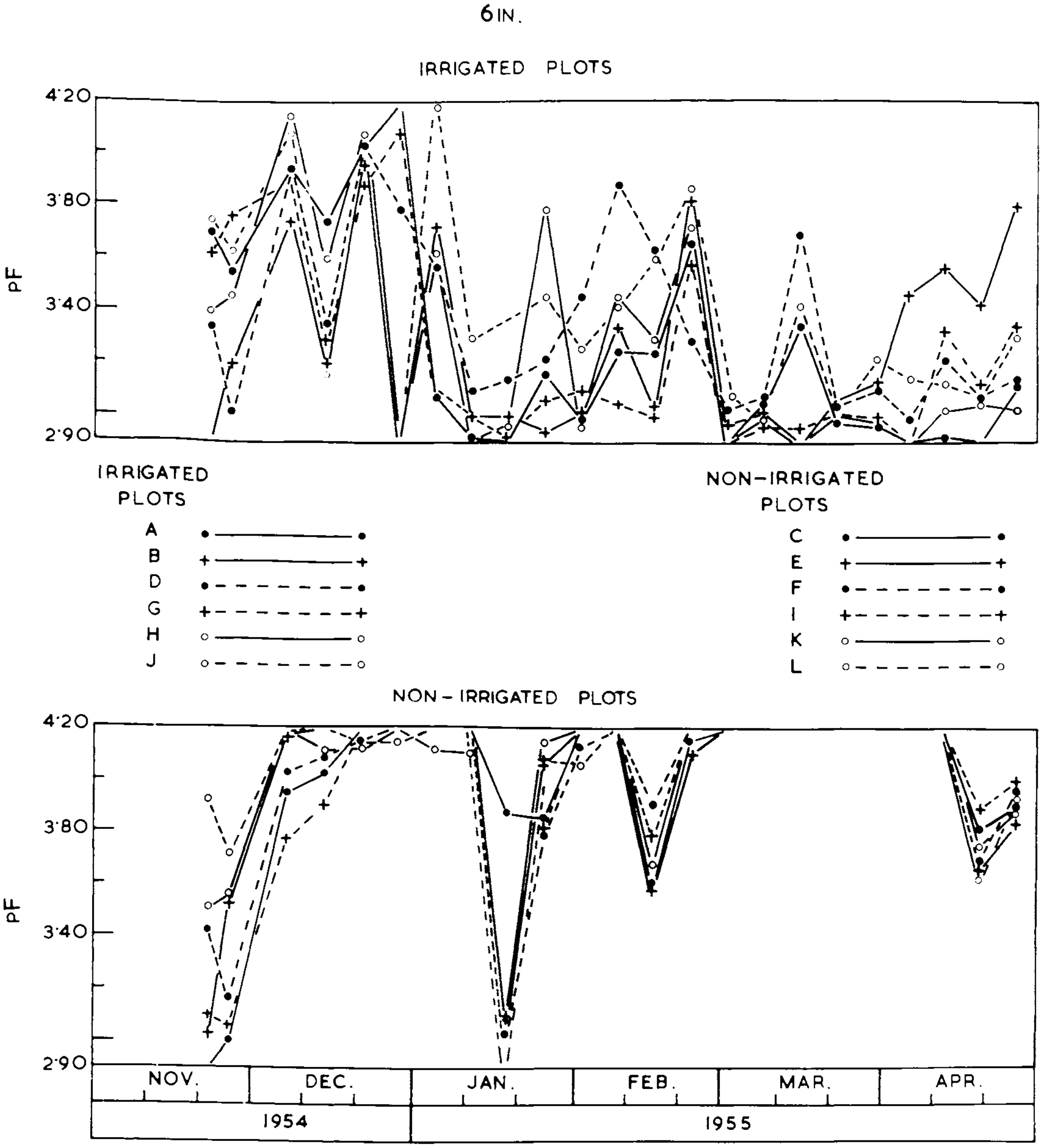

Fig. 7. Trends in soil - moisture tension changes at the 6 in. depth.

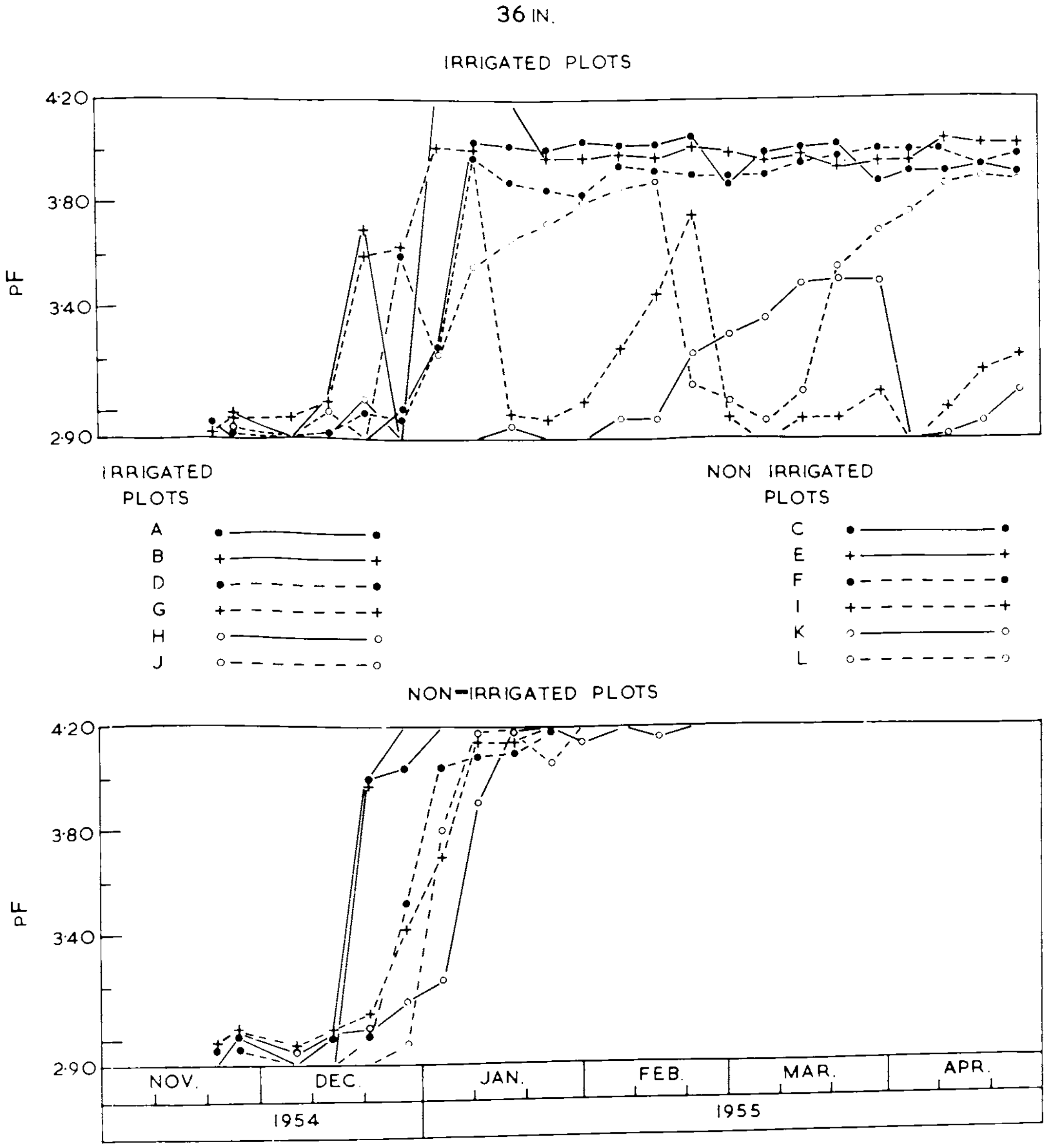

Fig. 8. Trends in soil moisture tension changes at the 36 in. depth.

the appropriate data for 36 inch depth. Values in the insensitive zones below pF 2.90 and greater than 4.20 are not shown on scale at the exact value, but are plotted as 2.90 and 4.20 respectively. These figures are included to illustrate the nature of the graphs obtained using the median pF values; the smoothness of the curves, particularly in the non-irrigated treatments, indicate that this method can be applied satisfactorily to express the general trend in the changes of pF in the soil. In the irrigated treatments, however, there are some departures from a smooth curve, possibly due to difference in time and amount of irrigation, uneven distribution and penetration of water or uneven drying of the soil by the lucerne roots. The consistency of the results from each plot is such that each median pF value is supported by the reading before and after, and the smoothness of each curve supports the use of the median values.

(p) Calculation of Moisture Percentage from pF data

In order to calculate the total amount of water used by the crop, the total amount of water stored in the soil, how much was available to plants or how much water should be applied to the soil to raise it to its field capacity, it was necessary to convert pF values to moisture percentage. The conversion was easily obtained from the different pF-moisture content curve for different depths. There was little difficulty in converting pF of those blocks to moisture content whose values were within the sensitive range, i.e. from pF 2.9 to 4.2, but it was, however, more difficult to calculate the moisture content for those blocks whose pF values at the particular time were below pF 2.9. The tension range of pF 2.0 to 2.9 covered almost half of the moisture range between field capacity and wilting percentage, for nearly all the soil depths concerned in this experiment. For example, the difference in moisture content between pF 2.0 to 2.9 for the depths of 6, 12, 24, 36, 48 and 60 inches was 7.2, 7.5, 6.0, 5.0, 4.5 and 3.5 per cent. respectively and between pF 2.0 to 4.2 was 14.6, 15.1, 10.1, 10.0, 8.8, 7.1 per cent. respectively. Similarly, Richards and Weaver (1944) concluded that the tension range of 0 to 0.85 atmospheres covered about half the moisture content range between field capacity and the wilting percentage. The amount of water between pF 2.0 and 2.9 was probably very important, particularly when the total amount of water used or stored in the soil was calculated. It is likely to be most important from the point of view of the total available water.

In another study (Butler and Prescott 1955) it was assumed that at values of less than pF 2.9 the soil is at field capacity. It will be clear later that this would lead to errors and that faulty conclusions might be drawn from such assumptions.

The insensitivity of the blocks below pF 2.9 presented serious problems when it was proposed to express results in terms of moisture percentage. Even if the mean moisture content between pF 2.0 and 2.9 was taken, the error would be considerable. For example, the moisture content for 6 inch depth soil at pF 2.0 to 2.9 is 21.2 and 14.0 per cent. respectively. The mean of the two would be 17.6 per cent, i.e. ± 3.6 per cent. Since 3.6 per cent. covered about 17 per cent. of the total available water for the 6 inch depth, the procedure resulted in a discrepancy of considerable magnitude which could not be overlooked. Finally, the method described below was adopted for calculating the probable moisture content of the soil where the blocks indicated the values of pF of less than 2.9. All pF values of sensitive blocks (i.e. those >2.9) given in Appendices B_1 and B_2 were converted to moisture percentage by referring to the pF-moisture content curve for the depths concerned.

In a plot in which one or two or all of the three blocks were within the insensitive range (i.e. those <2.9), it would be assumed that the mean moisture percentage of these blocks would always be within the two values. In other words, the moisture content of these blocks would be either at field capacity or at the moisture content at the value of pF 2.9 or somewhere between those two values, particularly when readings were taken after two or three days of irrigation.

With this assumption the missing values of gypsum blocks in terms of moisture percentage were calculated in the following way:

(a) For the day concerned the moisture percentages of all the sensitive blocks were subtracted from or added to the previous reading or the following one for the same blocks. This gave the general trend or slope of the mean moisture content of the plot as well as of the whole treatment. This value is referred to as "slope value". In other words, this value would give an indication of the magnitude of the expected decrease or increase in water content in terms of moisture percentages over that interval of time.

(b) If the mean moisture content of this plot, by taking the moisture percentage at pF 2.0 of the blocks (i.e. those <2.9) was higher than the value when subtracted from or added to the slope value of the same plot from the previous reading, then the moisture percentage at pF 2.0 was used.

(c) If the mean moisture content of the plot, by taking the moisture percentage at pF 2.9 of the blocks (i.e. those <2.9) was lower than the value when subtracted from or added to the slope value, then the moisture percentage at pF 2.9 was used.

(d) If the mean moisture content of the plot, by taking the moisture percentage at pF 2.9 of the blocks (i.e. those <2.9) was higher than the value when subtracted from or added to the slope value of the same plot from the previous reading, then the slope value was taken to represent the mean moisture percentage of that plot.

The moisture percentages calculated in this way are approximations but may reasonably be assumed to give a useful means for calculating the total amount of water used and the amount of water required at each irrigation, and all the calculations of water use were based on this calculation. It is suggested that this might be a suitable method of handling gypsum blocks when they are within insensitive range in similar investigations.

By way of example, the following calculations were made on the 6 inch depth data for an irrigated treatment for the day of 14th December 1954. One block of plot G (Appendix B1) gave a reading in the insensitive range, i.e. below pF 2.9. From the slope value of 7th December, 3.1 per cent. of moisture should be added to the mean moisture content of plot G of 7th December to obtain the mean moisture content of this plot for 14th December. It should be noted here that the values of two blocks (i.e. those >2.9) of this plot were also taken into consideration. If 3.1 per cent. was directly added to the mean moisture content of the values of 7th

December which is 8.0 per cent. it would be 11.1 per cent. If the missing value was taken as at field capacity (i.e. at pF 2.0), the mean moisture content became 15.1 per cent. and if it was taken as at the moisture content of the values of pF at 2.9 then it became 12.7 per cent. Since 12.7 per cent. would be the lowest possible under the circumstances and since it was less than the slope value of 11.1 per cent., 12.7 per cent. was then taken to represent the mean moisture content of that plot for that time.

It should be noted, however, that not much difference was found to the mean moisture content of all 18 blocks when considered as one unit, i.e. when mean moisture content values for the whole treatment were amalgamated as one. The mean moisture content for the whole treatment when considered only for 5 plots (i.e. of 15 blocks) without considering plot G was 10.6 per cent. But if the mean moisture content for plot G (i.e. of 18 blocks) was taken as 12.7, then it became 11.0 per cent. If the moisture percentage of the two blocks (i.e. those >2.9) of plot G (i.e. of 17 blocks) were also considered, the mean moisture content became only 11.2 per cent. The application of this method under the conditions and limitations of the experiment appeared to have little influence on the mean moisture content for the whole treatment.

(q) Water Use

The total amount of water used by the crop over a given time interval depends on the weather, the stage of the growth of the plant, and the amount of water available to plants throughout the root zone. If only the upper part of the dry soil is wetted, losses by evaporation are increased and plant growth is more reduced than if the entire zone is moistened.

It is, therefore, highly desirable to apply enough water to moisten the root zone without excessive loss by deep percolation, and to estimate how much water is to be added to the crop it is necessary to know how much has been used or removed by the plant. The total amount of water used by the plants will, however, also include the losses through evaporation from the soil surface, particularly in non-irrigated plots.

The following assumed values of apparent density (Holmes private communication), for the different depths were used to calculate the volume of water in inches:-

Depth of soil (inches)	Apparent Density
0 - 9	1.50
9 - 18	1.45
18 - 30	1.50
30 - 42	1.60
42 - 54	1.65
54 - 66	1.75

The moisture percentage of soil expressed as percentage on dry weight basis was converted into the volume of water in inches by the expression:

$$\frac{P \times (AD) \times D}{100}$$

Key to the symbols is given on pages 63, 64.

Available water in any particular soil sample at each depth can be calculated when volume weight and thickness of the horizon are known by the expression:

$$\text{Inches of available water} = \frac{(P_{2.0} - P_{4.2}) \times (AD) \times D}{100} \quad \ldots. \quad (i)$$

Available water in inches at any moment in time at each depth can be calculated by the expression:

$$\frac{(P_0 - P_{4.20}) \times (AD) \times D}{100} \quad \ldots\ldots \quad (ii)$$

Amount of water in inches required at any time interval at each depth to bring the soil back to field capacity can be calculated by the expression:

$$\frac{(P_{2.0} - P_0) \times (AD) \times D}{100} \quad \ldots\ldots \quad (iii)$$

This amount is also equal to the deficit that has to be supplemented by irrigation.

Amount of available water stored in soil in inches from 0 - 66 inches can be calculated by using the expression (i) for each depth, substituting the known values for Ad and D

$$\begin{aligned} Ws = \frac{1}{100}\Big\{&(P_6 \times 1.5 \times 9) + (P_{12} \times 1.45 \times 9) \\ &+ (P_{24} \times 1.50 \times 12) + (P_{36} \times 1.60 \times 12) \\ &+ (P_{48} \times 1.65 \times 12) + (P_{60} \times 1.75 \times 12)\Big\} \end{aligned}$$

$$\begin{aligned} \text{or} \quad &(P_6 \times 0.135) + (P_{12} \times 0.131) + (P_{24} \times 0.180) \\ &+ (P_{36} \times 0.190) + (P_{48} \times 0.200) + (P_{60} \times 0.210) \quad \ldots\ldots \quad (iv) \end{aligned}$$

Total available water stored in inches from 0 - 66 inches at any moment in time (t_0) was calculated by using the expression (ii) for each depth by substituting the known values for AD and D

$$Wst_o = \frac{1}{100}\left\{(P_6^1 \times 1.5 \times 9) + (P_{12}^1 \times 1.45 \times 9) + (P_{24}^1 \times 1.50 \times 12) + (P_{36}^1 \times 1.60 \times 12) + (P_{48}^1 \times 1.65 \times 12) + (P_{60}^1 \times 1.75 \times 12)\right\}$$

$$\text{or} = (P_6^1 \times 0.135) + (P_{12}^1 \times 0.131) + (P_{24}^1 \times 0.180) + (P_{36}^1 \times 0.190) + (P_{48}^1 \times 0.200) + (P_{60}^1 \times 0.210) \quad \ldots\ldots (v)$$

If total available water stored in inches at a second time (t_1) is Wst_1, then the amount of water taken from the soil over the time interval of t_o to t_1 will be given by the expression:

$$Wt = (Wst_o - Wst_1) \quad \ldots\ldots (vi)$$

Then for the irrigated plots the total water used over that interval of time will be given by the expression:

$$Wi = Wt + R + I - r \quad \ldots\ldots (vii)$$

For the non-irrigated plots the total water used over that interval of time will be given by

$$Wn - Wt + R - r \quad \ldots\ldots (viii)$$

<u>Symbols used:</u>

AD = Apparent Density (Volume weight)

D = Depth of soil in inches

P = Water content % on dry weight basis.

$P_{2.0}$ = " " " " " " " at pF 2.0

$P_{4.2}$ = " " " " " " " at pF 4.2

P_0 = " " " " " " " at observed pF

P_6 = " " " " " " " difference between $P_{2.0}$ and $P_{4.2}$ for 0-9" depth.

P_{12} = " " " " " " " " " 9-18" "

P_{24} = " " " " " " " " " 18-30" "

P_{36} = " " " " " " " " " 30-42" "

P_{48} = " " " " " " " " " 42-54" "

P_{60} = " " " " " " " " " 54-66" "

P^1_6 = " " " " " " " difference between P_0 and $P_{4.20}$ for 0-9" depth.

P^1_{12} = " " " " " " " " " 9-18" "

P^1_{24} = " " " " " " " " " 18-30" "

P^1_{36} = " " " " " " " " " 30-42" "

P^1_{48} = " " " " " " " " " 42-54" "

P^1_{60} = " " " " " " " " " 54-66" "

(Continued)

Symbols Used (Continued)

Ws = Amount of available water stored in the soil (in.) from 0-66 in. depth.

Wst_0 = " " " " " " " " at time t_0

Wst_1 = " " " " " " " " " " t_1

Wt = Amount of water taken from the soil (in.) over the time interval from $t_0 - t_1$

= $(Wst_0 - Wst_1)$

Wi = Amount of water used (in.) in irrigated plots

= $Wt + I + R - r$

Wn = Amount of water used (in.) in non-irrigated plots

= $Wt + R - r$

R = Rainfall (in.)

I = Irrigation (in.)

r = Runoff (in.)

Using these values of apparent density and the estimates of available water (%) obtained by the pressure membrane technique, the calculation of total available water stored using the expression (iv) to 66 inch depth gives the value of 10.92 inches. If for the moisture percentage for the value of pF 2.0 and 4.2 are substituted the field capacity estimated by the field sampling and the values obtained from the sunflower method, the total storage becomes 10.33 inches. It is of interest to note that total storage of the soil, although calculated from different techniques, are in general agreement.

The total available water stored on every occasion for each plot was calculated by the expression (v) and the total water used over the time interval by the expression (vii). Thus for all six irrigated plots the amount of water used was obtained separately. The mean of the six plots was then taken to represent the water use for that treatment over that interval of time.

Water used for non-irrigated plots was also similarly calculated for different plots using the expressions (v) and (viii) and the mean was then taken to represent the water used by that treatment over that interval of time.

(r) Water Requirement

The approximate amount of water required for every week for every plot to bring the soil back to field capacity for the depth at that time was estimated from the expression (iii). For a plot size of 43.3 x 35.0 feet the total water requirement (x) in inches (y) to a depth of 42 inches would be equal to

$$x = y \times 800 \text{ gallons} \quad . . . . (ix)$$

Since some of the gypsum blocks had begun to dry out at the depths of 24 and 36 inches at the start of the experiment, and since the blocks at 36 inches were taken to represent soil moisture content between 30 and 42 inches, the depth of root penetration may be assumed to be at 42 inches. Moreover, as the lucerne was only 61 days old it was thought in this soil type, roots would not be below 42 inches.

Unfortunately it was not possible to determine the depth of root penetration at the beginning of the experiment. This approximate value was considered sufficiently accurate for the purpose, having due regard to the method of calculating the water requirement. However, on January 11th 1955, a trench of 4 x 3 x 6 feet was dug at the border of plots A and F, following the method for root excavation described by Weaver (1926, p. 255). On this occasion the roots in the irrigated plot A were found between the depths of 52 and 56 inches. Subsequent water requirement was calculated for a depth of 66 inches.

(s) Irrigation

It was considered that for this type of experiment plastic 'Soakit' hoses would be most suitable for irrigating the lucerne, particularly in view of the equal and even distribution of water and the greatest possible reduction in runoff, as a result of the slow rate of application.

The distributing unit used for watering the plots consisted of three 1 inch diameter metal pipes, each 9 feet long, with three standard gate valves placed at 3 feet apart. To control the amount of flow in the distributing unit, a standard meter and a standard gate valve were also provided at one end and the other end of the unit was sealed. This distributing unit was connected to the main distributing tap through a 50 foot length of rubber hose. This enabled the whole unit to be moved from one plot to another and within the plot as desired without any dismantling. In this way the water flowing through the distributing unit and through the 'Soakit' hoses to the plot could be satisfactorily kept under control.

The 'Soakit' hoses were 50 feet long and $\frac{3}{4}$ inch in diameter with one end closed. They had lines of small holes punched in the top through which a jet of water emerged under pressure. The holes were so spaced that the entire strip of ground was covered at one setting and the flow of water was so regulated that a strip approximately 5 to 6 feet wide was covered in each application. When irrigating, the three 'Soakit' hoses were laid out in such a way that they covered approximately the whole plot. However, when the lucerne was about 30 days old this setting had to be changed to two due to the height of the plants. Generally the time of watering was arranged in such a way that three plots (A, B and D) were watered on Tuesday and Thursday, and the other three (G, H and J) on Wednesday and Friday. A close watch was kept on the plots while watering to avoid or minimise runoff.

Different rates of flow through the 'Soakit' hoses were maintained for different plots due to differences in slopes. In order to keep runoff to its minimum, the following rate of flow for different plots was found satisfactory:-

Plot	Rate of flow (galls./min.)
A	3
B	1
D	1
G	4
H	2
J	1

The approximate amount of water obtained from the expression (ix) for different plots could not be applied due to low infiltration rate*, quick runoff, time and other reasons. However, every week the maximum possible amount of water was applied to each plot.

By the beginning of January 1955, plants in the non-irrigated plots began to show indications of serious water shortage (photograph 4). Since there was a considerable risk of losing the lucerne stand, 1.5 inches of water was given by irrigation to all the "non-irrigated" plots on 14th, 15th and 16th January 1955.

(t) Runoff

In an irrigation experiment it is not how much water is added that is important but how much enters the soil. Baver (1956, p.429) states that the amount and velocity of runoff are dependent upon rainfall characteristics, the slope and the area of the land, and the ability of the soil to absorb and transmit water through profile. The amount and velocity of runoff will be largely determined by the amount and intensity of rain or irrigation.

An estimate of runoff was made in this investigation, although precise methods were not available. Briefly, water was collected in a pit fed by a drainage channel (Fig. 1) and was subsequently measured. It was found that when the rate of flow was maintained as mentioned earlier, no runoff occurred at all. Water begins to runoff only

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* Infiltration rate at field capacity is approximately 0.50 in./hour (Prescott, private communication).

Photograph 4. Serious indications of water shortage in non-irrigated plot C. In the background are the irrigated plots (B and A). On the left hand side are the non-irrigated plots E and F.

when the application of water exceeds 400 gallons in one application, i.e. about 0.5 acre-inches of water. If the amount of water applied exceeded this amount at one application the runoff was approximately 20 per cent. The amount of water applied was reduced by 20 per cent. in order to obtain a value for the amount of water entering the soil when more than 0.5 inches has been applied. This did not, however, happen many times.

Whenever rainfall intensities were high no allowance for runoff was made for the first 0.5 inches, but after that 20 per cent. reduction was made. The previous soil moisture content and the height and age of the plant were taken into consideration before this 20 per cent. reduction was made.

(u) Time of Cutting

In view of the productivity of lucerne, longevity of stand and the nature of the experiment, it was decided to cut the lucerne completely when about 25 per cent. of the plants were flowering. It was also decided to have two intermediate cuts between two complete cuts. For these cuts each plot was divided into four equal blocks, each randomised into 12 quadrats of 25 sq. links and each quadrat separated by a distance of 1 link. In every intermediate cut one quadrat from each block was removed. Four quadrats were taken from each plot. Intermediate cuts were arranged arbitrarily in such a way that time intervals between each cut were approximately equal. Time of cuttings (complete and intermediate) was different for the two treatments. Thus in the irrigated plots there were three complete cuts and therefore six additional intermediate cuts in the first year, and two complete cuts with three intermediate cuts in the second year; in non-irrigated plots there were four intermediate cuts or three complete cuts or two complete cuts in the second year (Fig. 8A).

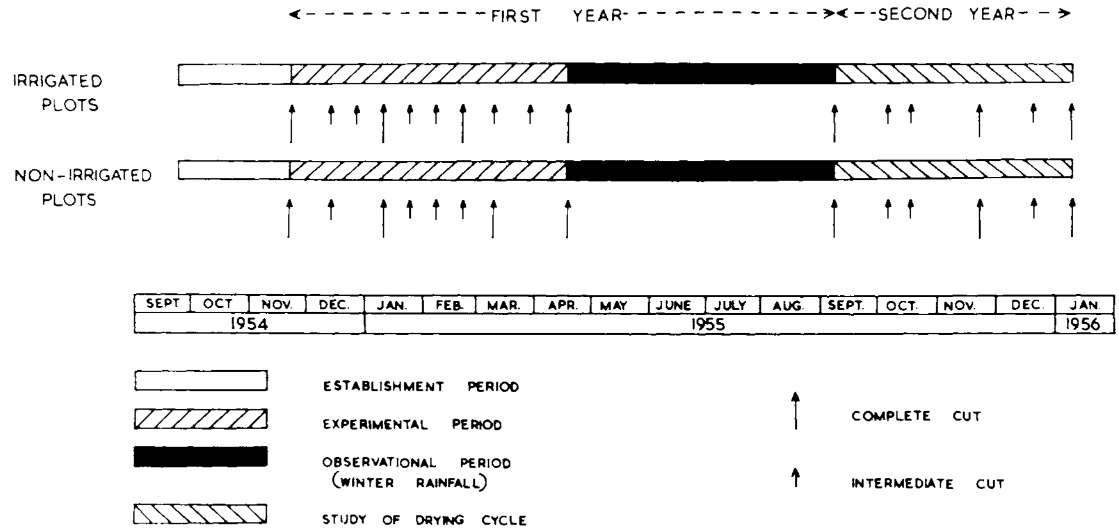

Fig. 8A. Diagram showing conduct of experiment.

After the lucerne was given a complete cut with an autoscythe 1 to 1½ inches above ground level on 22nd November 1954, 0.50 inch irrigation was given to all the twelve plots by sprinklers. This day was taken as the beginning of the experiment. The lucerne was subsequently cut with a hedge trimmer 1 to 1½ inches above ground level. At complete cuts - not at the intermediate cuts - after the quadrats were cut and the material removed to the laboratories, the complete plot was cut with an autoscythe.

(v) Cuts

Cuts were carried out on the following days:-

(Irrigated Plots)

Complete Cut	Intermediate Cut	Date	Days after complete cut	Days after sowing
		First Year	(1954-1955)	
0		22.11.54	0	61
	(i)	13.12.54	21	82
	(ii)	27.12.54	35	96
I	(iii)	10. 1.55	50	111
	(i)	24. 1.55	14	125
	(ii)	7. 2.55	28	139
II	(iii)	21. 2.55	42	153
	(i)	9. 3.55	16	169
	(ii)	29. 3.55	36	189
III	(iii)	18. 4.55	56	209
		Second Year	(1955-1956)	
0		7. 9.55	0	350
	(i)	5.10.55	28	378
	(ii)	17.10.55	40	390
I	(iii)	22.11.55	76	426
	(i)	20.12.55	28	454
II	(ii)	9. 1.56	48	474

(Cont'd)

(Continued)

(Non-irrigated Plots)

		First year	(1954-55)	
0		22.11.54	0	61
I	(i)	13.12.54	21	82
	(ii)	10. 1.55	50	111
II	(i)	24. 1.55	14	125
	(ii)	7. 2.55	28	139
	(iii)	21. 2.55	42	153
	(iv)	9. 3.55	58	169
III	(i)	18. 4.55	40	209
		Second year	(1955-1956)	
0		7. 9.55	0	350
I	(i)	5.10.55	28	378
	(ii)	17.10.55	40	390
	(iii)	22.11.55	76	426
II	(i)	20.12.55	28	454
	(ii)	9. 1.56	48	474

(w) Yield

In the present study it was considered that the most suitable way to assess the value of water use by the lucerne under irrigated and non-irrigated conditions would be in terms of dry matter production. It was also realised that the soil-water deficiency would be likely to have a more retarding effect on vegetative growth than on the development of reproductive organs.

Plot yields were estimated by removing the herbage from four quadrats, each 25 sq. links. The samples were collected separately from each quadrat and taken to the laboratory. These were then oven-dried at 80°C in a force-draught oven for at least 18 hours and weighed. The mean dry weight of six plots was then taken to represent the yield of the treatments and is expressed in hundredweight/acre.

(x) Plant Counts

Plant counts were taken on

(i) 6.12.1955 4
(ii) 22.4.1955, and
(iii) 19.1.56

to assess the effect of the treatments on the establishment and survival of lucerne. Quadrats 4 square links in area were used. Total number of lucerne plants and weeds per 4 square links were counted by throwing quadrats randomly in the plots. Twenty throws per plot were used. The mean of six plots was taken to represent the treatment and the results are expressed as the number of plants per square link.

RESULTS

(a) Soil-Temperature Studies

Temperatures obtained from the thermistors installed for correcting the block resistance readings have been used to compare the different effects of irrigation and natural rainfall on soil temperature. It will be remembered that temperature records had been obtained for two plots only; plot C, a non-irrigated plot, and plot G, an irrigated plot; these two plots have been taken as re resentative of the non-irrigated plots and irrigated plots respectively. It should be noted, however, that 0.5 inches and 1.5 inches of water were given by irrigation on non-irrigated plots on 22nd November 1954, and 14th, 15th and 16th January 1955 respectively. Duplicate thermistors were used for each depth in both plots.

Fig. 9 illustrates the general trends in temperatures in the two treatments. Mean values of the two temperature readings at each depth based on readings at intervals of approximately one week were used and plotted as a function of time and depth and the isotherms are drawn for intervals of 2°C. Values for the latter part of July and for the month of August and September were not taken, and the annual record is consequently incomplete. Since the top 0-3 inches of soil is subjected to more fluctuations than deeper layers, the isotherms are shown up to 3 inches of the soil surface; it would clearly be inadvisable to extrapolate the isotherms to the soil surface. Similarly it was considered inadvisable to draw the isotherms below 66 inches. Since the air temperature recorded at 9 a.m. (local time) in the meteorological observatory of the Institute (approximately 100 yards from the experimental site) was found to be approximately equal to the mean temperature of the

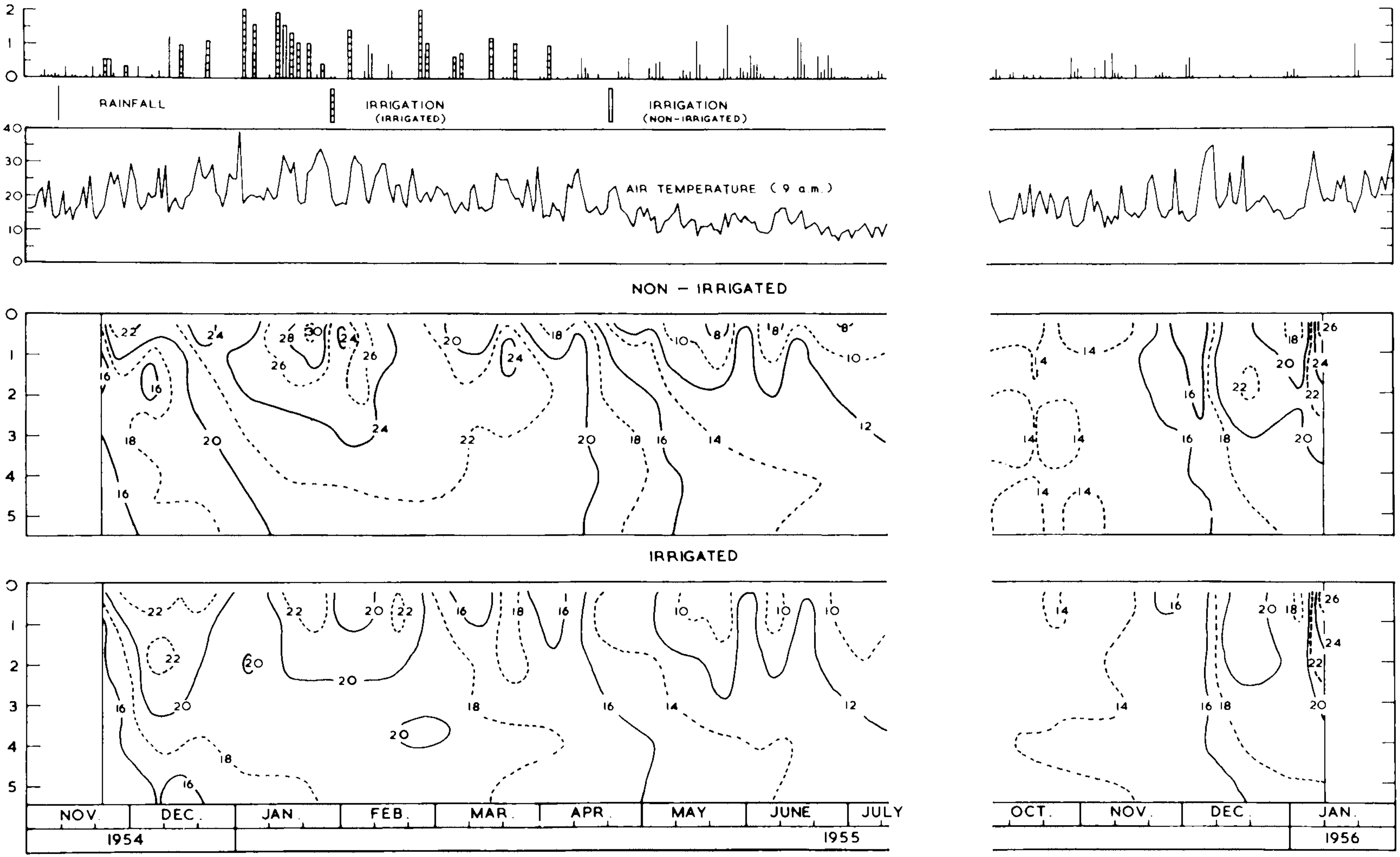

Fig. 9. Variations in soil temperatures at different depths in irrigated and non-irrigated plots.

day under Waite Institute conditions (Jenkinson, personal communication), the daily air temperature at 9 a.m. is taken to represent the air temperature and is plotted against time. The amount of rainfall received and the irrigation given are also shown.

For the sake of convenience the whole period has been divided into First Year and Second Year. The First Year includes (a) Experimental Period and (b) Observational Period. The duration of the experimental period was from 22nd November 1954 to 19th April 1955. The main experiment was conducted during this time. It should be noted that irrigation was terminated in plot C by 18th April 1955. The duration of the observational period was from 20th April 1955 to 12th July 1955, and during this time the readings were taken only to follow the effect of winter rain on the temperature distribution in soil. The period 5th October 1955 to 10th January 1956 will be referred to as Second Year; during this period no irrigation was given to any one of the plots and the lucerne was allowed to extract water until all the available water was used down to a depth of 66 inches. For convenience the plots are still referred to as irrigated and non-irrigated according to the treatments in the first year.

The graphic comparison of the two treatments in Fig. 9 shows the temperature trend throughout the whole soil profile for the first and second years. It also clearly indicates the magnitude of temperature fluctuations in the two treatments during the experimental period. The temperature increases progressively with increase in depth with time in the non-irrigated plot while in the irrigated plot the increase is slow and inconsistent. It also shows clearly that during the whole experimenta period the irrigated plot was colder throughout the whole soil profile than the non-irrigated plot.

The effect of winter rainfall in cooling the soil and thus lowering the soil temperature progressively increases with time and depth during the rainy season. The cooling effect of rainfall has been observed by many workers (e.g. Bouyoucos 1913; Keen 1931; see also Baver 1956, p.383).

Approximate soil temperature at depths of 6, 48 and 60 inches and slightly different temperature at depths of 12, 24, and 36 inches in both plots (Fig. 11 of 12.7.55) at the end of the first year suggest that percolation of rain water tends to equalise the temperature throughout the soil profile in both plots. This effect of rain water has been observed by many investigators (see Crawford 1952). It should be noted, however, that the soil temperature of non-irrigated plots still is higher than that of irrigated plots at all depths except at 6, 48 and 60 inches. Although irrigation had been discontinued throughout the winter months, at the beginning of the second year, soil temperature of the plots which had not been irrigated in the previous year, differed from the plot which had been previously irrigated.

Since the temperature differences between irrigated and non-irrigated plots will be discussed in detail later, it is sufficient here to mention that non-irrigated plots gave higher temperatures at nearly all depths than the irrigated plots in the second year.

(i) Temperature Gradients with Depth.- An examination of the temperature data for every occasion will enable a comparison to be made of the temperature gradient and differences at various depths between the two treatments in the present experiment. It would also enable a comparison to be made of the temperature gradient of the soil profile on consecutive occasions.

Actual temperatures used to draw isotherms for Fig. 9 have been plotted against each depth for each treatment. The date shown is that on which the readings were taken. The temperature in both the treatments at the start of the experiment (Fig. 10 for 22.11.1954) is approximately the the same at 12 and 48 inches and not at 6, 24, 36 and 60 inches depth, a discrepancy which is not easily understood. The moisture content at different depths at the start of the experiment (Table 3) indicates that the differences may not be due to experimental error; the non-irrigated plot has a higher moisture content at all depths than the irrigated plot except at 48 and 60 inches, and it is possible that moisture content may have been the reason for a higher temperature. The average temperature recorded at these depths (Table 4) of the whole soil profile (6 to 60 inches) on this day is approximately the same. The average temperature of the soil profile from 6 to 60 inches and the air temperature (9 a.m.) are given in Table 4.

By the beginning of December 1954 soil temperatures in the irrigated plot began to differ from those of the non-irrigated plot. The data (Fig. 10) for 7.12.54 clearly indicate that the soil profile down to

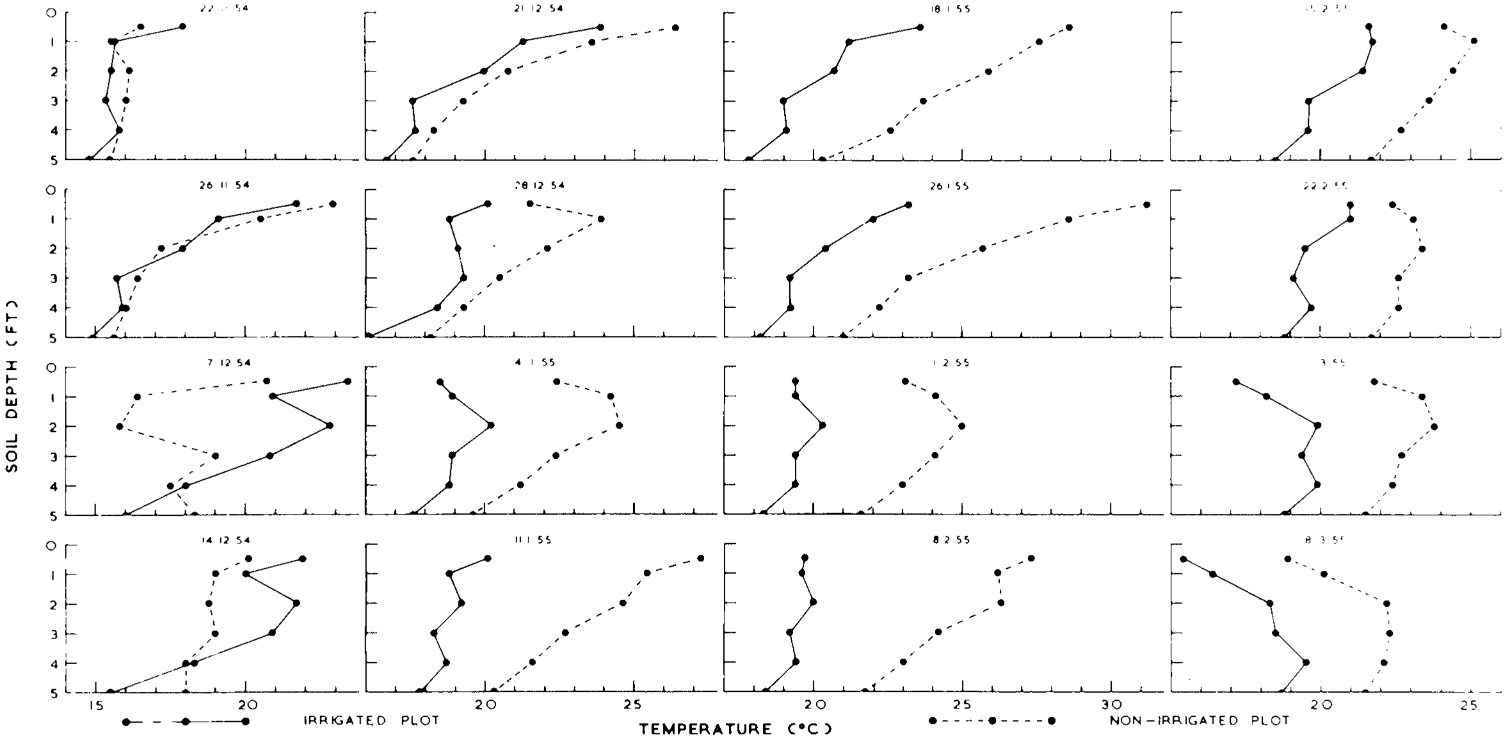

Fig. 10. Gradients of temperature with depth.
(22.11.54 - 8.3.55)

Table 3

Average Moisture Content* at various depths in the Non-irrigated and Irrigated Plots on 22.11.54

Depth (in.)	Non-Irrigated	Irrigated
6	13.6	10.5
12	16.8	11.3
24	23.7	23.5
36	26.9	24.5
48	24.4	24.7
60	20.3	20.5

* Expressed as percentages of oven-dry soil

Table 4

Average Soil Temperature of the Soil Profile (6 to 60 in.) at 10 a.m. (local time)

Date	Temp. of the air 9 a.m. (°C)	Non-Irrigated (°C)	Irrigated (°C)
1954			
Nov. 22	15.0	15.9	15.8
26	21.8	18.1	17.5
Dec. 7	19.3	18.0	20.3
14	18.7	18.8	19.7
21	31.3	21.0	19.5
28	16.6	20.9	18.6

(Continued)

Table 4 (Continued)

Date	Temp. of the air 9 a.m. (°C)	Non-Irrigated (°C)	Irrigated (°C)
1955			
Jan. 4	18.6	22.4	18.8
11	20.3	23.6	18.8
18	28.5	23.1	20.2
26	33.8	25.3	20.4
Feb. 1	18.2	23.4	19.4
8	19.4	24.8	19.4
15	22.1	23.6	20.4
22	27.1	22.6	19.9
Mar. 1	22.9	22.6	18.9
8	17.8	21.2	17.8
15	15.3	20.8	17.3
22	25.6	22.6	18.3
30	19.1	21.0	17.3
Apr. 5	16.0	20.1	16.3
12	26.7	20.6	17.2
19	14.4	18.2	15.4
26	14.5	16.5	15.2
May 3	12.9	15.9	14.4
10	15.6	13.9	13.0
18	11.3	13.1	12.4
24	8.7	12.0	11.5
31	14.0	13.3	13.0
June 9	15.2	11.8	11.7
14	12.4	12.9	12.6
28	7.4	11.8	11.5
July 12	11.1	11.4	11.1
Oct. 5	21.3	13.9	13.2
14	21.1	13.8	13.5
18	13.8	13.6	13.5
21	17.2	14.2	13.8
25	12.9	14.3	14.0
Nov. 1	12.7	14.0	13.6
15	14.3	14.8	14.2
25	13.5	16.0	15.5
Dec. 6	21.6	15.6	15.2
13	17.2	19.2	18.7
20	15.0	20.3	19.7
1956			
Jan. 3	15.5	19.0	18.4
10	20.7	22.5	22.2

48 inches in the irrigated plot has a higher temperature than the non-irrigated plot. This appears to be confirmed by the average temperature of the whole profile (Table 4) but this situation appears to be only temporary, and on 21.12.54 the non-irrigated plot has a higher temperature than the irrigated plot at all depths. The slope of the curve for 21.12.54 indicates that the rise in temperature at the depths of 6, 12 and 24 inches in the non-irrigated plot is greater than the rise in temperature at the depths of 6 and 12 inches in the irrigated plot, and there is a decrease in temperature at 24 inches in the irrigated plot. The steep temperature gradient of the non-irrigated plot is very marked on this day. The average temperature of the soil profile (6 to 60 inches) of the non-irrigated plot on 21.12.54 is slightly higher than that of the irrigated plot, and the higher average temperature of the whole soil profile of the non-irrigated plot over that of the irrigated plot is maintained throughout the experimental period. The results suggest that from 21.12.54 more heat is absorbed by the soil of the non-irrigated plot than by the soil of the irrigated plot. From this time on there is a temperature gradient from surface soil downwards in both treatments and the temperatures at the depths of 6, 12, 24, 36, 48 and 60 inches of non-irrigated soil are higher than the temperatures of the irrigated plot at all depths. Fig. 10 (from 21.12.54 onwards) indicates that the direction of heat flow is downward in both plots.

The direction of heat flow of the non-irrigated plots appears to be always changing in the top 12 inches suggesting that the top 12 inches of soil is more affected by air temperature. It can be said that from 24 inches downwards there is a general tendency for heat to move downwards as indicated by Figs. 10 and 11 till 12.4.55. However, the data for 19.4.55 shows that the temperature gradient is in the opposite direction and seems to be upwards.

The temperature of the top 24 inches is subjected to fluctuations in the irrigated plot and the magnitude of fluctuations is higher in the irrigated plot than in the non-irrigated plot. The direction of heat flow, particularly in the top 24 inches, is very erratic, probably due to the percolation of irrigation water. The slow increase in temperature at 36 inches suggests that water did not penetrate to that depth. The data for 19.4.55 indicate that there is a tendency for the temperature gradient to become established from the bottom to the top. In other words, the direction of the flow of heat is reversed. By the end of the experimental period, (i.e. on 19.4.55), the highest soil temperature is at 48 inches. It seems the temperature gradient from this depth is both upwards and downwards. At the end of the experiment, the average temperature (Table 4) of the whole soil profile was higher in the non-irrigated plot than in the irrigated plot.

By the end of the first year (see the graph of 12.7.55) it appears that the direction of heat flow is upwards. The average temperature (Table 4) of the whole soil profile in both the plots on this day is approximately the same.

At the start of the second year (5.10.55) there is no temperature gradient with depth in either treatment (Fig. 12); the average temperature of the whole soil profile in both the plots is approximately the same. There does not seem to be any change in the direction of slope till 25th October 1955. Fig. 11 of this day suggests that there is a tendency

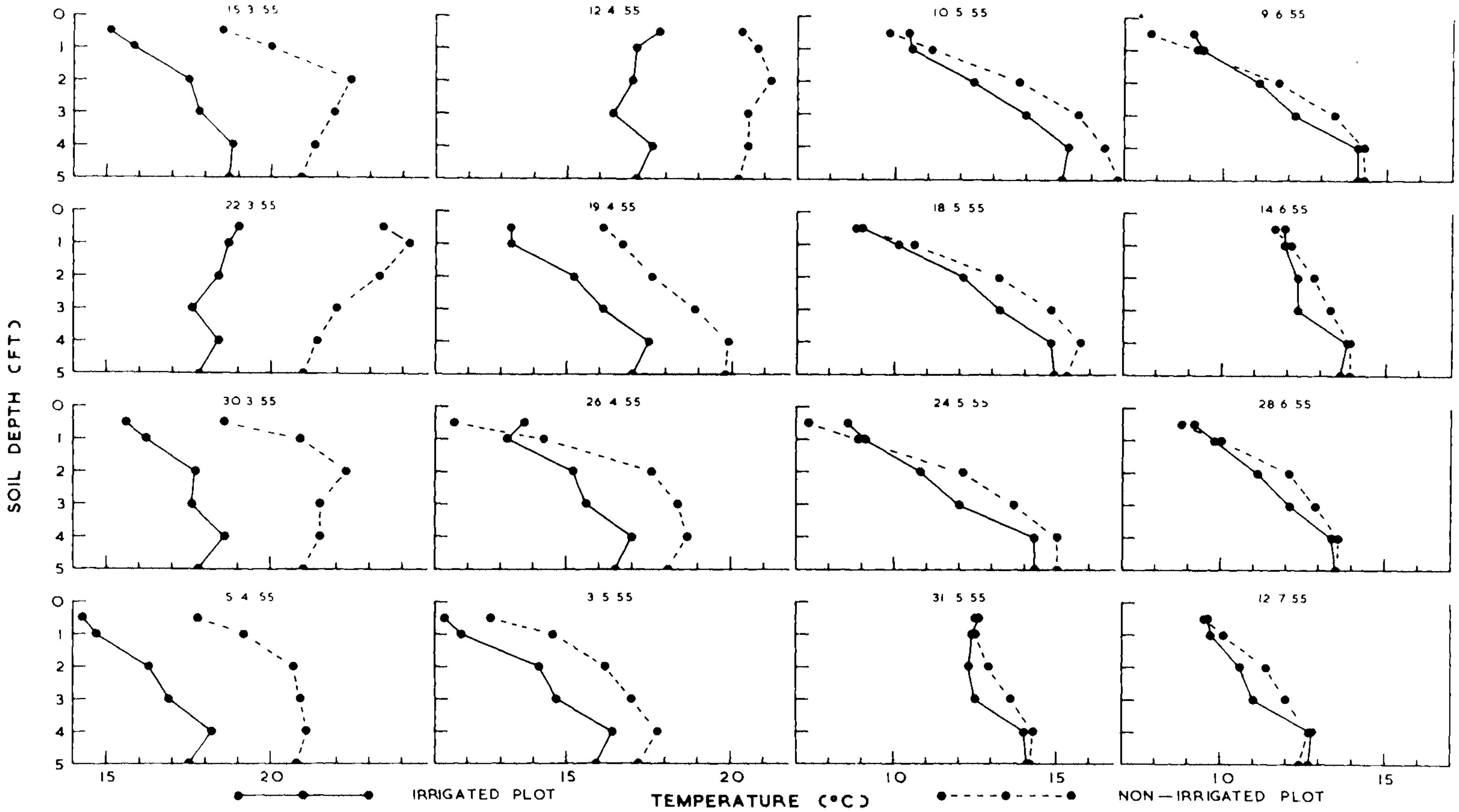

Fig. 11. Gradients of temperature with depth.

(15.3.55 - 12.7.55)

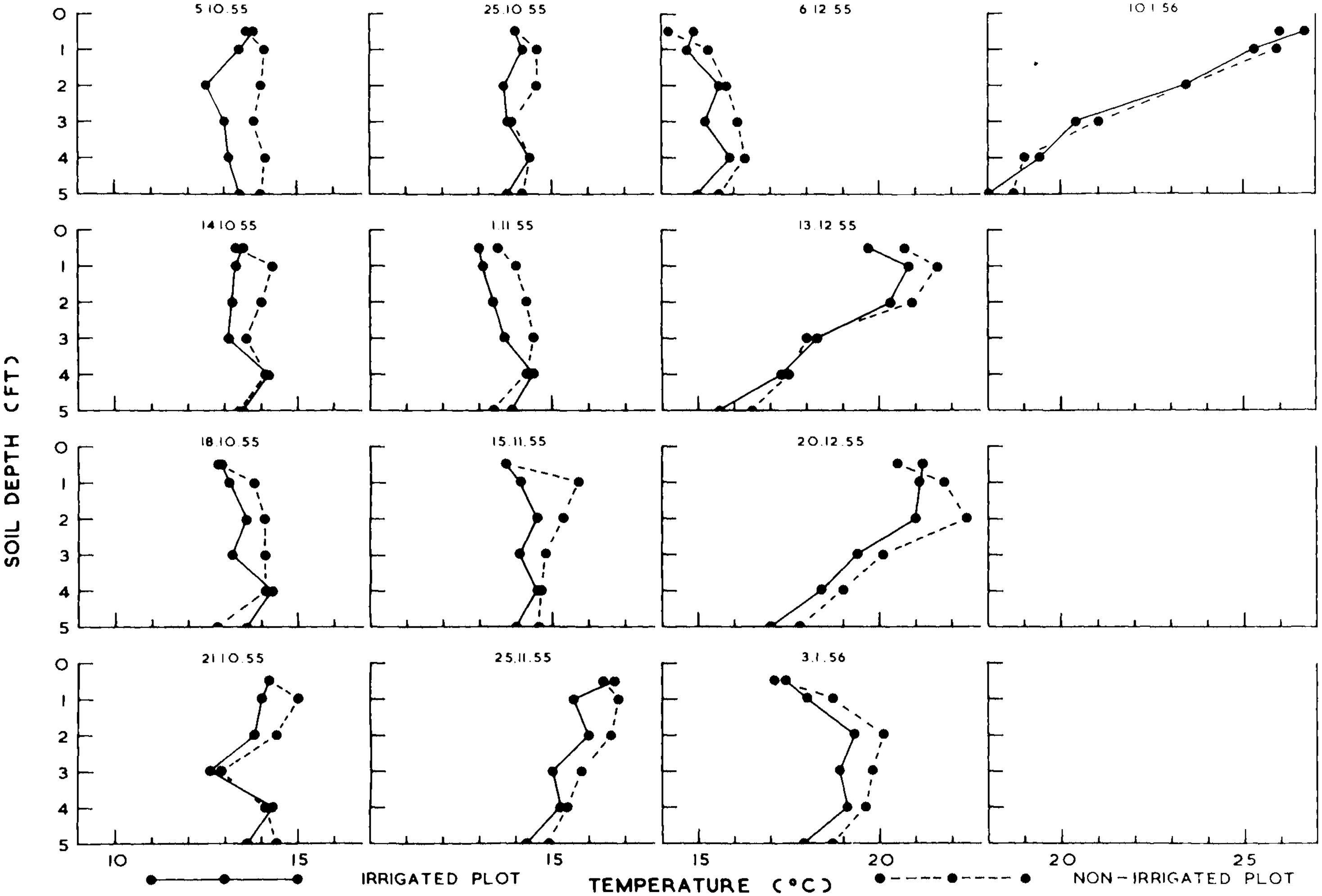

Fig. 12. Gradients of temperature with depth.

(5.10.55 - 10.1.56)

of temperature gradient from top to bottom. External environment seems to have changed the direction of temperature gradient of the top 6 inches on 13.12.55 while the temperature gradient from 12 inches is downwards in both the plots. On 10.1.56 (Fig. 12) the temperature gradient is steep and downwards. The average temperature of the whole soil profile on this day is approximately the same in both the plots.

(ii) Highest Temperature.- The significance of irrigation in reducing the highest temperature reached at each level in the soil is quite considerable, as indicated in Table 5. A comparison of the highest temperatures at various levels (Table 5) shows those of the irrigated plot to be consistently below those of the non-irrigated plot. The temperature differences between two treatments decrease with increase in depth, being highest at 6 inches.

It is interesting to note that the soil of the irrigated plot has a higher moisture content (Table 5) at all depths than the non-irrigated plot. It should be noted also that the irrigated plot was covered with a dense vegetative growth of lucerne while on the non-irrigated plot there was no cover at all. Attempts will be made later to discuss the temperature differences in terms of moisture content differences and vegetative cover.

(iii) Lowest Temperatures.- The effect of irrigation was to produce lower temperatures in the irrigated plot than in the non-irrigated plot at all depths, as indicated by Table 6. Although at all depths the lowest temperatures during the experimental period were recorded on the same day, the temperatures in the irrigated plot were consistently lower

Table 5

The Highest Temperatures and Moisture Content
at various depths at 10 a.m. (local time)
in the Non-irrigated and Irrigated Plots

Experimental Period

Depth (in.)	Non-irrigated		Irrigated		P.W.P.†
	Temp. (°C)	Moisture * (%)	Temp. (°C)	Moisture* (%)	
6	31.2	8.2	23.9	8.0	6.6
			23.6	14.3	
12	28.6	11.2	22.0	14.2	7.4
24	26.3	19.9	22.8	22.4	19.9
36	24.2	17.7	20.9	22.2	17.7
48	23.0	16.9	19.9	20.2	16.6
	23.0	16.9			
60	21.6	16.5	18.3	17.3	14.4
	21.7	15.5	18.4	17.2	
	21.7	15.5	18.5	17.2	
	21.7	15.3	18.8	17.2	
	21.5	14.9	18.8	17.1	
	21.5	14.7	18.7	17.1	
	20.9	14.7	18.7	17.1	

* Expressed as percentages of oven-dry soil.

† P.W.P. = Permanent Wilting Percentage

than those in the non-irrigated plot. The average temperature (Table 4) from 6 to 60 inches also indicates that the non-irrigated plot is warmer than the irrigated plot.

It is interesting to note that on the day on which the lowest temperatures were recorded in both treatments, the soil of the irrigated plot has a higher moisture content (Table 6) at all depths, than that of the non-irrigated plot.

Table 6

The Lowest Temperatures and the Moisture Contents
at the same date at various depths at 10 a.m.
in the Non-Irrigated and Irrigated Plots.

Experimental Period

Depth (in.)	Non-Irrigated			Irrigated		
	Temp. (°C)	Date	Moisture* (%)	Temp. (°C)	Date	Moisture* (%)
6	16.1	19.4.55	8.7	13.3	19.4.55	12.7
12	16.7	19.4.55	7.4	13.3	19.4.55	10.9
24	17.6	19.4.55	19.9	15.2	19.4.55	23.0
36	18.9	19.4.55	17.7	16.1	19.4.55	21.6
48	19.9	19.4.55	16.9	17.5	19.4.55	20.3
60	19.8	19.4.55	14.6	17.0	19.4.55	17.1

* Expressed as percentages of oven-dry soil

(iv) Heat Penetration and Loss.- It has been suggested (Smith 1932) that it is advisable to measure the temperature of the soil at depths below 48 inches or more to show accurately the total amount of heat absorbed by the soil; records taken at depths less than 48 inches are less satisfactory, since they are greatly affected by fluctuations in air temperatures. Hence the temperatures at 60 inches (maximum depth of study) were assumed to indicate the total amount of heat absorbed by the soil.

The highest temperatures were recorded in both irrigated and non-irrigated plots at 60 inch depth between 1st February and 15th March 1955 (Table 7). The effect of good vegetative cover in shading the soil and thus preventing the absorption of solar radiation was quite noticeable as

Table 7

Dates of Highest Temperatures at 10 a.m. (local time) at various depths in the Non-Irrigated and Irrigated Plots

Experimental Period

Depth (in.)	Highest Temp. Non-Irrigated		Highest Temp. Irrigated	
	Temp. (°C)	Date	Temp. (°C)	Date
6	31.2	26.1.55	23.9	21.12.54
			23.6	18.1.55
12	28.6	26.1.55	22.0	26.1.55
24	26.3	8.2.55	22.8	7.12.55
36	24.2	8.2.55	20.9	14.12.54
48	23.0	1.2.55	19.9	1.3.55
	23.0	8.2.55		
60	21.6	1.2.55	18.3	1.2.55
	21.7	8.2.55	18.4	8.2.55
	21.7	15.2.55	18.5	15.2.55
	21.7	22.2.55	18.8	22.2.55
	21.5	1.3.55	18.8	1.3.55
	21.5	8.3.55	18.7	8.3.55
	20.7	15.3.55	18.7	15.3.55

indicated by the highest temperatures at 60 inch depth of irrigated plots. The same table also shows the dates at which the highest temperatures were recorded in both the treatments at 60 inch depth. Since there was very little change in temperature between 1st February and 15th March 1955, in both treatments, it was very difficult to judge the exact time at which the highest temperatures were attained. It was not clear whether there was any lag in the time at which the two treatments reached the highest temperatures at 60 inch depth, and four-weekly running means were used to smooth out the fluctuations which are due to so many varying factors and to obtain a smooth curve. Fig. 13 shows these four weekly running means plotted as a function of time, only curves for 6 and 60 inches being shown. Air temperatures (9 a.m.) shown are also based on four-weekly running means.

A comparison of the curves for irrigated and non-irrigated plots at the 60 inch depth shows that the former lagged behind the latter by about three weeks. Examination of the similarly drawn curves of non-irrigated and irrigated soils for 12, 24, 36 and 48 inches indicates that the irrigated soil at all depths of 12, 24, 36 and 48 inches lagged about a week behind the non-irrigated soil. All these results indicate that the delay in heat penetration in the irrigated plot is probably due to the dense vegetative cover of lucerne. The curve of 6 inches of non-irrigated soil, however, points out that the non-irrigated soil lagged about a week behind the irrigated soil. This might be due to irrigation on the irrigated plot. Examination of all the curves drawn for all depths (6 and 60 inch only shown) indicates that the effect of irrigation and vegetative cover not only resulted in the delay of heat penetration (except at 6 inches) but also resulted, as mentioned earlier, in reducing the highest temperatures at all depths studied. It is clear from Fig. 14 that the time of occurrence of highest temperatures in both plots at depths ranging from 6 to 60 inches is approximately a linear function of depth. Smith (1932) also found that the time of occurrence of the maximum and minimum soil temperatures in 1930, at depths ranging from 1 foot to 12 feet, was practically a linear function of depth.

It is of interest to note that the highest temperature recorded

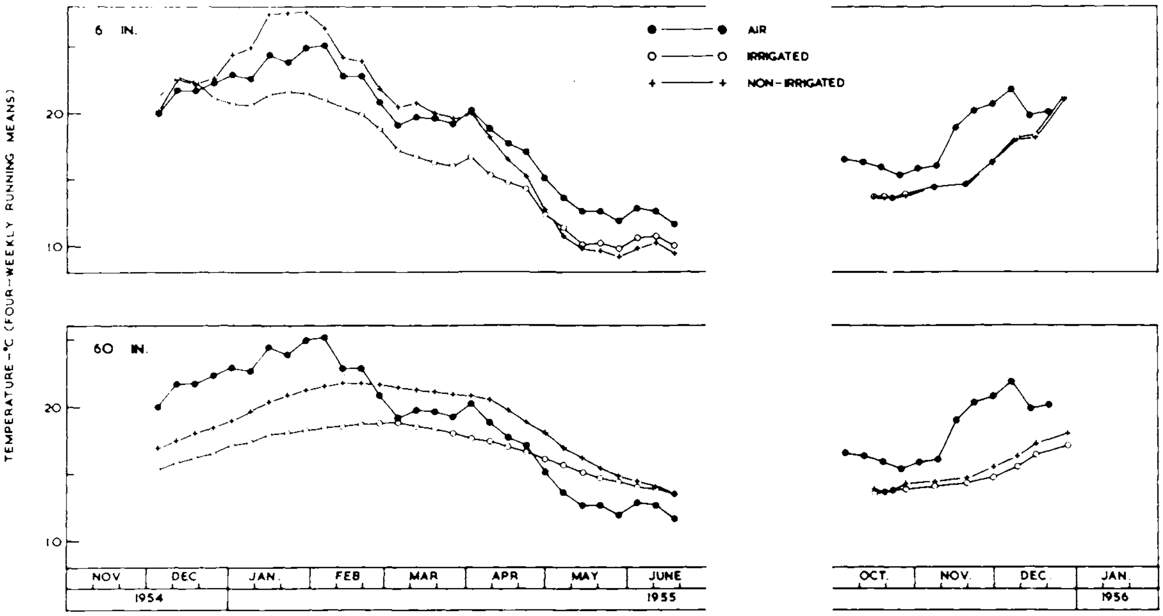

Fig. 13. Four-weekly running means of air and soil temperature.

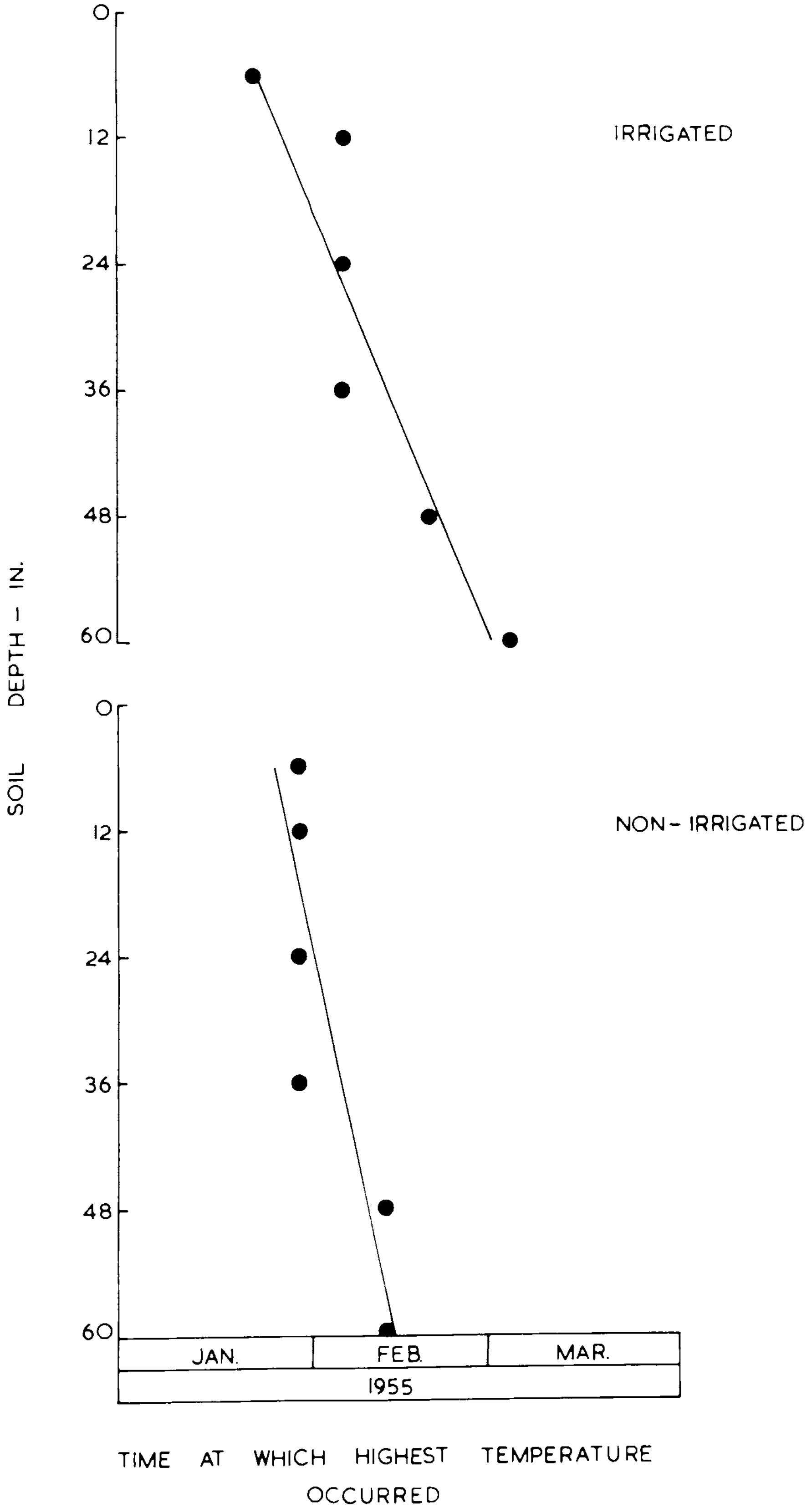

Fig. 14. Time at which highest temperature occurred in irrigated and non-irrigated plots at different depths.

at 6 inches depth in the irrigated plot is lower than the highest temperature recorded in 60 inches soil of non-irrigated plot (Fig. 13). This indicates that the high vegetative cover and irrigation were more effective in reducing the highest temperature than the 60 inches of soil of the non-irrigated plot in this experiment. It has been reported (Baver 1956, p.365; Schofield 1940) that the grass covered soil is more effective in reducing the rate and depth of frost penetration than is the bare soil.

In both the treatments the lowest temperatures (Table 6) were attained on the same day during the experimental period. Irrigation and vegetative cover reduced the lowest temperatures attained in the present experiment during the experimental period at all depths. In other words, irrigation and vegetative cover did not affect the time of reaching the lowest temperatures in the experimental period of this investigation, but did affect the actual lowest temperature values attained.

(v) *Soil-Air Temperature Relationships.*- It is clear from Fig. 13 that from the start of the experiment the temperature at 6 inches in the non-irrigated plot is consistently higher than the air temperature for the greatest part of the experimental period, indicating that during this period the direction of heat movement was upwards. It also appears that the 6 inch soil temperature of the non-irrigated plot closely follows the air temperature, suggesting that at this depth in this treatment the soil-air temperature differences are greater at high soil temperatures than at low temperatures. There is a steady increase in the 6 inch soil temperature of the non-irrigated plot till the end of January 1955, but thereafter it tends to decrease.

The decrease in soil temperature keeps pace with the decrease in air temperature, with the result that there is a decrease in soil-air temperature difference, so that by the beginning of April 1955 there is virtually no difference at all as indicated by Fig. 13. The air temperature then tends to be higher than the soil temperature in the non-irrigated plot. This tendency is maintained till the end of the first year.

For about three weeks from the start of the experiment the 6 inch soil temperature of the irrigated plot, like the non-irrigated plot, is higher than the air temperature and is also higher than the 6 inch soil temperature of the non-irrigated plot. Thereafter, the 6 inch soil temperature of the irrigated plot tends to decrease while the 6 inch soil temperature of the non-irrigated plot tends to increase (Fig. 13). The 6 inch soil temperature of the irrigated plot continued to decrease for about three weeks and then increased with air temperature. This tendency lasted for about three weeks and was then followed by a constant decrease. The 6 inch soil temperature of the irrigated plot is lower than the air temperature throughout the experimental period and, in fact, till the end of the first year. The smoothness of the 6 inch soil temperature curve of the irrigated plot, whether decreasing or increasing, indicates that it is less subjected to fluctuations of air temperatures than the 6 inch soil temperature of the non-irrigated plot. The result tends to suggest that irrigation and high vegetative cover kept the 6 inch soil temperature of the irrigated plot always lower than the air temperature in this investigation (first three weeks being an exception).

It is interesting to note that for about three weeks from the start of the experiment the 6 inch soil of both plots had a higher temperature than the air temperature. Thereafter the non-irrigated plot had a higher temperature while the irrigated plot had a lower temperature than the air temperature. Since at the start of the experiment the lucerne was completely cut, the field was virtually bare, and the absence of cover might be the reason for the 6 inch soil of both plots having a higher temperature than the air. This lasts only for a few weeks, and after about three weeks the effect of the treatment begins to appear on the 6 inch soil temperature of both plots. The temperature of the non-irrigated plot is higher than air temperature as the shading of the soil by lucerne goes on decreasing with time, while in the irrigated plot the constant shading of the soil by actively growing lucerne keeps the temperature low, with the result that the 6 inch soil temperature of the irrigated plot never exceeds that of the air temperature.

At the start of the experiment the 60 inch soil temperature of both plots was lower than the air temperature (Fig. 13). The 60 inch soil temperature in the non-irrigated plot tends to be lower than the air temperature till the end of February 1955. Thereafter, the 60 inch soil temperature of this plot exceeds air temperature till the end of the experimental period, and in fact till the end of the first year.

Irrigation and high vegetative cover kept the 60 inch soil temperature of the irrigated plot consistently lower than the air temperature till the end of the experimental period. Thereafter, the 60 inch soil temperature of this plot tends to be higher than the air temperature till the end of the first year. It is of interest to note that at the end of the first year the 60 inch soil temperature of both plots is approximately the same, as indicated by Fig. 13.

Examinations of similarly drawn curves for the depths of 12, 24, 36 and 48 inches (not shown) of both the treatments suggest:

(a) The 12, 24, 36, and 48 inch soil temperatures of the non-irrigated plot are lower than the air temperature for about $3\frac{1}{2}$, 5, $10\frac{1}{2}$ and 12 weeks respectively. Thereafter the soil temperature at these different depths is always higher than the air temperature till the end of the experimental period, and in fact till the end of the first year, 12 inch being an exception. After the experimental period the air temperature is higher than the 12 inch soil temperature till the end of the first year. The difference in time taken by the soil temperature of 12, 24, 36 and 48 inches of non-irrigated plot to exceed the air temperature indicates the delay in heat penetration with depth. If this difference in time is plotted against depth, it is seen that the time taken to exceed the air temperature is approximately a linear function of depth.

(b) The irrigation and high vegetative cover in the irrigated plot keeps the soil temperature at 12, 24, 36 and 48 inches lower than the air temperature throughout the experimental period, and in fact till the end of the first year, 36 and 48 inches being an exception. The 36 and 48 inches of soil then tend to have higher temperatures than the air temperature after the experimental period and are maintained till the end of the first year.

(vi) Soil Temperature observation subsequent to Experimental and Observational Periods (Second Year) - It is evident from Fig. 13 that in the second year the 6 inch soil of both plots was at approximately the same temperature till the end of the investigations. However, the 60 inch soil of the non-irrigated plot was consistently higher than that of the irrigated plot except at the beginning. It has already been mentioned that these curves drawn are based on four-weekly running means.

Examinations of similarly drawn curves for 12, 24, 36 and 48 inches (not shown) for both plots suggest:-

(1) At the beginning of the second year the 12, 24, and 36 inch soils of non-irrigated plots were at higher temperatures than those of irrigated plots. This tendency is maintained till the end of the investigation.

(2) Although at the beginning the temperature differences of the 48 inch soil of both plots are irregular, later on the 48 inch soil of the non-irrigated plot tends to be at a higher temperature with increasing difference with time than in the irrigated plot.

The temperature data of all depths for all occasions of the second year (Fig. 12) were subjected to statistical analysis in an endeavour to find out whether the repetition of the experiment, under similar conditions, will consistently give differences of the same order (or at least in the same direction).

The mean difference for the whole period and the standard error of difference over the whole period are given in Table 8. It is clear from Table 8 -

(1) at 6 inches there is no significant difference in the mean temperature of irrigated and non-irrigated plots over the whole period.

(2) The mean soil temperatures of 12, 24 and 36 inches of

Table 8

Mean Difference of Temperature (°C) and Standard Error of the Difference over Whole Period

Second year

Soil depth (in.)	6	12	24	36	48	60
Mean Difference for whole period	0.13 °C	0.84 °C	0.74 °C	0.59 °C	0.20 °C	0.43 °C
Standard Error of difference over whole period	±0.15 °C	±0.17 °C	±0.13 °C	±0.28 °C	±0.13 °C	±0.21 °C
Level of Significance	N.S.	0.1%	0.1%	5%	N.S.	5%

Table 9

Mean Difference of Temperature (^{o}C) and Standard Error of the Difference over periods I and II for 48 and 60 inches

	Period I			Period II		
Soil Depth (in.)	Mean Difference	S.E.	Level of Significance	Mean Difference	S.E.	Level of Significance
48	0.06 °C	± 0.18 °C	N.S.	0.37 °C	± 0.20 °C	7%
60	0.12 °C	± 0.38 °C	N.S.	0.56 °C	± 0.25 °C	5%

non-irrigated plots are significantly (P = 0.001, 0.001 and 0.05) higher than the mean temperature of the corresponding depths in the irrigated plots.

(3) There is no significant difference in the mean temperature of the soil of 48 inches in irrigated and non-irrigated plots over the whole period. Examination of four-weekly running means of temperature of these two plots suggests that the temperature variation can be split into two periods; one period (5.10.55 - 15.11.55) in which there are no significant differences and the other period (after 25.11.55) in which the mean temperature of the non-irrigated plots is higher than the mean temperature of the corresponding depth in the irrigated plots which would be significant only at 7 per cent. level (Table 9).

(4) Similarly the data of the 60 inch soil temperature of both plots were examined, but it was found that there are no significant differences in one period (5.10.55 - 21.10.55) and the other period (after 25.10.55) the mean temperature of the non-irrigated plots is significantly (P = .05) higher than the mean temperature of the corresponding depth in the irrigated plots (Table 9).

(b) <u>Plant Counts</u>

Examination of Table 10 suggests:

(i) <u>Irrigated Plots</u>

(1) Under constant irrigation the number of lucerne plants per square link was reduced from 6.5 to 4.3 (significant at P = 0.05).

(2) Under constant irrigation for about 5 months the number of weeds per square link fell from 0.83 to zero.

Table 10

Number of Plants (Lucerne and Weeds) per square link

	Irrigated Plots			Non-irrigated Plots	
Plots	Lucerne	Weeds	Plots	Lucerne	Weeds
			6.12.54		
A	7.0	1.0	C	5.5	0.5
B	6.5	1.5	E	6.0	0.5
D	6.3	0.4	F	6.3	1.1
G	6.0	1.0	I	6.0	0.4
H	7.3	0.7	K	4.8	2.3
J	5.3	0.4	L	5.5	1.9
Mean	6.4	0.83		5.7	1.1
			22.4.55		
A	5.0	0.0	C	3.1	0.4
B	4.2	0.0	E	3.6	1.1
D	3.7	0.0	F	3.7	1.9
G	4.3	0.0	I	2.9	0.3
H	3.6	0.0	K	2.4	1.4
J	5.0	0.0	L	2.9	1.5
Mean	4.3	0.0		3.1	1.1
			19.1.56		
A	3.7	0.0	C	2.9	0.0
B	3.2	0.0	E	3.2	0.0
D	2.9	0.0	F	3.1	0.0
G	3.5	0.0	I	3.4	0.0
H	3.7	0.0	K	3.3	0.0
J	3.9	0.0	L	3.3	0.0
Mean	3.5	0.0		3.2	0.0

(ii) Non-irrigated Plots

(1) The number of lucerne plants per square link is significantly ($P = 0.05$) reduced from 5.7 to 3.1 in about five months.

(2) No reduction in the total number of weeds per square link could be found.

The data of 22.4.55 indicate that there is no difference in the number of lucerne plants per square link in irrigated and non-irrigated treatments.

(iii) Second Year.- There is no significant difference between the number of lucerne plants per square link in the irrigated and non-irrigated plots at the end of the second year. It is of interest to note that during the second year there has been complete suppression of weeds in the non-irrigated plots, probably due to adequate moisture in winter.

(c) Soil-Moisture Tension Measurements

The general trend in soil moisture tension (pF) in non-irrigated and irrigated treatments is presented in Fig. 15. Weekly median pF values of both treatments (Appendices B_1 and B_2) have been plotted as a function of depth and time. Fig. 15 shows isopleths of pF 2.90, 3.22, 3.55, 3.87 and 4.20 respectively. Different types of hatching show the areas with pF <2.90, 2.90-3.22, 3.22-3.55, 3.55-3.87, 3.87-4.20 and >4.20. The amount of rainfall received and the irrigation given (appropriate allowance being made for runoff) are also shown.

For the sake of convenience the whole period has been divided into First Year and Second Year. The first year includes (a) Experimental Period

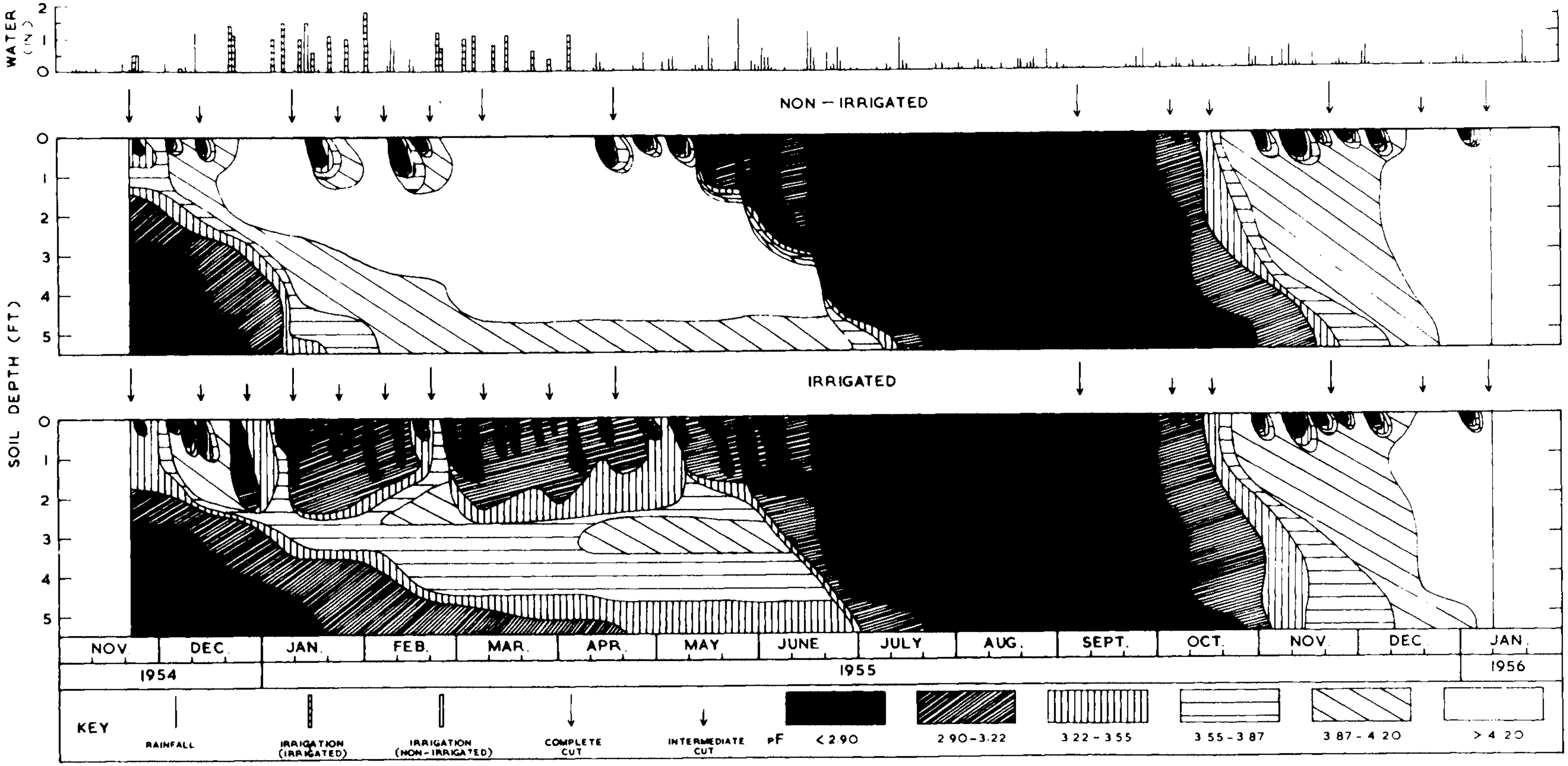

Fig. 15. Changes in soil - moisture tension under irrigated and non-irrigated lucerne.

and (b) Observational Period. The duration of the experimental period was from 22nd November 1954 to 19th April 1955, during which time the main experiment was conducted. It should be noted that irrigation was terminated in irrigated plots by 18th April 1955. It should also be noted, however, that 0.5 inches and 1.5 inches of water were given by irrigation on non-irrigated plots on the 22nd November 1954 and on 14th, 15th and 16th January 1955 respectively. The duration of the observational period was from 20th April 1955 to 7th September 1955 and during this time the readings were taken only to follow the depth of penetration of winter rainfall. The period 7th September 1955 to 10th January 1956 will be referred to as Second Year; during this period no irrigation was given to any of the plots and the lucerne was allowed to extract water until all available water was used down to a depth of 66 inches. For convenience the plots are still referred to as irrigated and non-irrigated according to the treatments in the first year.

In order to indicate the probable effects of rain and irrigation on the changes of the pF of the soil water at different depths in both treatments, the following assumptions were taken into consideration in preparing the diagram (Fig. 15).

(1) There will always be a definite line of demarcation between dry and wet soil when water is added to the soil.

(2) The wetting front will move with depth and time depending on the amount and duration of rain or irrigation.

(3) The decrease in pF of the soil water at a certain depth

denotes that the water must have infiltrated at least to that depth and that the pF of the soil water of the whole profile including the surface layer must have been at one stage at less than 2.90.

(4) If the amount of water added by rain or irrigation (appropriate allowance being made for runoff) and the initial moisture content of the soil of the different horizons is known, the appropriate depth of penetration of water can be obtained.

(5) Knowing the depth of penetration of water, it appears safe to assume that for one or two days, depending upon the duration and quantity of rain or irrigation, the pF of the soil water of the whole profile to that depth would be less than 2.90.

The graphic comparison of the two treatments in Fig. 15 shows the changes in the pF of the soil water throughout the whole soil profile for first and second years. The pF of the soil water increases progressively with increase in depth with time in the non-irrigated plots, while in the irrigated plots the increase is slow and inconsistent. Since it is reasonably well established that the extent to which moisture is removed from the soil depends largely on the concentration of roots in the soil (Aldrich, Work and Lewis 1935; Veihmeyer and Hendrickson 1938), it may be assumed that the slopes of isopleths of different pF give a qualitative indication of the distribution of active roots. It also shows clearly that during the whole experimental period the pF of the soil water throughout the whole profile in the irrigated plots is never greater than 4.20, while in the non-irrigated plots the pF of the soil water is greater than 4.20 for the most part of the experimental period.

Fig. 15 also demonstrates that the weekly irrigation could not maintain the pF of the soil water of the whole profile at or below 2.90. It is seen that under the soil type and the crop studied it was possible to maintain only the top $2\frac{1}{2}$ feet and this was also only partially achieved.

The effect of winter rain in lowering the pF of the soil water at different depths progressively increases with time and depth. It may be seen that at the opening of the season the response of 1 and 2 foot depth levels in both treatments is very rapid. There seems to be a considerable delay before the wetting front reached the 4 and 5 foot levels. This delay will, however, depend on the amount of rainfall, initial moisture content of the soil, thickness of the plant cover and availability of water for downward movement as well as on the permeability of the soil. Aitchison and Holmes (1953) suggested that during an average winter season in Adelaide the 6 foot level profile becomes wet about four months after the first substantial falls of rain. However, the wetting front (Fig. 15) reached $5\frac{1}{2}$ feet about two months after the first fall of rain (i.e. mid-July 1955) in this experiment. This is probably due to an unusually wet winter, 15.36 inches being recorded in May, June and July.

The pF of the soil water throughout the whole profile was less than 2.90 till the beginning of October. From then, the pF continues to increase throughout the whole profile. At the end of December 1955 the pF of the soil water of the whole profile is greater than 4.20 and so remains till the end of the experimental period (i.e. 10.1.56) in both treatments.

Examination of Fig. 15 suggests:

(i) Non-irrigated Plots

(1) At the start of the experiment the pF of the soil water of the whole profile is not uniform; in the top 3 feet it is greater than 2.90 while at 3-5½ feet it is less than 2.90.

(2) The steep drop of isopleths of 3.87 at the depth of the top 1 foot in the beginning of December 1954 indicates that the extraction of water by the plants was probably greatest at that time. The isopleths of 2.90, 3.22 and 3.55 show a steady slope indicating that the plants were extracting water probably at a uniform rate.

(3) By the end of December 1954 the pF of the soil water at all depths was greater than 2.90, indicating that the active roots are extracting water from deeper horizons. Conrad and Veihmeyer (1929) also concluded that moisture is absorbed from progressively expanding zones if there is no material addition of moisture during the season. During this time the pF of the soil water of the top 2½ feet is greater than 4.20.

(4) By the beginning of January 1955, the pF of the soil water of the top 2½ feet is greater than 4.20 while at the lower depths it is less than 4.20. It is of interest to note the sudden vertical drop in the isopleths of 3.22, 3.55 and 3.87 indicating that the demand for water from lower depths became more severe as the available water in the top 2½ feet was depleted.

(5) The 1.5 inches of irrigation given on 14th, 15th and 16th January 1955 lessened the demand for water from the lower depths as

indicated by the changing behaviour of the isopleths of 3.55, 3.87 and 4.20 which became almost horizontal. As soon as the 1.5 inches of irrigation water was used by the lucerne, the isopleths of 3.55 and 3.87 changed their horizontal pattern to the vertical, indicating that the plants were again extracting water from the deeper layers.

(6) By the beginning of February 1955 the pF of the soil water in the top 3½ feet was greater than 4.20 while deeper layers were still less than 4.20.

(7) By the end of July the pF of the soil water at all depths was less than 2.90 due to percolation of winter rain and remained practically unchanged till the beginning of October.

(8) The fact that the pF of the soil water of the whole profile from the end of July to the beginning of October remained practically unchanged, suggests that during this period the water use by lucerne was either equal to or less than the rainfall.

(ii) <u>Irrigated Plots</u>

(1) At the outset of the experiment the pF of the soil water of the top 3 feet was greater than 2.90 while that of 3-5½ feet was less than 2.90.

(2) Irrigation was able to maintain the pF of the soil water of the top 2½ feet below 3.55 for most of the experimental period.

(3) The change in the pF of the soil water below 2½ feet probably indicates the activities of roots below this layer. The parallel behaviour of the isopleths of 3.22 and 3.55 gives a qualitative indication of the

extraction of water along with depth and time.

(4) Frequent irrigation at the surface appears to lessen the demand for water from the deeper layers as indicated by the isopleths of 2.90, 3.22 and 3.55.

(5) The lucerne roots under the present experiment were not able to increase the pF of the soil water at $5\frac{1}{2}$ foot level above 3.22 during the experimental period.

(6) The fact that the pF of the soil water at $5\frac{1}{2}$ feet depth is reduced to 2.90 in about two months from the outset of the experiment and from 2.90 to 3.22 in about three months, indicates that under frequent irrigation lucerne takes quite a considerable time to raise the pF of the soil water from less than 2.90 to 3.22.

(7) A quick increase in pF of the soil water of the top $2\frac{1}{2}$ feet to 3.55 and even to 3.87 indicates that most of the absorbing roots are present in this layer. During five years' studies on the water uptake by alfalfa in an irrigation soil Bowen (1938) found that 77 per cent. of total water used was taken from the top 3 feet of soil. Under frequent irrigation ('wet' or little moisture stress) alfalfa utilised 85 per cent. of the total water used from the surface 4 feet of soil (Stanberry 1955) and at that time the percentage of root distribution (by weight) to 3 feet was 82.6 per cent.

(8) By the end of July 1955 the pF of the soil water at all depths was less than 2.90 due to percolation of winter rain and remained practically unchanged till the beginning of October, suggesting that during this period the water use by lucerne was either equal to or less than the rainfall.

(iii) Second Year.- The extraction of water by lucerne in both non-irrigated and irrigated plots decreases with increase in depth and the rate of extraction is greatest in the top 1 or 2 feet, so that the available water is first depleted from those layers as indicated by the differences in the slopes of the isopleths of 2.90, 3.22, 3.55, 3.87 and 4.20 (Fig. 15). The shift in the isopleth of 4.20 is probably due to intermittent rainfall.

The differences in the rate of extraction at different depths at different pF can be explained in terms of percentage of root concentration at different depths as well as in terms of differences in the slopes of the pF-moisture content curve, which are different for different depths.

An analysis of pF data (Appendices B_1 and B_2) for all plots at all depths showed that there were slight differences in the final median pF values of non-irrigated and irrigated plots. In spite of the slight differences in the final median pF values of non-irrigated and irrigated plots, the variability among the plot values is so great that the differences are not statistically significant.

(d) Soil-Moisture Calculations

It has already been mentioned that all individual pF data were converted to moisture percentage by the pF-moisture content curve appropriate to the depth. Means of three values for each depth were then taken to represent the moisture status of that depth for the plot and the mean of six plots was taken to represent the moisture status of the treatment.

As an example, Tables 1 and 2 (Appendix C) summarise the average moisture content of two plots; plot B (irrigated) and plot C (non-irrigated) with the dates and amount of rain and irrigation water applied (appropriate allowance being made for runoff).

Fig. 16 shows the approximate weekly variation in moisture content of the whole profile in the non-irrigated and irrigated plots. Since the changes in pF in both treatments have already been described, no attempt will be made to describe the changes in soil moisture content.

(i) <u>Total Available Water Stored.</u>- Fig. 17 shows the trend in total available water stored (inches) from 0-66 inches, against time, in irrigated plots. Each line indicates the total available water stored (inches) to that depth from the surface.

The methods used to calculate the available water (inches) at each depth and the total available water stored (inches) in the whole profile have already been described. Table 11 shows the mean moisture content (%) and the available water (inches) between pF 2.00 and 4.20 at each depth. The total available water stored, then

from 0"-9" is 1.97 (inches)
0"-18" " 3.94 "
0"-30" " 5.77 "
0"-42" " 7.66 "
0"-54" " 9.42 "
0"-66" " 10.92 "

In Fig. 17 the scale of ordinate is so chosen that it represents the total amount of available water (inches) stored in the whole soil profile. The lines of A_9, A_{18}, A_{30}, A_{42}, A_{54} and A_{66} indicate the total available water stored (inches) from 0-9, 0-18, 0-30, 0-42, 0-54 and 0-66 inches depth respectively against time.

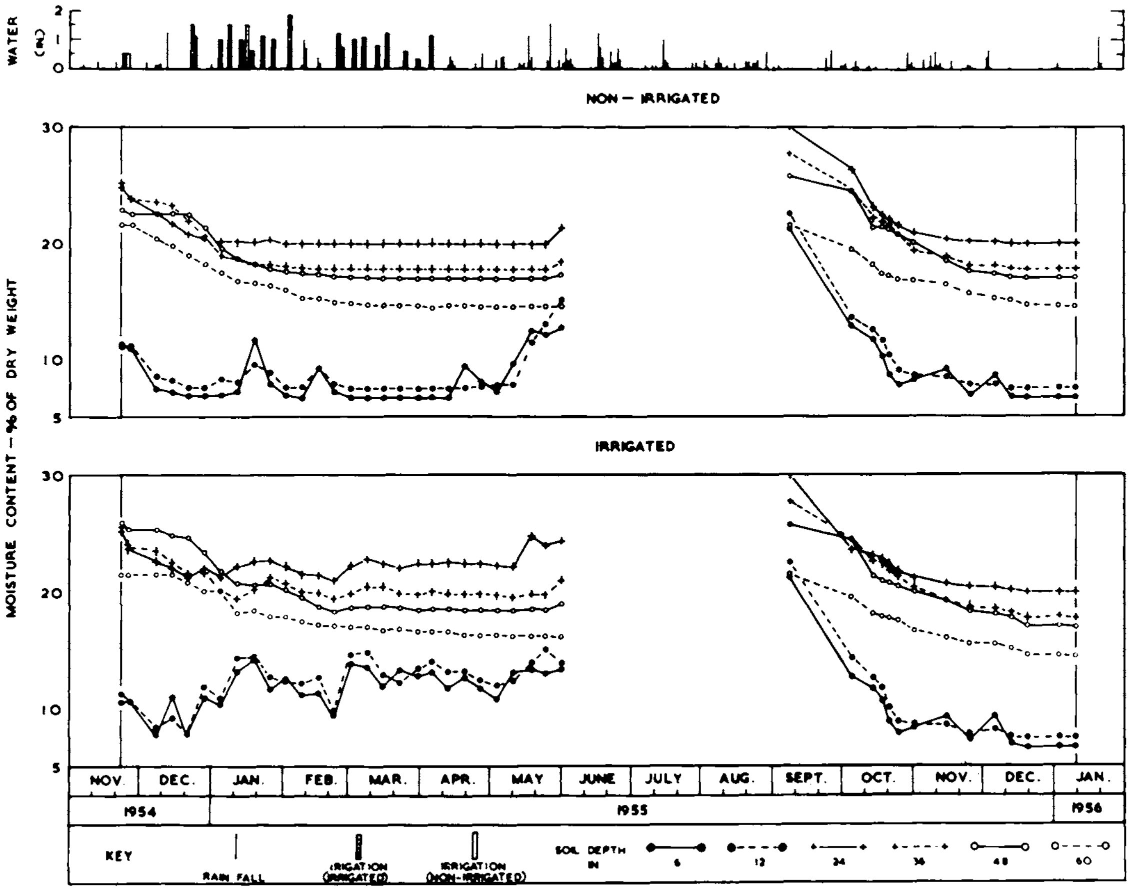

Fig. 16. Weekly values of soil moisture content under irrigated and non-irrigated lucerne.

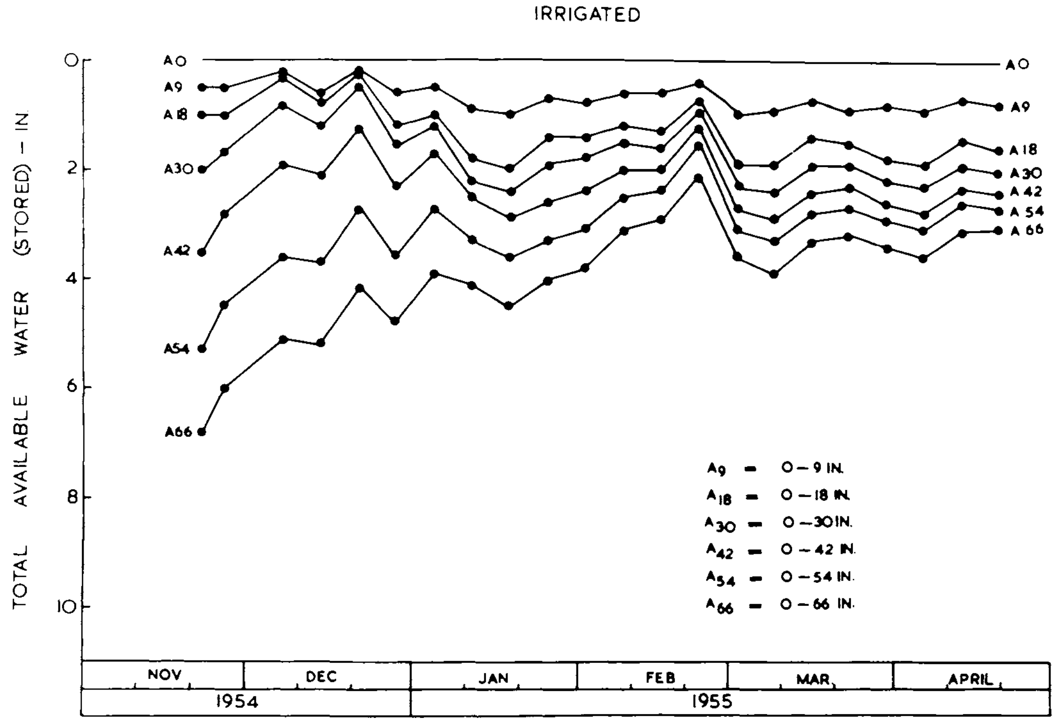

Fig. 17. Trends in amounts of total available water stored from 0 - 66 in. depth.

Table 11

Mean Water Content* and Available Water between pF 2.00 and 4.20 at different depths

Depth of Soil (in.)	Water Content at pF 2.00 (%)	Water Content at pF 4.20 (%)	Available water Content between pF 2.00 and 4.20 (%)	Available water stored between pF 2.00 and 4.20 (in.)
0-9	21.2	6.6	14.6	1.97
9-18	22.5	7.4	15.1	1.97
18-30	30.0	19.9	10.1	1.83
30-42	27.7	17.7	10.0	1.89
42-54	25.7	16.9	8.8	1.76
54-66	21.5	14.4	7.1	1.50

* Expressed as percentage of oven-dry soil

The purpose of presenting Fig. 17 (irrigated plots only being shown) is:

(i) it indicates the history of available water stored

(ii) it indicates the amount of available water stored at each depth

(iii) it indicates the total available water stored for the whole profile

(iv) narrowing of lines indicates the drying of soil

(v) widening of lines indicates the wetting of soil

(vi) it is easy to follow the trend of available water stored in any desired layer of the profile.

(e) Effect of Water Use on Dry Matter Production

For the sake of convenience the whole period has been divided into First Year and Second Year. The duration of the first year was from 22nd November 1954 to 19th April 1955. The main experiment was conducted during this time. It should be noted that irrigation was terminated in irrigated plots by 18th April 1955. The duration of the second year was from 7th September 1955 to 10th January 1956. During this period no irrigation was given to any one of the plots and the lucerne was allowed to extract water until all the available water was used down to the depth of 66 inches. For convenience the plots are still referred to as irrigated and non-irrigated according to the treatments in the first year.

Again, for convenience the first, second and third complete cuts of the first year experiment will be referred to throughout as Harvest I, II and III and the complete cuts of the second year as Harvest IV and V respectively for both treatments.

The cumulative yield of dry matter of lucerne (cwts per acre) and cumulative water used* (inches per acre) of six irrigated plots and six non-irrigated plots are given in Tables 12 and 13. These tables show the average yield of each plot, the average cumulative yield of dry matter of each treatment, and the amount of water added by rain and irrigation (appropriate allowance being made for runoff) for each plot and treatment. The date shown is the day on which the cuts were taken.

If the total amount of water stored in the soil on any occasion was greater than the total amount of water in the soil of the previous occasion, the increase in the amount was subtracted from the total amount

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*This includes plant transpiration, surface evaporation and percolation of water below sampling depths, if any.

Table 12

Cumulative Water Used (Inches/acre), and Cumulative Yield of Dry Matter (Cwt./acre)

Irrigated Plots

Harvest - I (23.11.1954 to 10.1.1955)

First Cutting (13.12.54)

Plot		A	B	D	G	H	J	Mean
	a	0.50	0.50	0.82	0.80	0.64	0.58	0.64
	b	1.53	1.53	1.53	1.53	1.53	1.53	1.53
	c	0.81	2.68	1.63	1.21	1.67	1.79	1.63
	d	2.84	4.71	3.98	3.54	3.84	3.90	3.80
Yield		5.23	6.15	8.18	10.81	7.72	6.56	7.44

Second Cutting (27.12.54)

Plot		A	B	D	G	H	J	Mean
	a	1.87	3.42	1.35	2.11	3.39	3.62	2.63
	b	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	c	1.39	-0.94	1.45	1.91	-1.14	-0.29	0.40
	d	6.10	7.19	6.78	7.56	6.09	7.23	6.83
Yield		16.18	22.96	16.48	30.69	14.46	18.87	19.94

Third Cutting (10.1.55)

Plot		A	B	D	G	H	J	Mean
	a	3.10	1.46	2.13	3.76	2.89	1.80	2.52
	b	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	c	-0.40	2.76	0.80	-0.19	0.41	1.02	0.73
	d	8.85	11.46	9.76	11.18	9.44	10.10	10.13
Yield		33.62	38.36	26.98	43.35	25.67	27.61	32.60

a - Irrigation water applied (inches/acre)

b - Rain (inches)

c - From the soil (inches)

d - Cumulated Total of Water Used (inches/acre)

Table 12 (Cont'd)

Harvest - II (11.1.55 to 21.2.55)

First Cutting (24.1.55)

Plot		A	B	D	G	H	J	Mean
	a	2.65	2.99	3.75	5.14	0.00	1.87	2.73
	b	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	c	0.64	-0.56	-0.69	-1.71	3.68	1.11	0.42
	d	3.29	2.43	3.06	3.43	3.68	2.98	3.15
Yield		9.52	9.02	10.09	14.74	13.05	12.03	11.41
Second Cutting (7.2.55)								
	a	3.31	3.06	1.67	1.75	4.10	2.66	2.76
	b	0.07	0.07	0.07	0.07	0.07	0.07	0.07
	c	0.32	0.77	2.33	1.28	-1.37	0.01	0.56
	d	6.99	6.33	7.13	6.56	6.48	5.72	6.54
Yield		22.86	31.39	19.53	31.23	24.96	22.83	25.47
Third Cutting (21.2.55)								
	a	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	b	2.14	2.14	2.14	2.14	2.14	2.14	2.14
	c	1.45	1.58	-0.10	1.06	1.67	0.57	1.04
	d	10.58	10.05	9.17	9.73	10.29	8.43	9.72
Yield		37.15	36.10	31.72	37.53	34.29	32.93	34.95

Table 12 (Cont'd)

Harvest - III (22.2.55 to 18.4.55)

First Cutting (9.3.55)

Plot		A	B	D	G	H	J	Mean
	a	3.71	4.24	3.81	4.32	3.32	4.91	4.05
	b	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	c	-1.50	-1.77	-1.17	-2.48	-1.92	-1.65	-1.75
	d	2.26	2.52	2.69	1.89	1.45	3.31	2.35
Yield		7.02	9.57	8.99	10.04	9.43	9.55	9.10

Second Cutting (29.3.55)

	a	2.67	1.79	2.64	2.30	2.48	3.35	2.54
	b	0.11	0.11	0.11	0.11	0.11	0.11	0.11
	c	-0.29	1.09	0.29	0.26	0.22	1.14	0.45
	d	4.75	5.51	5.73	4.56	4.26	7.91	5.45
Yield		28.94	28.62	23.81	32.05	27.91	30.51	28.64

Third Cutting (18.4.55)

	a	0.98	1.58	1.28	0.95	1.42	2.26	1.41
	b	1.26	1.26	1.26	1.26	1.26	1.26	1.26
	c	0.06	0.62	-0.15	1.08	-0.14	0.09	0.26
	d	7.05	8.97	8.12	7.85	6.80	11.52	8.38
Yield		35.37	37.72	32.63	42.04	31.79	37.87	36.24

Table 13

Cumulative Water Used (Inches/acre), and Cumulative Yield of Dry Matter (Cwt./Acre).

Non-Irrigated Plots

Harvest - I (23.11.1954 to 10.1.1955)

First Cutting (13.12.54)

Plot		C	E	F	I	K	L	Mean
	a	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	b	1.53	1.53	1.53	1.53	1.53	1.53	1.53
	c	2.89	3.88	1.47	2.30	1.88	1.58	2.33
	d	4.92	5.91	3.50	4.33	3.91	3.61	4.36
Yield		8.70	7.61	6.44	7.62	4.75	6.28	6.90

Second Cutting (10.1.55)

Plot		C	E	F	I	K	L	Mean
	a	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	b	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	c	3.84	1.72	3.60	1.61	1.68	3.44	2.65
	d	8.81	7.68	7.15	5.99	5.64	7.10	7.06
Yield		16.67	13.71	13.48	8.49	5.17	7.31	10.81

a - Irrigation water applied (inches/acre)
b - Rain (inches)
c - From the soil (inches)
d - Cumulated Total of Water Used (inches/acre)

Table 13 (Cont'd)

Harvest II (11.1.55 to 9.3.55)

First Cutting (24.1.55)

Plot		C	E	F	I	K	L	Mean
	a	1.50	1.50	1.50	1.50	1.50	1.50	1.50
	b	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	c	-0.40	1.07	-0.06	0.02	0.42	-0.28	0.13
	d	1.10	2.57	1.44	1.52	1.92	1.22	1.63
Yield		1.82	2.20	5.92	2.18	7.45	2.69	3.71

Second Cutting (7.2.55)

	a	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	b	0.07	0.07	0.07	0.07	0.07	0.07	0.07
	c	1.05	0.32	0.85	0.79	0.55	0.73	0.72
	d	2.22	2.96	2.36	2.38	2.54	2.02	2.42
Yield		4.83	5.67	7.74	6.04	14.03	9.69	8.00

Third Cutting (21.2.55)

	a	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	b	2.14	2.14	2.14	2.14	2.14	2.14	2.14
	c	0.01	0.00	-0.14	0.11	-0.02	0.02	0.00
	d	4.37	5.10	4.36	4.63	4.66	4.18	4.56
Yield		9.54	13.93	20.36	12.47	16.59	17.31	15.03

Fourth Cutting (9.3.55)

	a	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	b	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	c	0.16	0.29	0.21	-0.05	0.24	0.28	0.19
	d	4.58	5.44	4.62	4.63	4.95	4.51	4.80
Yield		12.67	16.04	25.43	12.71	23.27	23.37	18.92

Table 13 (Cont'd)

Harvest III (10.3.55 to 18.4.55)

<u>First Cutting</u> (18.4.55)

Plot	C	E	F	I	K	L	Mean
a	0.00	0.00	0.00	0.00	0.00	0.00	0.00
b	1.37	1.37	1.37	1.37	1.37	1.37	1.37
c	-0.27	-0.34	-0.46	-0.49	-0.23	-0.31	-0.35
d	1.10	1.03	0.91	0.88	1.14	1.06	1.02
Yield	4.40	4.90	5.53	6.43	6.02	6.03	5.51

of water added by rain and irrigation to obtain the total amount of water used by the lucerne during that interval of time, and the amount is given in Tables 12 and 13 by negative (-) sign. If the total amount of water in the soil on the occasion was lower than the total amount of water stored in the soil of the previous occasion, the decrease in the amount was added to the amount of rain and irrigation to get the total amount of water used by lucerne during that interval of time.

It has already been mentioned that even quantities of water could not be applied to all six irrigated plots. It is apparent from Table 12 that this resulted in uneven amounts of water being taken from the soil or added to the soil.

Since no record of water use and production of dry matter was obtained immediately before the start of the harvest, it has been assumed that at the beginning of every harvest the dry matter production and water use are approximately zero. This has been done on the assumption that in the absence of water use, there is no dry matter production. This assumption may not be true in the strict sense but it was thought that even if small amounts of water were used and dry matter production occurred at the outset of each harvest, such amounts would not be great enough to alter the slope of the curve for that harvest. This has been assumed for all harvests in both the treatments for both years.

(i) Irrigated Plots.- Mean cumulative curves showing the relation between dry matter production and water use for harvests I, II and III are given in Figs. 18, 19 and 20. Cumulative yield of dry matter has been plotted against the cumulative water use for each plot and for each cutting.

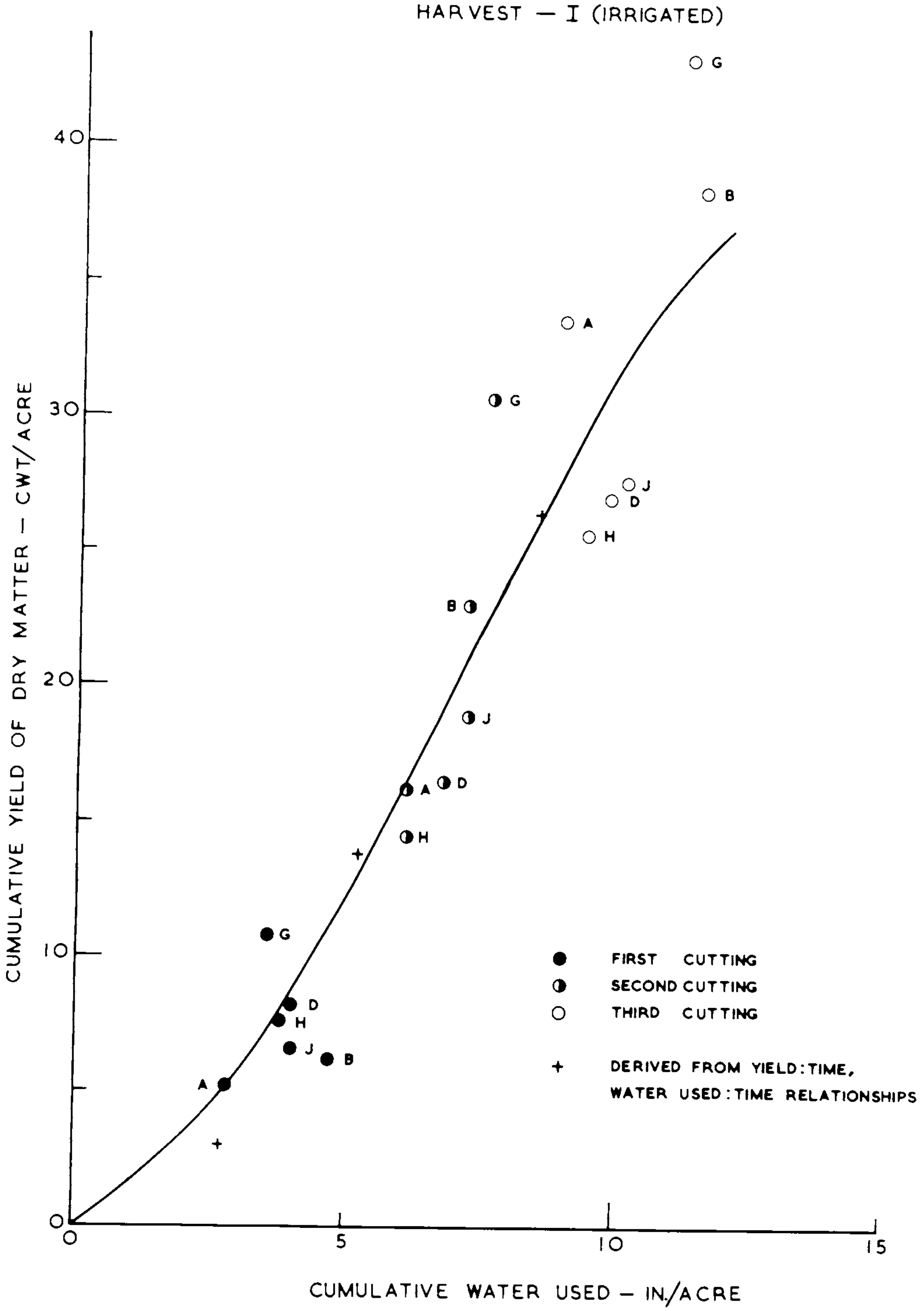


Fig. 18. Relation between cumulative yield of dry matter (cwt/acre) and cumulative amount of water used (in./acre) in irrigated plots - Harvest I.

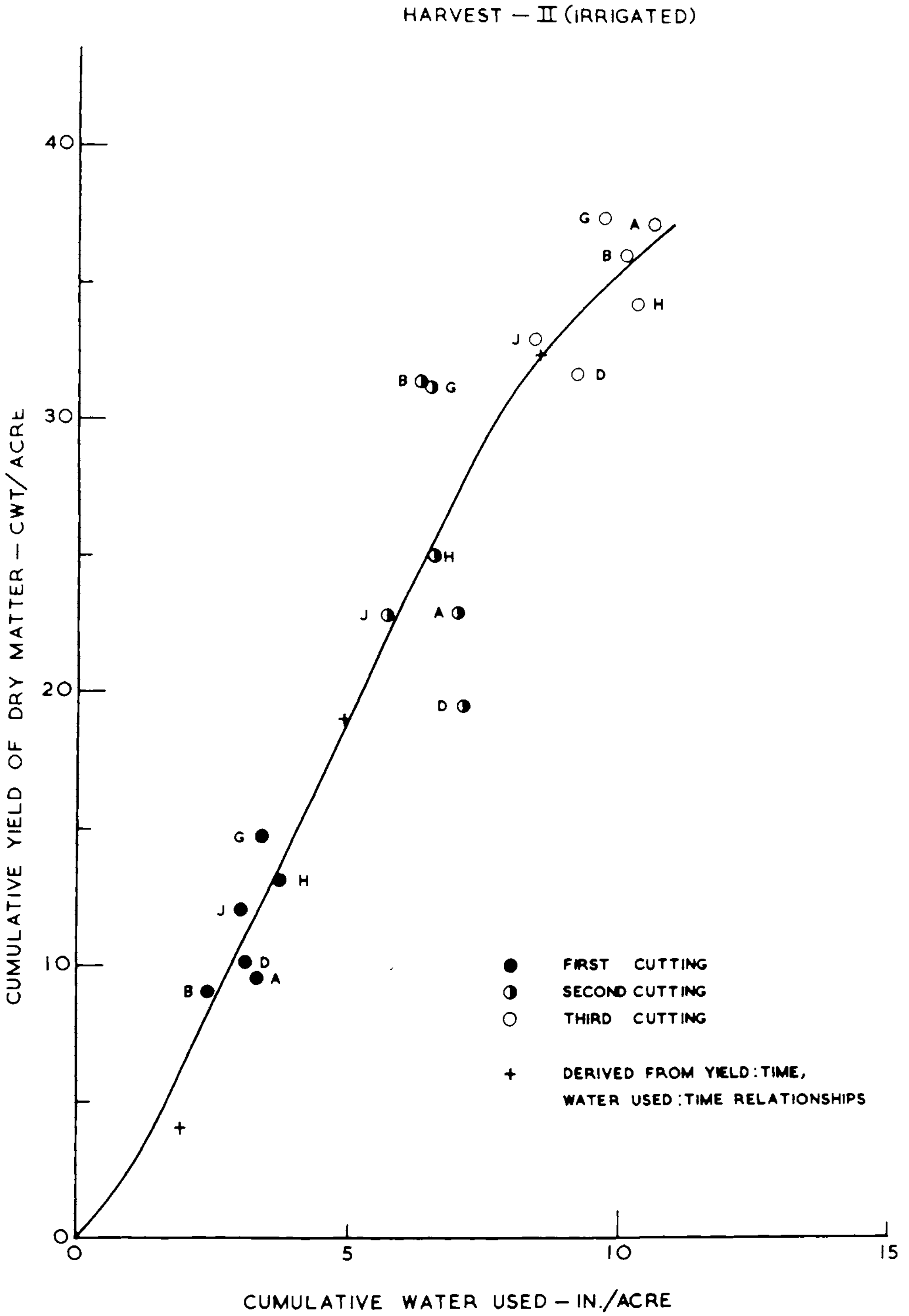


Fig. 19. Relation between cumulative yield of dry matter (cwt/acre) and cumulative amount of water used (in./acre) in irrigated plots - Harvest II.

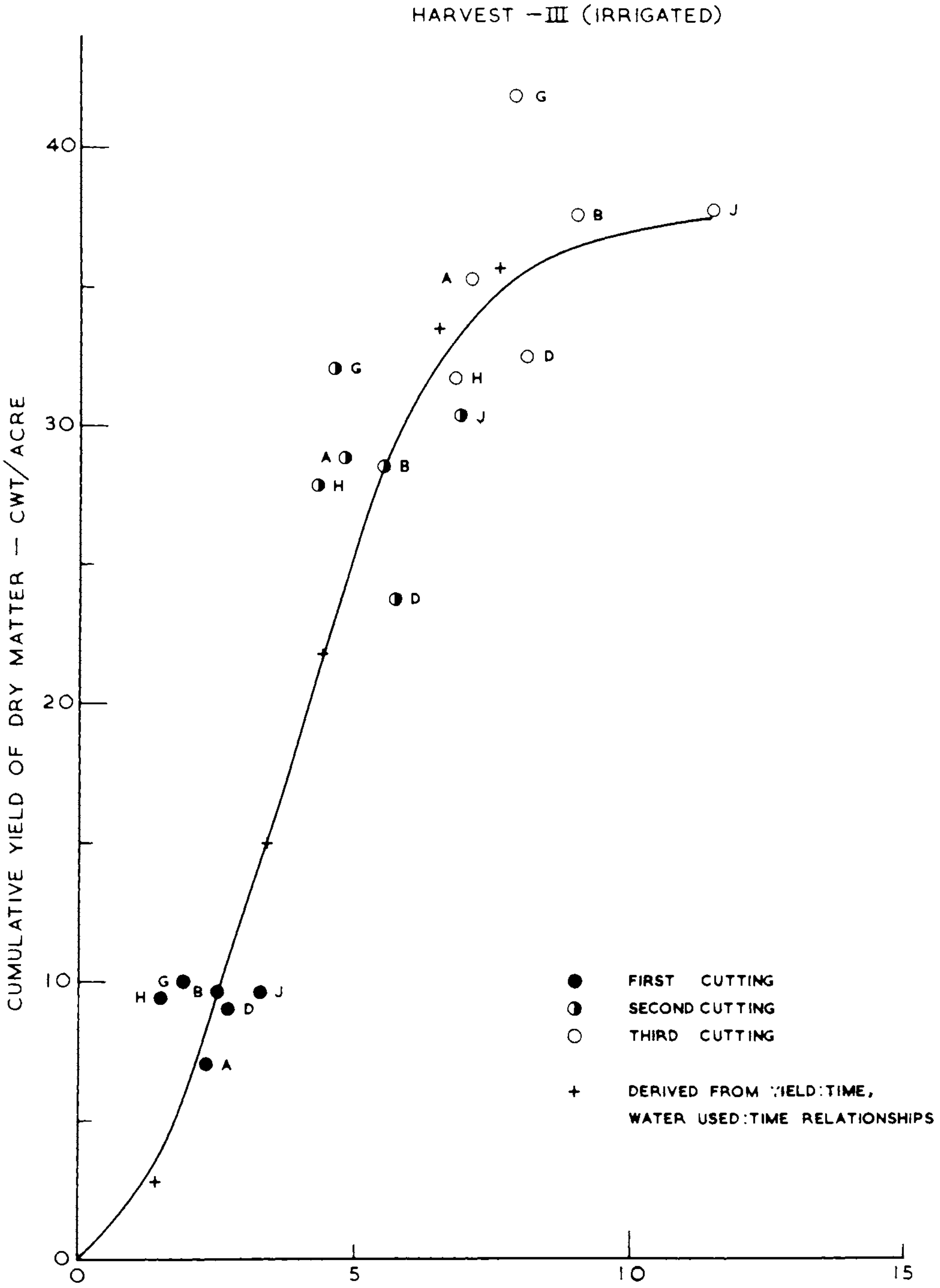


Fig. 20. Relation between cumulative yield of dry matter (cwt/acre) and cumulative amount of water used (in./acre) in irrigated plots - Harvest III.

To show the general curve of each plot in relation to dry matter production and water use, individual plots are indicated in the diagram. This enables a comparison to be made of the cumulative water-yield curve of individual plots with the mean curve.

In order to obtain the approximate relation between cumulative yield of dry matter and cumulative water use between cuttings, dry matter and water used curves were each drawn against time. From these curves approximately weekly values of yield of dry matter and water use were obtained. One or two values (depending upon the duration of the cutting) between each cutting are shown in Figs. 18, 19 and 20. These derived values appear to fit reasonably well. Examination of Figs. 18, 19 and 20 suggests that:-

(1) As might be expected, as the cumulative water supply increases, so too do the cumulative yield of dry matter and the quantity of water used. The increase is slow at the outset of each harvest, then increasing very rapidly and finally gradually decreasing.

(2) Relatively high and continuous moisture supply is conducive to the production of dry matter. Similar results have been reported by many workers (e.g. Beckett and Dunshee 1932; Schwalen and Wharton 1930; and see also Richards and Wadleigh 1952).

(3) The differences in the ascending and descending portions of the curves of the three harvests suggest that some other factors besides water supply and use were controlling the rate of growth.

(4) All the three curves of the three harvests start with different slopes and remain slightly different from each other; however, all the curves appear to extrapolate to the same point, suggesting that in all

the harvests the maximum production will be the same independent of the amount of water used.

Harvest I

Plots D, H and J all indicate a general relationship and all data seem to lie on the same curve suggesting that their rate of water use and rate of dry matter production are similar. On the other hand, plot G shows a consistently higher yield and lower water use than the other five plots. Plots A and B show an irregular relationship between water use and dry matter production.

Harvest II

All plots show increasing dry matter production with increasing water use. Plot D gave slightly lower yield only in the second cutting. The points of plots B and G follow the same path of curve showing higher production of dry matter and less water use than the remaining four plots.

Harvest III

Plots B and G still show higher production of dry matter and less water use than the other four. Four of the plots show a steady decrease in the production of dry matter in the third cutting, plots D and J being the exceptions.

It is evident from Table 12 and Figs. 18, 19 and 20 that plot G always gave higher yields with smaller amounts of water used compared with other plots. It is suggested that a possible reason for this discrepancy might be that plot G was almost flat, resulting in more even distribution of water.

From the inspection of curves (Figs. 18, 19 and 20) it is clear that the relation between cumulative water use and cumulative yield of dry matter is not unique. Since cumulative water used or total water loss from an actively growing lucerne field is approximately the transpiration loss (assuming that surface evaporation is negligible compared with plant transpiration), any external factors that will influence transpiration will also affect the water loss. There is a strong indication that when water-supply is non-limiting, (as may be assumed here), the transpiration loss or water loss is mostly influenced by weather (Penman 1956; Schofield and Penman 1948; Schofield 1950, 1952; and Thornthwaite 1948). Since environmental factors will be discussed in detail later, it is sufficient to mention here that the differences in slope of the curves could be explained in terms of those factors.

(ii) Non-irrigated Plots.- The relation between the amount of water used and dry matter production is shown as a mean cumulative curve in Fig. 21 for harvests I and II. Since harvest III had only one cut, no curve is shown. Approximately weekly values of cumulative yield of dry matter and cumulative water used were similarly obtained as in irrigated plots and are shown in Fig. 21.

In harvest I the yield of dry matter increases as the amount of water use increases, but as the effect of water stress was visible by the beginning of the second cutting, only two cuts were taken. The serious wilting and drooping of leaves was noted at the end of the second cutting. The soil moisture tension diagram (Fig. 15) reveals that the pF of the soil water from 0-30 inches and 30 to 60 inches was higher than 4.20 and 2.90

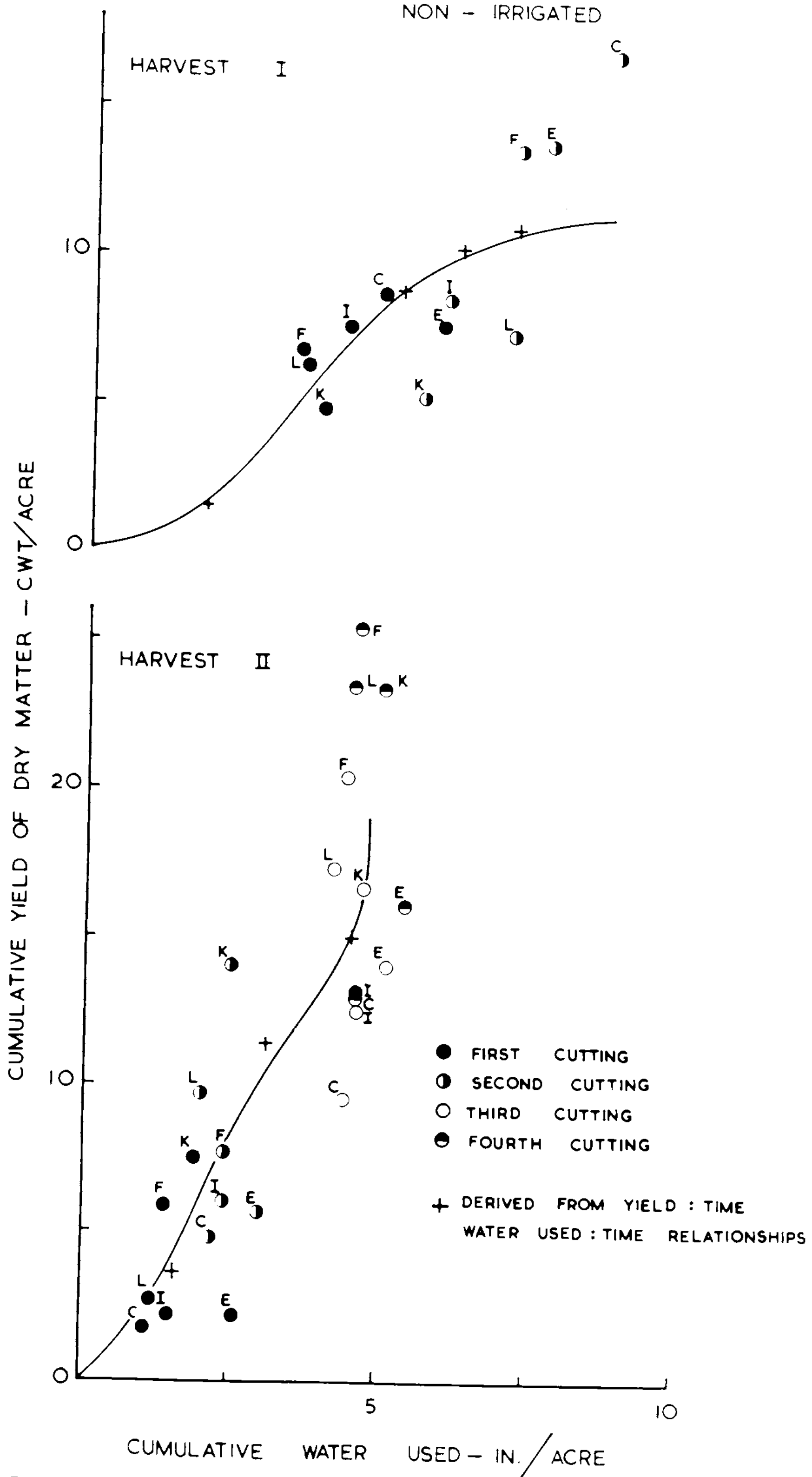


Fig. 21. Relation between cumulative yield of dry matter (cwt/acre) and cumulative amount of water used (in./acre) in non-irrigated plots - Harvests I & II.

respectively at the end of the harvest. There is a definite indication that water loss by direct evaporation is confined to shallow depths and losses from deeper layers are due to transpiration through the plants (Conrad and Veihmeyer 1929; Veihmeyer 1927). Veihmeyer and Hendrickson (1938) have even used the pattern of moisture extraction as an indication of the probable root distribution. Similarly Stanberry (1955) reported that the moisture extraction pattern is an indication of root activity and the moisture loss in the various horizons defines the active root zone. He further remarks there that the zone of moisture extraction is roughly proportional to the distribution of the alfalfa roots when the moisture held at the root zone is at the same tension. The increase in soil moisture tension (Fig. 15) down to the depth of 66 inches, therefore, can be taken as an indication of the presence of active lucerne roots. Unfortunately it was not possible at that time to determine the depth of root penetration in the non-irrigated plot. However, in the irrigated plot (A) the roots were found to be somewhere between 52 and 56 inches on 11th January 1955.

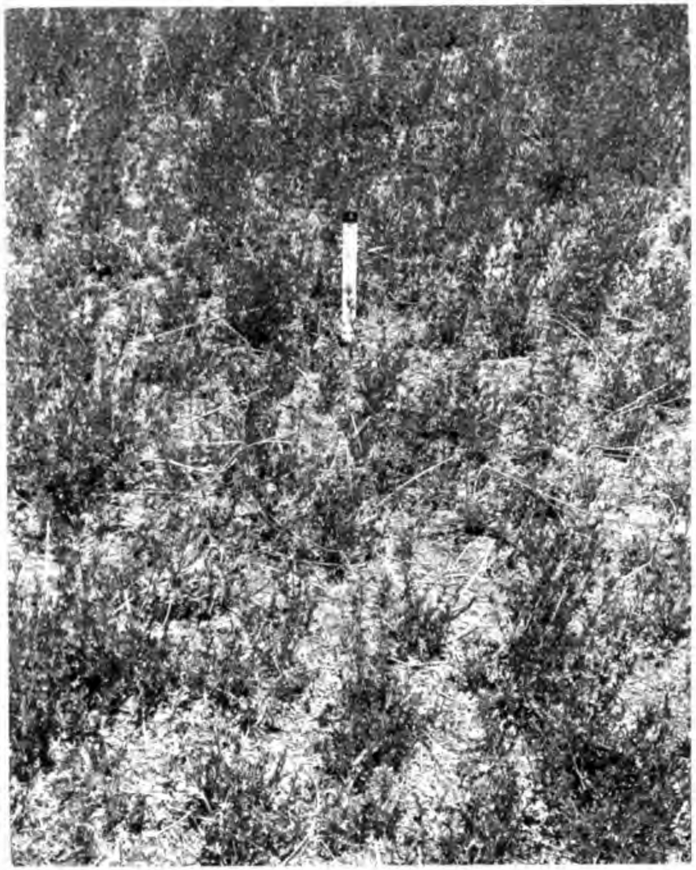
Serious wilting and drooping of leaves were noted even when pF of the soil water below 30 inches was higher than 2.90. This suggests that under the soil type and crop studied water is not equally available over the range from field capacity to permanent wilting percentage. This supports the hypothesis (Richards and Wadleigh 1952) that the rate of vegetative growth is reduced as soil-moisture stress is increased in the moisture content range from field capacity to near the permanent wilting percentage.

It has already been mentioned that at the outset of harvest II all non-irrigated plots were given 1.5"of water on 14th, 15th and 16th January 1955. The curve (Fig. 21) of harvest II shows a steady increase in the first cutting, a steep increase in the second cutting, a gradual decrease in the third cutting, and a very steep increase in the fourth cutting.

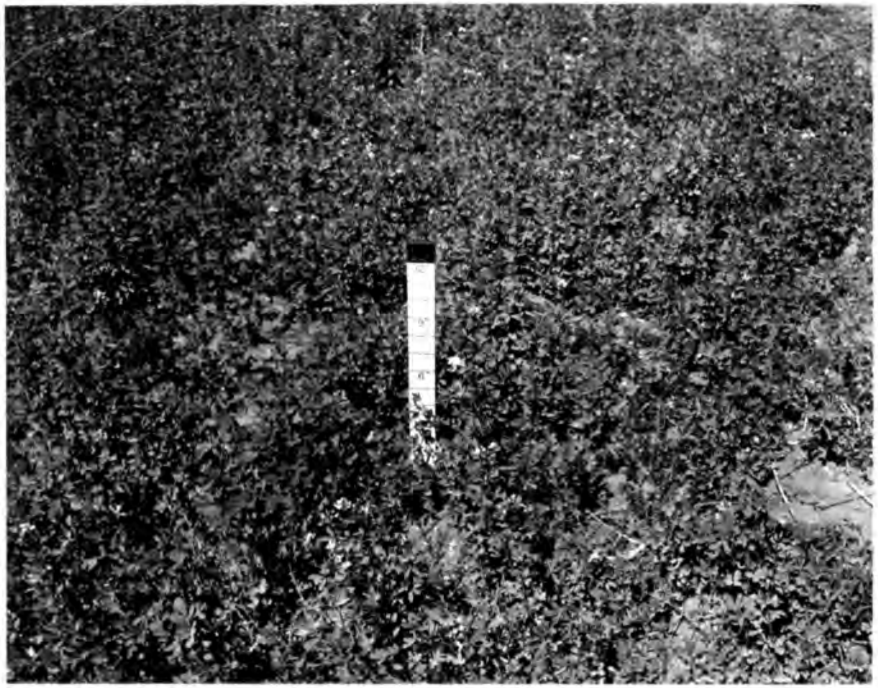
The ascending cumulative curve indicates that between the first and second cuttings, and between the third and fourth cuttings, lucerne was getting water from deeper zones of the soil. As there were no gypsum blocks below 60 inches there is no record to indicate water being taken from deeper layers than 66 inches, but the total amount of water used appears to be underestimated.

The diagram of soil moisture tension (Fig. 15) indicates that at the beginning of harvest II the pF of the soil water down to the depth of 60 inches was 3.22. At the end of the second cutting the pF of the soil water down to the depth of 42 inches was higher than 4.20 and in between 42 and 66 inches was slightly lower than 4.20. The serious shortage of water is evident from the picture (photograph 5) taken just before 2.14 inches of rain fell. The immediate effect of rain can be visualised from the picture (photograph 6) taken just before the third cutting. The lucerne plants were then green and were about 9 inches high. The increase in dry matter in the third cutting can partly be ascribed to the rain; 2.14 inches of rain was mostly used by the end of the third cutting. The total available water stored at the end of the third cutting was 0.28 inches down to the depth of 66 inches.

The steep increase in the curve from the third cutting to the



Photograph 5. View of plot C (non-irrigated) taken just before rain, on 7th Feb. 1955.



Photograph 6. View of plot C (non-irrigated) taken on 19th Feb. 1955. 2.14 in. of rain fell on 8th and 9th Feb. 1955.

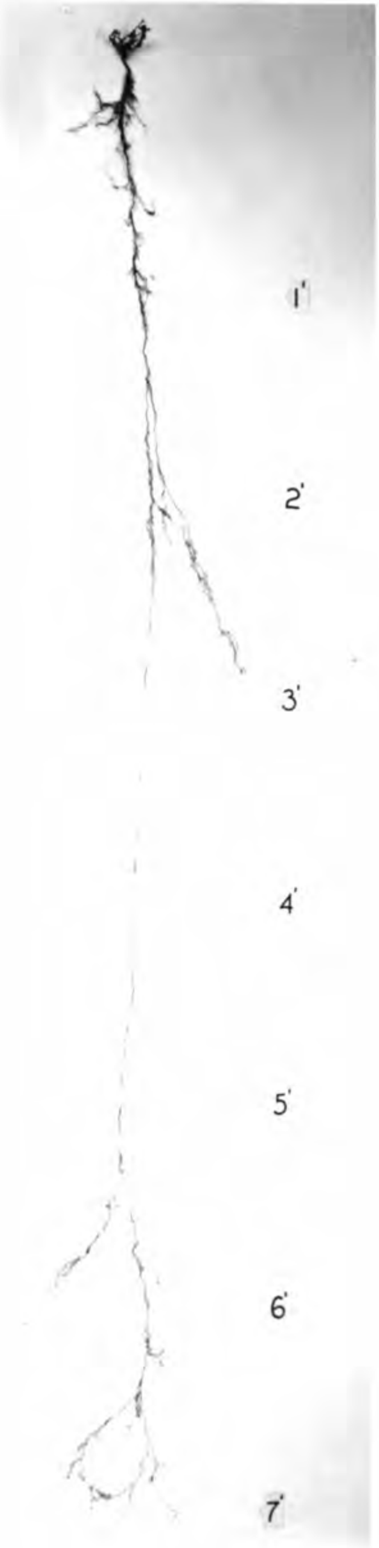
fourth cutting is very unusual. It is suspected that the lucerne roots are present below 66 inches. Examination of lucerne roots (photographs 7, 8 and 9) indicates that the roots were present to a depth of 86 inches on 29.4.55. During five years' studies on the water uptake by alfalfa in an irrigated soil, Bowen (1938) found that 97 per cent. of total water used was taken from the top 5 feet of soil and only 3 per cent from 6 feet depth. Stanberry (1955) reported that alfalfa irrigated frequently ("wet" or little moisture stress) utilised 27 per cent. of the available moisture from the surface 48 inches of soil between irrigation and 85 per cent. of the total water used came from the surface 48 inches of soil. While alfalfa irrigated infrequently ("dry" or appreciable moisture stress) used 80 per cent. of the available moisture from the surface 48 inches of soil and 72 per cent. of the total water used came from the surface 48 inches of soil. No literature appears to be available in which studies of water use from different depths were made under similar conditions to this investigation. It is suggested that to study lucerne under the soil type and similar investigations, the soil-moisture tension running device should be installed at depths exceeding 60 inches. Similar suggestions had been made by Richards and Wadleigh (1952).

(f) Efficiency of Water Use

It is evident from earlier results that the cumulative yield of dry matter increases as the cumulative amount of water used increases. However, the relation between cumulative yield of dry matter production and cumulative amount of water used fails to give:

(1) The amount of dry matter produced for each inch of water used at each cutting or between cuttings or between harvests, and

Photograph 7. Lucerne roots are shown under field conditions. The roots are just reaching the water.



Photograph 8. Dissected root system of a lucerne plant from a non-irrigated plot (F). Note the prominent tap root. Laterals are not abundant below 16 in. Note the laterals are present below 60 in. Roots were found to the depth of 86 in.

Photograph 9. View of the roots between 60 and 86 in.

(2) The stage of growth at which the production of dry matter per inch of water used was highest.

The efficiency of water use (e), here defined as the ratio of the amount of dry matter produced to the amount of water used by the lucerne from unit area in unit time, may be used in the further examination of these data.

The efficiency of water use for both treatments was calculated by the expression:

$$e_{0-1} = \frac{Y_1 - Y_0}{W_1 - W_0} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad \text{(i)}$$

$$e_{1-2} = \frac{Y_2 - Y_1}{W_2 - W_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad \text{(ii)}$$

$$e_{3-2} = \frac{Y_3 - Y_2}{W_3 - W_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad \text{(iii)}$$

$$e_{4-3} = \frac{Y_4 - Y_3}{W_4 - W_3} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad \text{(iv)}$$

The ratios $\frac{Y_1 - Y_0}{W_1 - W_0}$, $\frac{Y_2 - Y_1}{W_2 - W_1}$, $\frac{Y_3 - Y_2}{W_3 - W_2}$ and $\frac{Y_4 - Y_3}{W_4 - W_3}$ were placed at $\frac{t_1 - t_0}{2}$, $\frac{t_2 - t_1}{2}$, $\frac{t_3 - t_2}{2}$ and $\frac{t_4 - t_3}{2}$ days respectively in Figs. 22 and 23.

In order to get more points and also finer intervals Y,t (yield against time) and W,t (water used against time) curves were drawn separately for each harvest. The ratios Y/W were then obtained for 0-10, 10-20, 20-30, 30-40 and 40-50 days respectively. These ratios were then graphed at 5, 15, 25, 35 and 45 days respectively (Figs. 22 and 23) and a smooth curve drawn from these derived values. The curve appears to fit reasonably well with the actual values obtained at each cutting. Similarly the efficiency of water use for all harvests was calculated and are shown in Fig. 22 for irrigated plots and Fig. 23

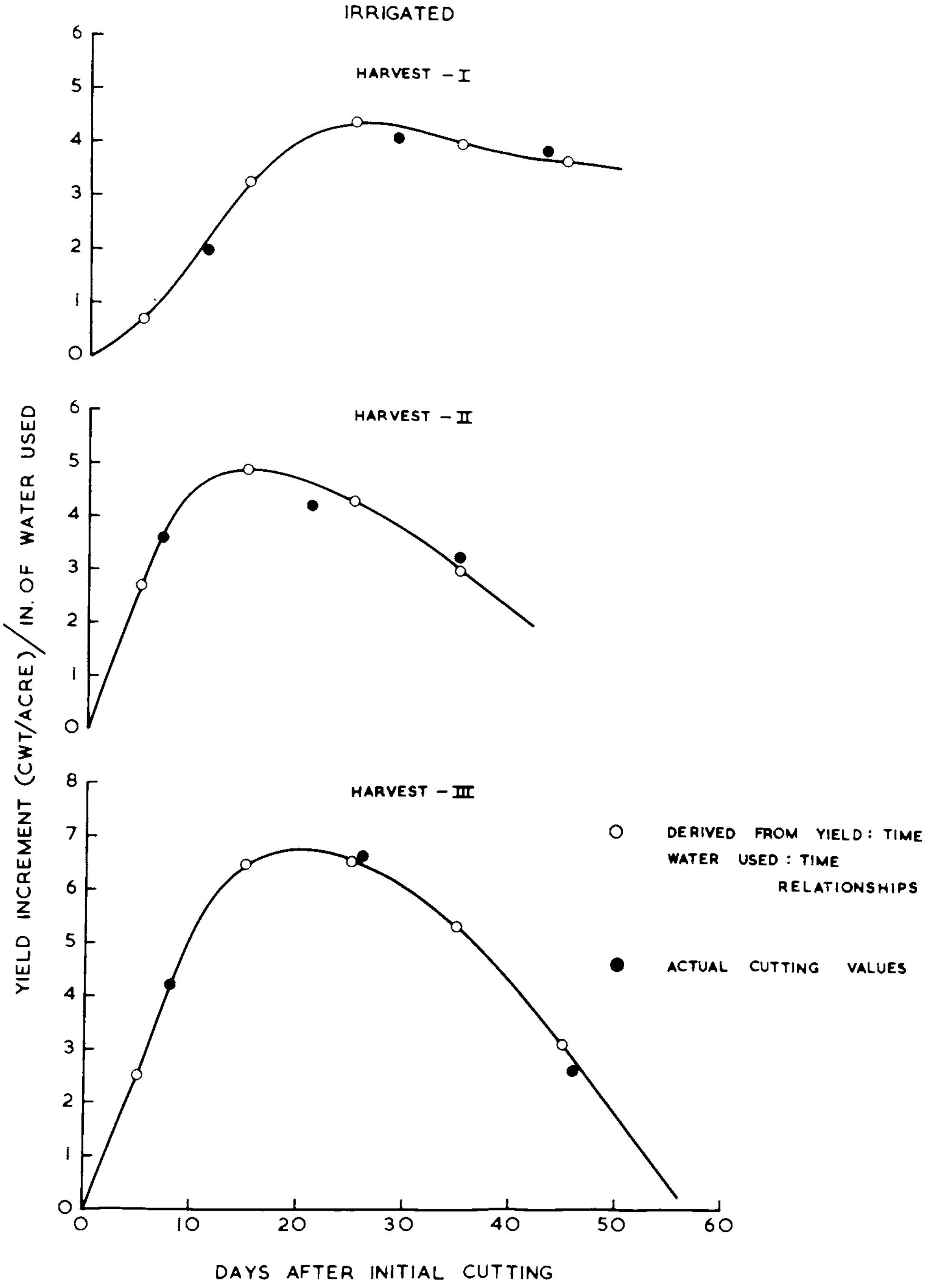


Fig. 22. Efficiency of Water Use for Harvests I, II & III. (Irrigated Plots).

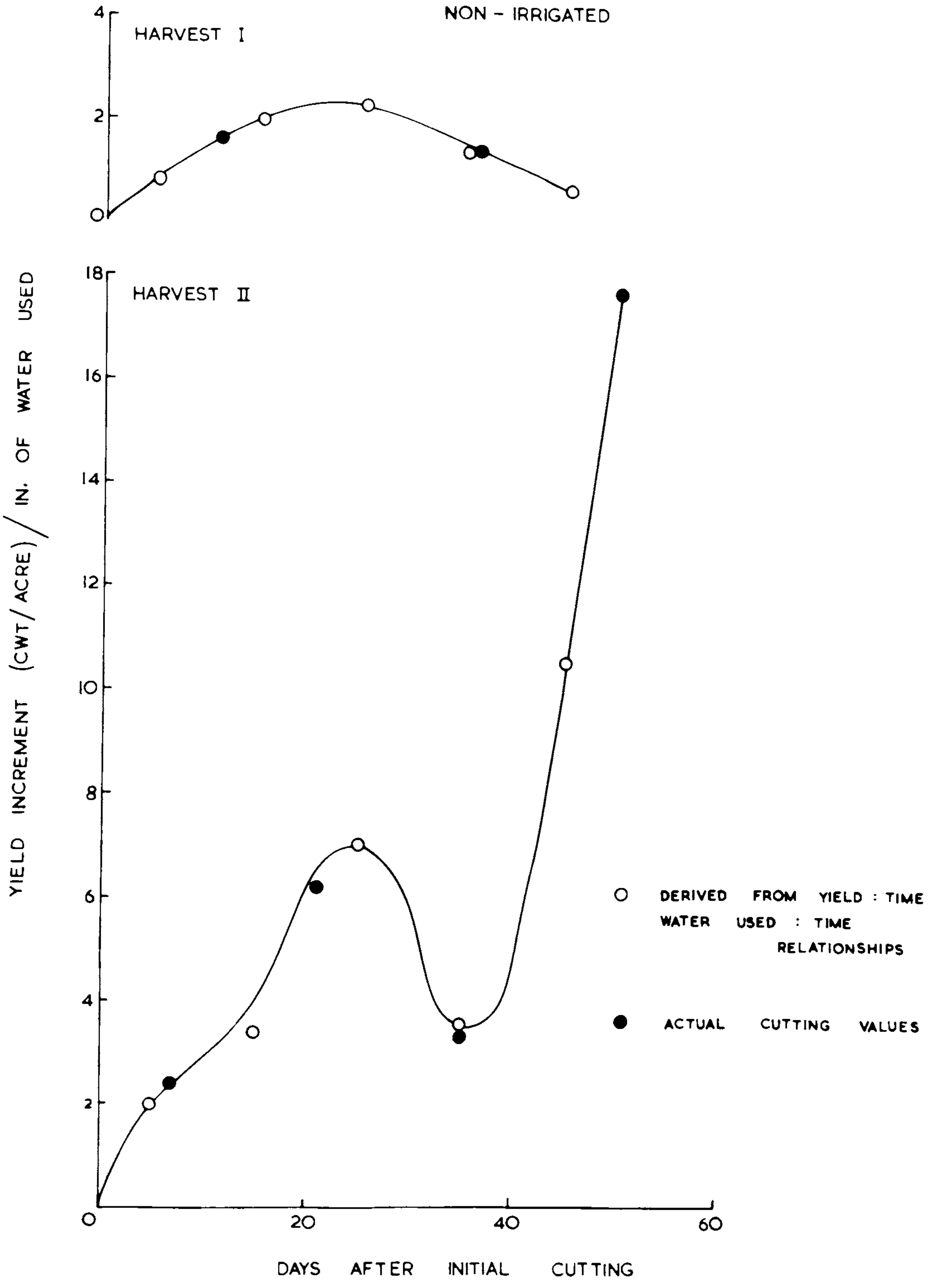


Fig. 23. **Efficiency of Water Use for Harvests I & II. (Non-irrigated plots).**

for non-irrigated plots. Yield increment (cwt/acre) er inch of water used has been plotted against time. The ordinate of the curve gives e_t at any time t for the harvest concerned.

Key to the symbols is given on page 126.

(i) Irrigated Plots.- Examination of the curves in Fig. 22 suggest that:

(1) All three efficiency of water use curves against time show a rapid increase at the beginning of the harvest period (harvest 1 being an exception) and then increasing rapidly and finally gradually decreasing.

(2) The dissimilarity in slope of curves indicates that e is not constant and varies from cutting to cutting, harvest to harvest, and varies markedly with time (Tables 14 and 15).

(3) The differences in slope of the curves indicate that e is controlled by some other factors and not by the total amount of water used.

The highest e was recorded in harvest III, followed by harvests II and I respectively (Table 15). The lowest e was also recorded in harvest III, followed by harvests II and I respectively. It is of interest to note that harvest III which recorded highest e also recorded lowest e.

Symbols Used

e = Efficiency of Water Use.

e_t = Efficiency of Water Use at any time t

e_0 = Efficiency of Water Use at cutting 0

e_{0-1} = Efficiency of Water Use from cutting 0 to cutting 1

e_{1-2} = " " " " " 1 " 2

e_{2-3} = " " " " " 2 " 3

e_{3-4} = " " " " " 3 " 4

Y = Yield of dry matter (cwt/acre)

Y_0 = Cumulative yield of dry matter (cwt/acre) using W_0 amount of water (in./acre) at cutting 0 in time t_0 (days)

Y_1 = " " " " W_1 " " " " 0 to cutting 1 in time t_1 (days)

Y_2 = " " " " W_2 " " " " 0 " 2 " t_2 "

Y_3 = " " " " W_3 " " " " 0 " 3 " t_3 "

Y_4 = " " " " W_4 " " " " 0 " 4 " t_4 "

W = Amount of Water Use (in./acre)

W_0 = Cumulative amount of Water Use (in./acre) yielding Y_0 amount of dry matter (cwt./acre) at cutting 0 in time t_0 (days)

W_1 = " " " " " " Y_1 " " " from cutting 0 to cutting 1 in time t_1 (days)

W_2 = " " " " " " Y_2 " " " " " 0 " " 2 " " t_2 "

W_3 = " " " " " " Y_3 " " " " " 0 " " 3 " " t_3 "

W_4 = " " " " " " Y_4 " " " " " 0 " " 4 " " t_4 "

Table 14

Efficiency of Water Use - Cwt/acre per inch of Water Used

(Irrigated Plots)

Plot	Harvest I						Harvest II						Harvest III					
	A	B	D	G	H	J	A	B	D	G	H	J	A	B	D	G	H	J
Cutting 1	1.84	1.31	2.06	3.05	2.01	1.68	2.89	3.71	3.30	4.30	3.55	4.04	3.11	3.80	3.34	5.31	6.50	2.89
Cutting 2	3.36	6.78	2.96	4.95	3.00	3.70	3.61	5.74	2.32	5.32	4.25	3.94	8.80	6.37	4.88	8.24	6.58	4.56
Cutting 3	6.34	3.61	3.52	3.50	3.35	3.05	3.98	1.27	5.98	1.97	2.45	3.73	2.80	2.63	3.69	3.04	1.53	2.04

Table of Mean Values

	H_1	H_2	H_3	Mean
C_1	2.00	3.62	4.15	3.26
C_2	4.13	4.18	6.58	4.96
C_3	3.88	3.25	2.60	3.24
Mean	3.34	3.68	4.44	3.82

S.E. for the mean of cuttings = ± 0.297

S.E. for the mean of harvests = ± 0.297

Analysis of Variance

	D.F.	S.S.	M.S.	V.R.	S.L.
Total	53	149.57			
Plots	5	6.97	1.39		N. S.
Harvests	2	11.52	5.76	3.62	X
Cuttings	2	35.36	17.68	11.12	XXX
Harvests x cuttings	4	31.99	8.00	5.03	XX
Error	40	63.73	1.59		

Variance ratios $\frac{\text{Harvests}}{(\text{H x C})}$ and $\frac{\text{Cuttings}}{(\text{H x C})}$ are not significant

Significant differences at	5%	1%	0.1% levels
Among harvest x cutting means	1.47	1.97	2.59
Among harvest means	0.85	1.13	1.49
Among cutting means	0.85	1.13	1.49

Table 15

Variation in Efficiency of Water Use (obtained from
(Fig. 22) with time (days) for different harvests
(Irrigated Plots)

Day	Harvest I	Harvest II	Harvest III
5	0.70	2.70	2.50
10	1.90	4.50	5.15
15	3.30	4.90	6.45
20	4.10	4.68	6.70
25	4.40	4.30	6.50
30	4.28	3.80	6.00
35	4.00	3.00	5.30
40	3.85	2.24	4.30
45	3.70		3.10
50	3.60		1.80
55			0.45

Values of e for each plot, mean values and significant differences are given in Table 14. It is clear from Table 14 that in this experiment there were significant differences in e between the harvests, and between the cuttings in harvests. This suggests that the high e recorded in harvest III was probably due to the greater quantity of water applied (Table 16). This is contrary to the conclusions reached by Richards and Wadleigh (1952) that the yield of alfalfa per foot of irrigation water applied is independent of the depth of water applied as irrigation.

An analysis of the variance ratio of harvests and harvest-cutting interactions showed that the harvest-cutting interaction was insignificant and hence there is no evidence of real variation of efficiency among harvests in general. Similarly no evidence of real variation of efficiency among cuttings was in general found. These results are in accordance with the views put forward by Richards and Wadleigh (1952). Similar conclusions were reported by Scofield (1945) that no difference in efficiency of water use by alfalfa under different irrigations could be found.

Since it has been found that there is no reason to expect a genuine relation between water use and dry matter production, no further analysis was attempted.

Table 16

Total Amount of Water Applied (Irrigation + Rain)
in inches/acre
(Irrigated Plots)

Harvest	Cutting (1)	Cutting (2)	Cutting (3)	Total
I	2.17	2.63	2.57	7.37
II	2.73	2.83	2.14	7.70
III	4.10	2.65	2.67	9.42

(ii) <u>Non-irrigated Plots.</u>- The efficiency of water use of non-irrigated plots (Fig. 23) is somewhat similar in trends to efficiency of water use of irrigated plots (Fig. 22). The efficiency of water used : time curves for both harvests show an increase at the beginning, then a rapid increase and finally a gradual decrease, the fourth cutting of harvest II being an exception.

It has already been mentioned that serious wilting and drooping of leaves were noted at the end of harvest I. This probably resulted in lower values of e of harvest I compared with the values of e of irrigated plots. Similarly Kiesselbach (1916) reported that there was an increase in the water requirement whenever soil moisture content approached wilting percentage or above but this was associated with an even greater decrease in yield of dry matter. The result of lower values of e, however, does not contradict the hypothesis (Richards and Wadleigh 1952) that soil moisture had little effect on e as long as the moisture content is above the wilting percentage.

The high value of e in harvest II indicates the effect of rain and irrigation. At the beginning of the harvest 1.5 inches of water was given by irrigation and in the third cutting 2.14 inches of rain fell. The similarity in e curve with similar curves for the irrigated plots suggests that the e of lucerne under non-irrigated conditions will be similar to irrigated plots whenever water is applied either by rain or irrigation.

The steep rise in the efficiency curve in the fourth cutting is very irregular. It has already been discussed earlier that during this time interval it is suspected that water was being used from deeper layers. Hence the value of the amount of water used during this time is lower than it should be, resulting in a steep increase in efficiency of water use value.

Values of e of each plot and mean values are given in Table 17. Since the number of cuttings of each harvest was not uniform, no statistical analyses were performed.

Table 17

Efficiency of Water Use - Cwt/acre per inch of Water Used

(Non-irrigated Plots)

	Harvest I						Harvest II						Harvest III					
Plot	C	E	F	I	K	L	C	E	F	I	K	L	C	E	F	I	K	L
Cutting 1	1.77	1.29	1.84	1.76	1.21	1.74	1.65	0.86	4.11	1.43	3.88	2.20	4.00	4.76	6.08	7.31	5.28	5.69
Cutting 2	2.05	3.45	1.93	0.72	0.24	0.30	2.69	8.90	1.98	4.49	10.61	8.75						
Cutting 3							2.19	3.86	6.31	2.86	1.21	3.53						
Cutting 4							14.90	6.21	19.50	24.00	23.05	18.36						

Table of Mean Values

	H_1	H_2	H_3
C_1	1.60	2.36	5.52
C_2	1.45	6.24	
C_3		3.33	
C_4		17.67	

(iii) Second Year.- Values of e at each cutting of each plot and mean values of irrigated and non-irrigated plots of harvests IV and V are given in Table 18. It is seen that there are slight differences in the mean values of e between irrigated and non-irrigated plots in the two harvests, but those differences are not significant. However, the variability among the values for each plot is so great that the differences in the mean values are not statistically significant.

Table 18

Efficiency of Water Use - Cwt/Acre/In. of Water Used

Harvest - IV

First Cutting

Irrigated Plots			Non-irrigated Plots		
Plot	Efficiency of Water Use	Mean	Plot	Efficiency of Water Use	Mean
A	3.76	3.87	C	3.40	3.66
B	4.30		E	4.32	
D	3.61		F	3.64	
G	3.25		I	4.28	
H	4.00		K	3.63	
J	4.29		L	2.69	
		Second Cutting			
A	2.46	2.82	C	2.35	1.94
B	1.97		E	2.13	
D	4.11		F	1.43	
G	4.33		I	1.73	
H	2.22		K	2.08	
J	1.81		L	1.89	
		Third Cutting			
A	1.10	0.48	C	0.61	0.47
B	0.38		E	0.06	
D	0.37		F	0.98	
G	0.35		I	0.36	
H	0.33		K	0.08	
J	0.35		L	0.74	

(Cont'd)

Table 18 (Cont'd)

Harvest - V

First Cutting

Irrigated Plots			Non-irrigated Plots		
Plot	Efficiency of Water Use	Mean	Plot	Efficiency of Water Use	Mean
A	7.64		C	5.99	
B	8.45		E	6.16	
D	8.29	7.01	F	6.60	7.12
G	6.42		I	10.71	
H	5.35		K	7.12	
J	5.91		L	6.11	

Second Cutting

Plot	Efficiency of Water Use	Mean	Plot	Efficiency of Water Use	Mean
A	10.01		C	5.79	
B	1.52		E	2.36	
D	2.00	5.57	F	4.66	3.38
G	5.37		I	2.17	
H	4.31		K	2.72	
J	10.22		L	2.60	

(g) **Factors affecting Water Use***

It has already been mentioned that weekly W data for successive periods of one week were available in both irrigated and non-irrigated treatments. For examining environmental and other factors affecting W weekly values of W (inches/day) are used whenever possible, while for the factors affecting dry matter production values for each cutting (cwt/acre/day) are used.

(i) Irrigated Plots.- In order to determine the factors affecting Wi*, the following were examined:

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* The term Water Use (general) will be referred to as "W".
" " " " (irrigated plots) will be referred to as "Wi".
" " " " (non-irrigated plots) " " " " "Wn".

(1) Environmental Conditions

(2) Mean Weight of Herbage Present

(1) Environmental Conditions.- There is ample evidence to show that when the supply of available water is non-limiting the transpiration from the actively growing crop is primarily influenced by weather (Penman 1956; Schofield and Penman 1948; Schofield 1950, 1952; and Thornthwaite 1948). The total amount of water used or the total water loss from an actively growing lucerne field in this experiment is assumed to be approximately the same as the transpiration loss (surface evaporation is assumed to be negligible compared with plant transpiration). It is also considered that in the irrigated plots the supply of available water was never limiting and that the lucerne was in a stage of active vegetative growth and effectively covering the soil.

In view of the probable dependence of water loss on weather conditions, the following factors (Table 1, Appendix D) were examined in an attempt to obtain a quantitative relationship:-

(i) Solar Radiation,

(ii) Mean Air Temperature,

(iii) Evaporation from a free water surface,

(iv) Saturation Deficit,

(v) Hours of sunshine,

(vi) Wind Speed.

(i) Solar Radiation.- In order to provide latent heat of vaporisation there must be a continuous supply of energy. At the same time the removal of water vapour from the evaporating area is also essential

It has been suggested that when the stomata are fully open and the roots are adequately supplied with water the amount of water transpired depends on the external supply of energy (e.g. see Russell 1950, p.367; and Thornthwaite 1948).

Since evaporation or transpiration would cease if there were a saturated layer of air above the evaporating surface, turbulence is an important factor in disturbing the vapour pressure gradient between the surface of the vegetation or soil and the upper air. However, Schofield and Penman (1948) reported that over an extended period turbulence is much less important than sunshine in determining the total evaporation.

The close relation between transpiration and solar radiation suggested an examination of the relation between the solar radiation and the amount of Wi by lucerne in the present investigation. In the absence of actual records of solar radiation empirical formula had to be resorted to, to calculate the total amount of solar energy received. The mean amount of solar radiation received (Adelaide - Lat. 35^{o}S) was calculated by the expression:

$R_C = R_A (0.25 + 0.54\ {}^{n}/N)$ for southern Australia (Penman 1952)

where R_C = incoming short-wave radiation (equiv. mm/day)

R_A = theoretical maximum incoming solar radiation (equiv. mm/day) that would reach the earth in the absence of an atmosphere.

n = actual duration of bright sunshine

N = maximum possible duration of bright sunshine.

The amount of Wi (as mm/day) has been plotted against R_C (equiv. mm/day) and are shown in Fig. 24. The correlation coefficient

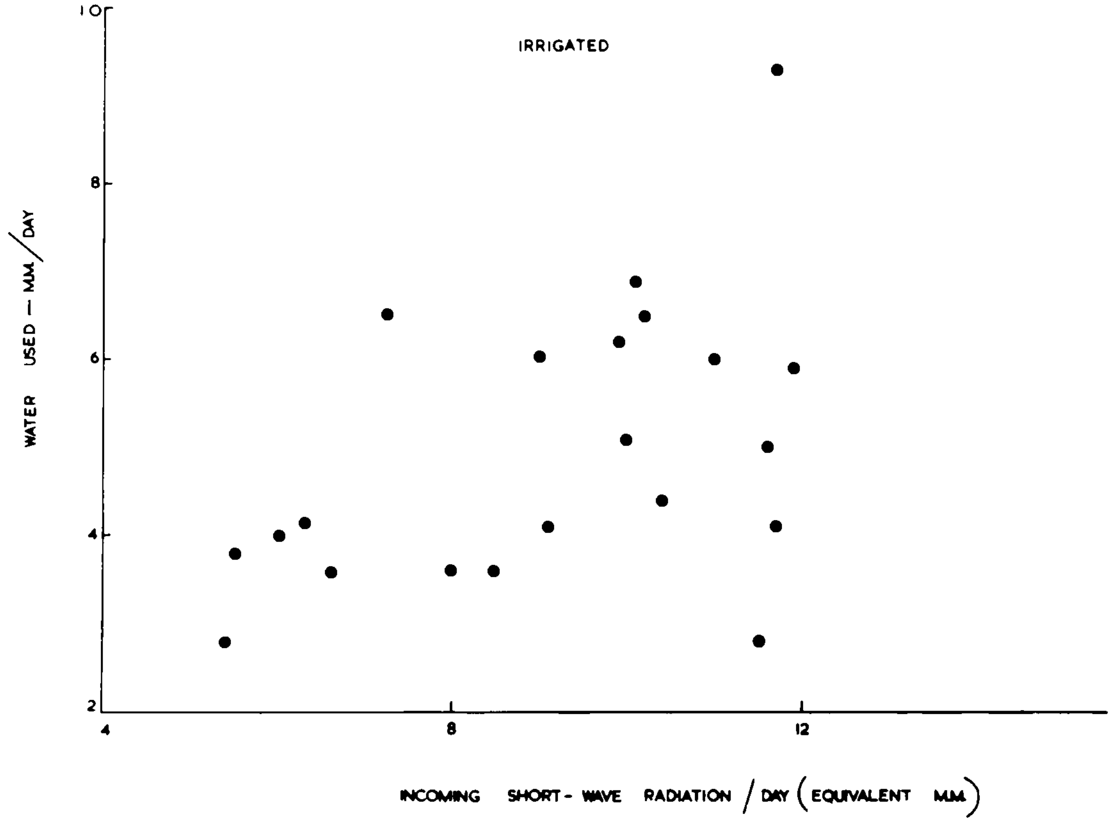

Fig. 24. Relation between water use and incoming short-wave radiation R_C (irrigated plots).

of Wi with R_C is 0.5030 which is significant only at 2 per cent. level. Due to a too great scatter of points and the absence of values at lower levels, a smooth curve could not be shown.

Notwithstanding the poor relation between R_C and Wi (Fig. 24) there is an indication that increasing Wi by lucerne is associated with an increase in the amount of R_C received.

Since one of the most important effects of solar radiation upon transpiration may be expected to operate through its influence on air temperature and on leaf temperature, it is proposed to examine the effect of air temperature on Wi in conjunction with the effect of solar radiation on water use.

(ii) Mean Air Temperature.- It is clear from Fig. 25 that there is a good relation between Wi and mean air temperature. Mean daily air temperature (obtained from weekly maximum and weekly minimum) is plotted against the mean daily Wi in inches (obtained from weekly values). The data (Fig. 25) are very scattered and there are too few at lower levels; as a result it was difficult to draw a reasonable curve to fit the data.

Reasons for these discrepancies were then investigated. It was thought that the total available water (amount of water stored in the soil at the beginning of the period plus irrigation and rain) in the soil might be one of the most likely factors. Table 2 (Appendix D) gives the Wi, mean daily air temperature (^{o}F), the total available water* and the analysis of variance. The analysis of variance shows that both the temperature

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* This will be referred to as "Wa".

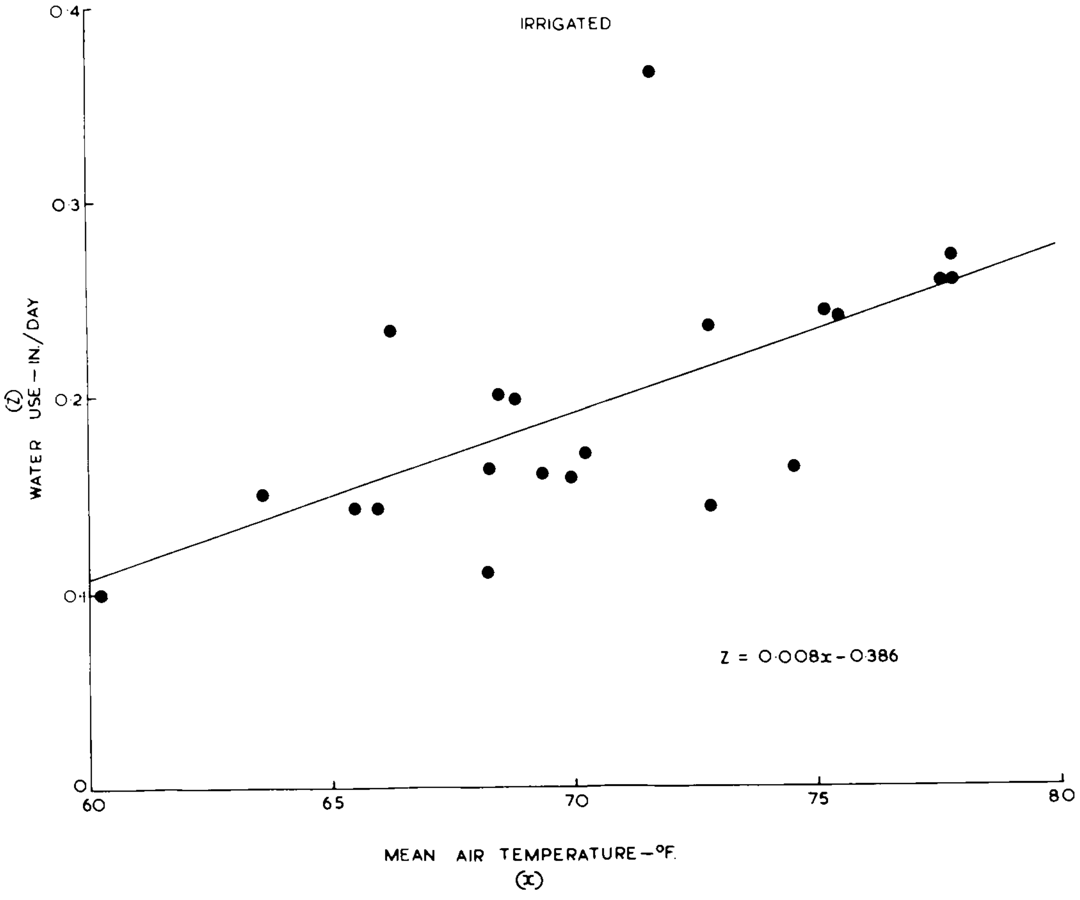

Fig. 25. Relation between Water Use and mean air temperature (irrigated plots).

and Wa have highly significant effects ($P < 0.001$) on Wi. Temperature alone shows a highly significant effect ($P < 0.001$) on Wi by lucerne; while Wa also gave a significant effect ($P < 0.05$) on Wi. Nevertheless it is clear from Table 2 (Appendix D) and Fig. 26 that there is also a relation between the mean air temperature and Wa, a decrease in which is associated with a fall in the mean air temperature. This suggests that the relation obtained between Wi and Wa is, in fact, spurious, and results from the relation between Wa and the mean air temperature. It is, however, appreciated that the rate of transpiration decreases as Wa decreases. No further analysis is possible in the absence of more detailed data.

Fig. 26 shows the isopleths of Wi ($\frac{1}{100}$ in./day) against the mean air temperature ($^{\circ}$F) and Wa (in.). The regression equation

$$Z = 0.008 X - 0.386$$

where Z = Water Use (in./day) = Wi

X = Mean air temperature ($^{\circ}$F)

is calculated on the assumption that in this experiment Wi is largely dependent on mean air temperature and independent of Wa as already discussed earlier. In Fig. 25 a straight line is drawn based on the above equation. If the straight line drawn in the above figure is taken as a correct representation of the relation between Wi and mean air temperature it shows (within the range of Wi and temperature) that W in the irrigated plots is a linear function of mean air temperature.

Since evaporation is directly proportional to the vapour pressure difference between leaf and air, the positive relation between Wi and mean air temperature can best be explained in terms of difference in vapour pressure.

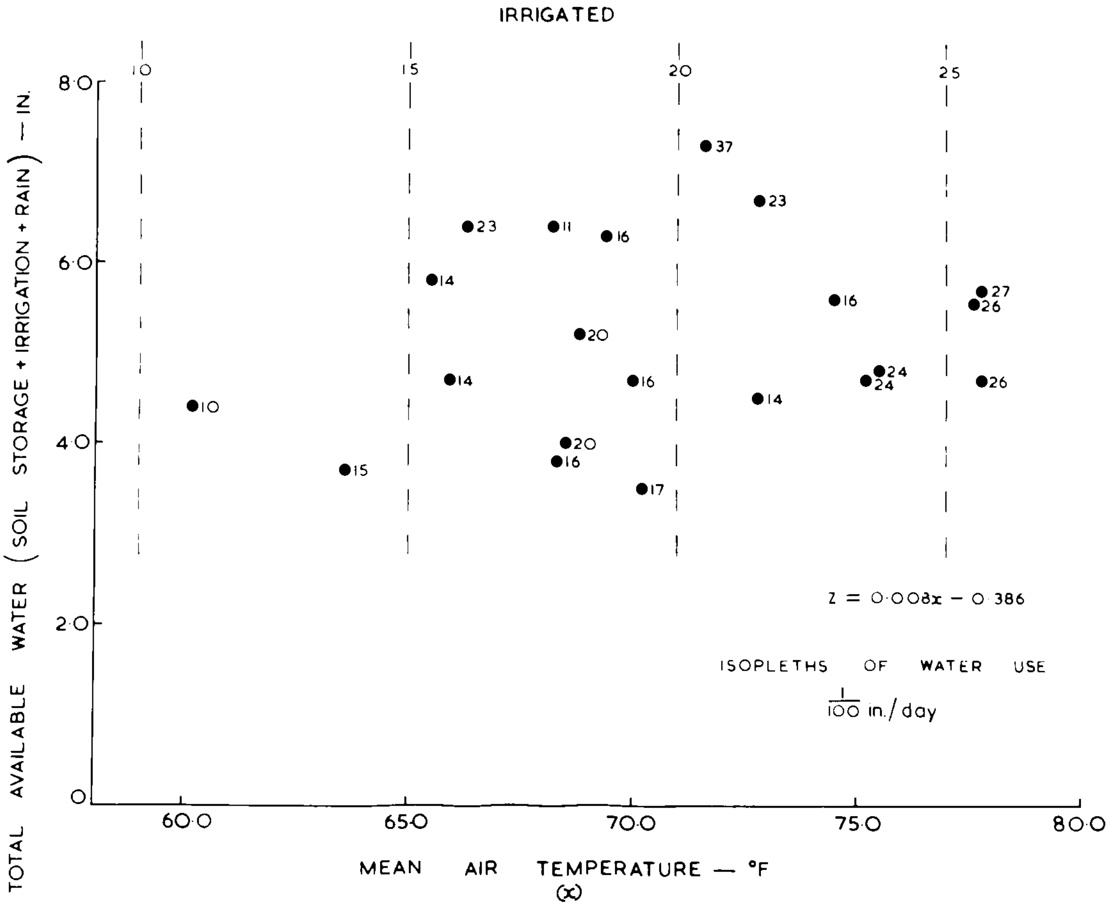

Fig. 26. Relation between water use, total available water and mean air temperature. Experimental values of water use ($\frac{1}{100}$ in./day) are shown plotted.

(iii) Evaporation from a free water surface.- The finding of Briggs and Shantz (1916b) that transpiration loss closely followed variations in wet-bulb depression and evaporation from a shallow tank, emphasised the importance of the physical factors of environment on transpiration loss. In order to assess the agricultural potential of any environment, efforts have been made to predict the potential loss from a vegetated surface from a study of climatic data.

Prescott's (1949) index of rainfall efficiency enables the prediction of water loss by evaporation and transpiration from a consideration of the monthly loss from a free water surface. It is claimed that this is more widely applicable than Trumble's Transeau ratio of 1/3 for the break of season and yet has the same virtue of simplicity. Prescott has shown that water losses from vegetated soils can be related to evaporation from a free-water surface by the expression:

$$E_{tr}/E_W^{m} = K$$

where E_{tr} = monthly rate of evaporation (or evapo-transpiration) from a vegetated surface.

E_W = corresponding evaporation from a free water surface.

m and K = constants

From a number of considerations he gives the following values for K when m is taken as 0.75 -

For vegetation of low transpiration = 0.8
For vegetation of average transpiration
and catchment areas generally = 1.2
For high transpirations = 1.6
For rice fields = 2.0

Butler (1951) reported that the regression equation relating evapo-transpiration to evaporation from a free water surface at the period of maximum transpiration of wheat crop could be expressed as:

$$E_{tr}/E_W^{0.75} = 1.67$$

In view of this relation between evaporation and evapo-transpiration it is proposed to apply Prescott's formula to the present data. Since the Wi data were found to be inconsistent, no attempt has been made to calculate the regression equation relating the evapo-transpiration (Wi in this experiment) to evaporation from a free water surface. It was thought that under these conditions it would be advisable to take one factor as a constant, and it was decided to retain the value 0.75 of m.

Nevertheless the data show good correspondence with a Prescott-type relation $E_{tr} = K\ E_W^{0.75}$ and a curve of this type was fitted to data as shown in Fig. 27. The value of K is 1.32 when the units for E_{tr} and E_W are in in./month respectively. This value of K is slightly higher than Prescott's value (1.2) for vegetation of average transpiration. The relation between Wi and E_W in this experiment has therefore the form of

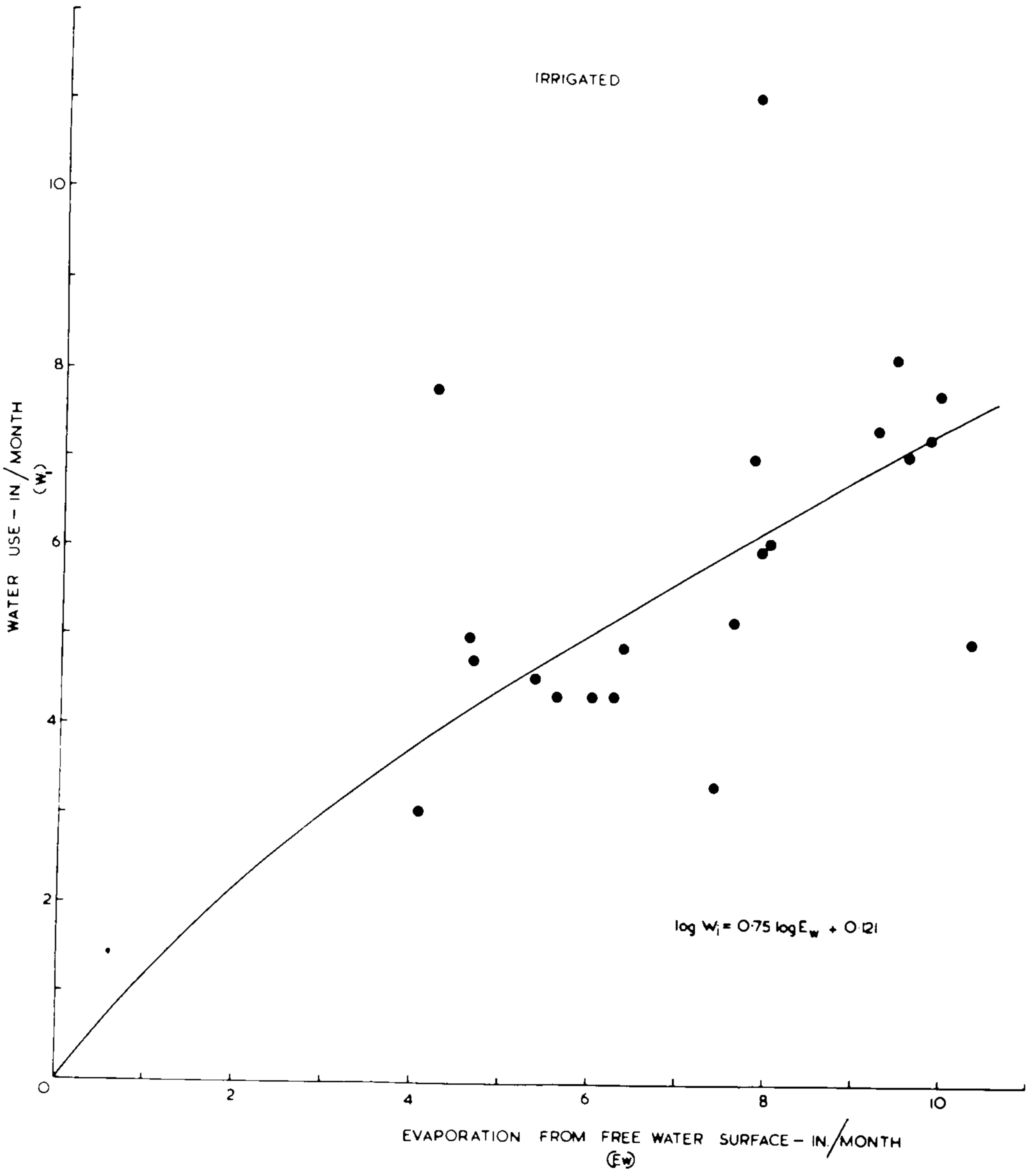

Fig. 27. Relation between amount of water use by irrigated lucerne and evaporation from free water surface.

$$Wi = 1.32 \quad E_W^{0.75}$$

or $\log Wi = 0.75 \log E_W + 0.121$

where Wi = Water used by lucerne (in./month)

E_W = Evaporation from a free water surface (in./month)

(iv) Saturation Deficit.- For Australian records, Patton (1930) and Prescott (1931a) have shown that evaporation from a free water surface is a linear function of the saturation deficit of the air. Prescott (1931b) reported that for twentythree stations in Australia the mean evaporation in inches is related to the saturation deficit in inches of mercury by the expression:

$$E_W = 263 \quad s.d.$$

where E_W = the depth of evaporation expressed in inches

s.d. = the saturation deficiency expressed in inches of mercury.

Prescott, Collins and Shirpurkar (1952) have indicated that if in Prescott's (1949) equation

$$E_{tr}/E_W{}^m = K$$

E_W is substituted by 21 s.d., the index $E_W^{0.75}$ becomes $21^{0.75} \times s.d.^{0.75}$. The values of K, then approximately become:

For vegetation of low transpiration = 8.0

For vegetation of average transpiration and catchment areas generally = 12.0

For high transpiration = 16.0

For rice fields = 20.0

The water use data of this experiment show a good correspondence with a Prescott-type relation $E_{tr} = K (s.d.)^{0.75}$ and a curve of this type was fitted to the data as shown in Fig. 28. The value of K is 12.1 when the units for Etr and s.d. are in in./month and in. Hg. respectively. This value of K, 12.1 corresponds exactly to Presocott's index for vegetation of average transpiration. The relation between Wi and the saturation deficit has therefore the form of,

$$\log Wi = 0.75 \log s.d. + 1.081$$

where Wi = monthly rate of water use by lucerne in in.

s.d. = saturation deficit (in. Hg)

(v) Hours of Sunshine and (vi) Wind Speed.- No satisfactory correlations were obtained between Wi and hours of sunshine (hours/day) and wind speed (miles/day).

(2) Mean Weight of Herbage Present during Interval between each intermediate cut - - - - The mean weight (cwt/acre of dry matter) of herbage present during the interval and water use (in./day) during that period are given in Table 19. It is clear from this table that Wi is independent of the amount of herbage present. This result supports the view put forward by Schofield (1952) that when water is non-limiting, the water use by crops is independent of the nature of the plant cover as long as there is complete cover and active vegetative growth.

(ii) Non-irrigated Plots.- Since it was not possible to obtain a satisfactory correlation of Water Use and various environmental factors

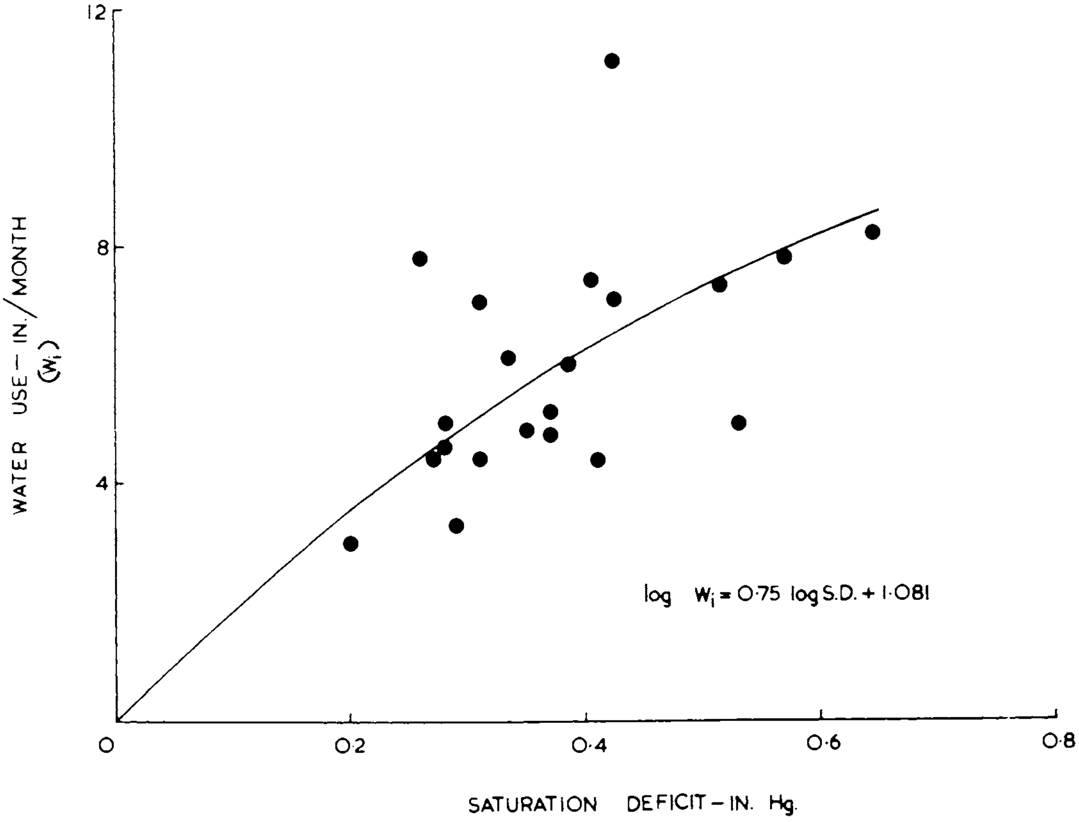

Fig. 28. Relation between amount of water use by irrigated lucerne and saturation deficit.

Table 19

Relation between the Mean Weight of Herbage Present and the amount of water use

(Irrigated Plots)

INTERVAL		Amount of Water Use (in./day)	Weight of * Herbage Present (cwt/acre)
Harvest	Cutting		
I	1	0.173	3.72
	2	0.216	13.69
	3	0.236	26.27
II	1	0.225	5.71
	2	0.242	18.44
	3	0.227	30.21
III	1	0.147	4.55
	2	0.155	18.87
	3	0.147	32.44

* Mean weight (cwt/acre of dry matter) of herbage present during interval.

(viz. mean air temperature, solar radiation, saturation deficit, hours of sunshine and wind speed) and dry matter production for non-irrigated plots, an examination was made of the relationships of Wn with the initial amount of available water stored (Ws - n) in the soil to a depth of 66 inches at the beginning of the period and the irrigation plus rain (In + R).

Table 3 (Appendix D) gives Wn and In + R in in./day and Ws - n in inches. A multiple regression analysis showed that In + R and Ws - n both have very high significant ($P < 0.001$) effects on Wn. Fig. 29 shows the relation of In + R and Ws - n on Wn, and the actual amounts

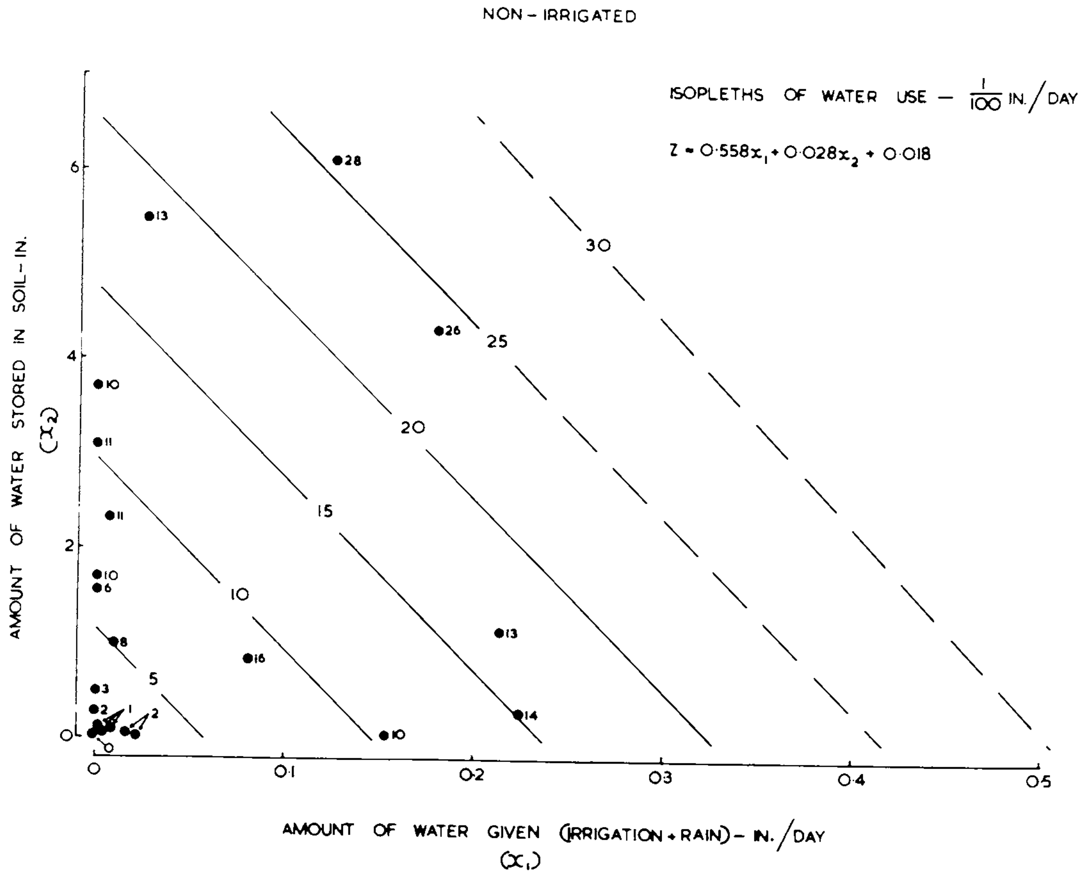

Fig. 29. The relation between water use, amount of water stored in the soil and the amount of water given (irrigation and rain). Experimental values of water use ($\frac{1}{100}$ in./day) are shown.

of Wn have also been shown on the diagram. The isopleths (Fig. 29) Wn (in./day) are based on the equation:

$$Z = 0.558\ X_1 + 0.028\ X_2 + 0.018$$

where Z = Water Use (in./day) = Wn

X_1 = Irrigation + rain (in./day) = In + R.

X_2 = Initial amount of water stored in the soil to a depth of 66 inches at the beginning of the period = Ws - n.

If the isopleths drawn are taken as a true representation of the combined effect of In + R and Ws - n on Wn, it may be concluded that Wn is a function of both In + R and Ws - n. All the actual Wn data fit reasonably well with the isopleths drawn (Fig. 29).

It will also be clear from Fig. 30 that estimated values of Wn (in./day) from the regression equation fit reasonably well the actual values of Wn (in./day) obtained in the experiment. A line is drawn at 45° (100 per cent. correlation) to indicate the extent of departure from the perfect relationship.

(h) Factors affecting Dry Matter Production*

In order to obtain an indication of the way in which the rate of DMP of lucerne in the two treatments was controlled, the following factors were examined:

(1) Environmental Conditions

(2) Dry Weight of Tops Present

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* The term dry matter production will be referred to as "DMP".

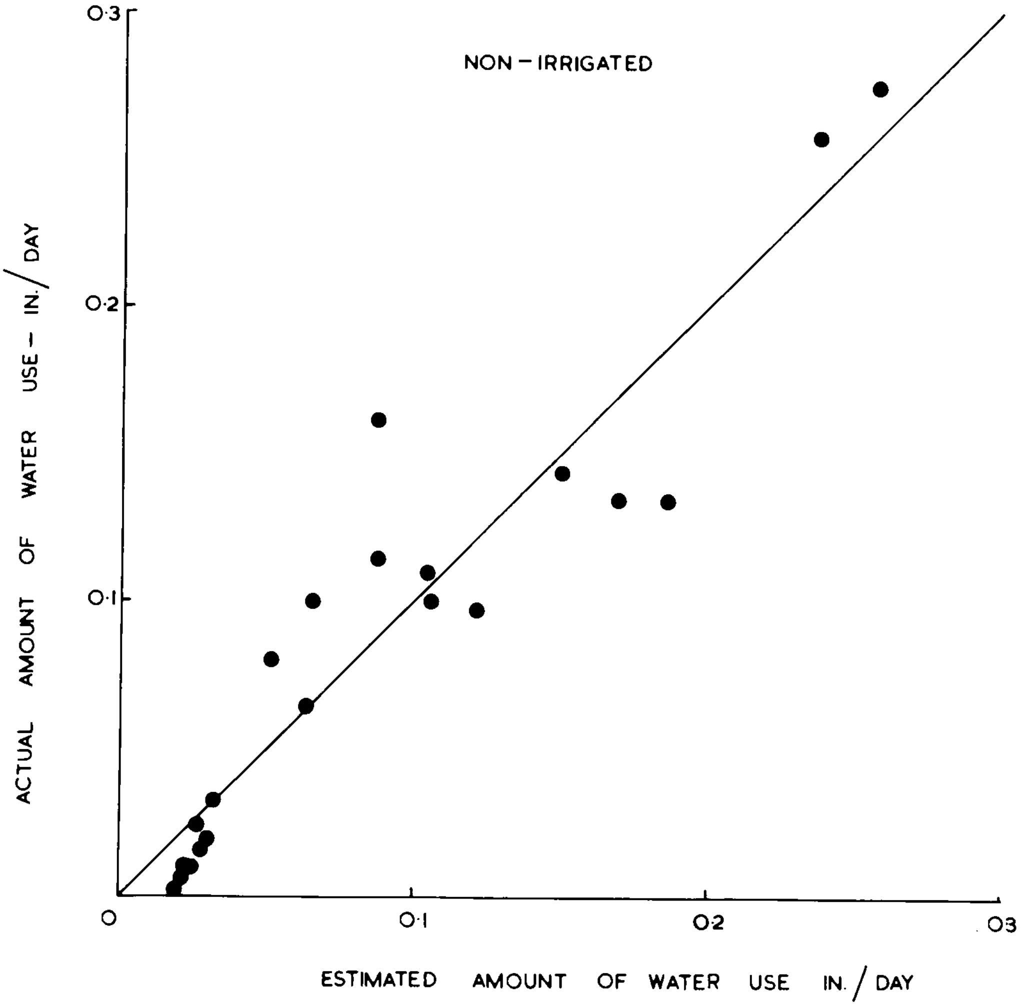

Fig. 30. Comparison between actual amount of water use and the water use derived from equation $Z = 0.558\ X_1 + 0.028\ X_2 + 0.018$. The line of perfect agreement is shown.

It has already been mentioned that nine and seven intermediate cuts were taken in irrigated and non-irrigated treatments respectively. To examine the effect of the above mentioned factors, the yield of dry matter (cwt/acre) at each cutting has been converted to DMP per day (as cwt/acre) for both the treatments.

(1) Environmental Conditions.- Regardless of the habitat in which it is growing, a plant is continuously subjected to the variabilities of a complex, more or less interdependent, set of environmental factors. With this background the following principal physical factors of the environment which ordinarily exert a practically direct effect upon the growth, were examined:

(i) Mean Air Temperature

(ii) Solar Radiation.

Figs. 31 and 32 show the relation between DMP (cwt/acre/day) and mean daily air temperature (°F) and estimated solar radiation (R_C) per day (equivalent mm) for both the treatments respectively. Examination of Figs. 31 and 32 show that none of these factors appear to have any significant effect on DMP. However these figures do suggest that the relation between DMP and environmental factors is less inconsistent in the irrigated treatment than that in the non-irrigated treatment, indicating that more data might reveal better relationships between DMP and environmental factors in the irrigated treatment than in the non-irrigated treatment. It appears safe to indicate at this stage that if the plants are grown under water stress no other environmental factors have any effect on growth.

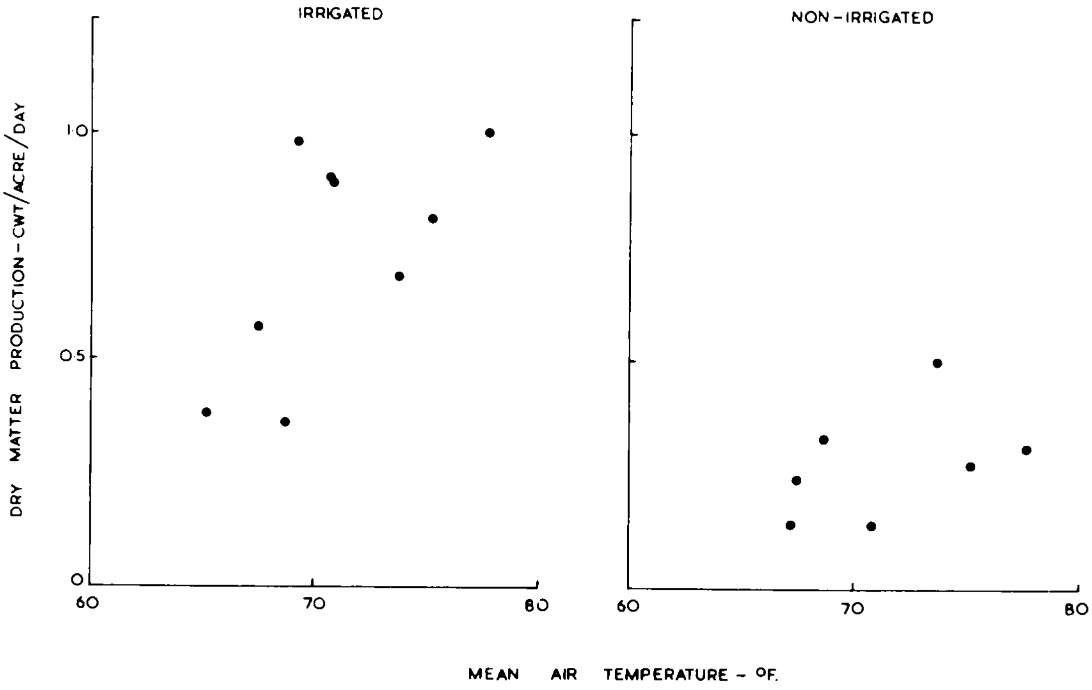

Fig. 31. Relation between dry matter production of mean air temperature.

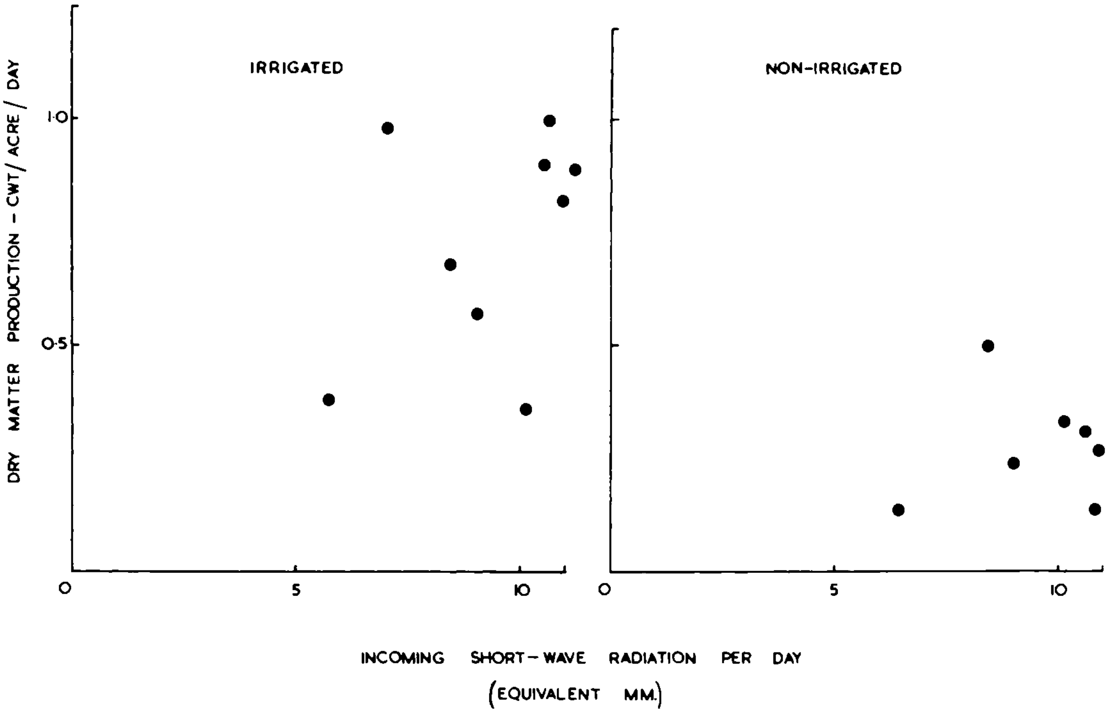

Fig. 32. Relation between dry matter production and incoming short-wave radiation (Rc)

(2) Dry Weight of Tops Present*.- Since it appeared that none of the environmental factors examined gave a satisfactory explanation of the rate of DMP in both treatments, the effect of initial dry weight of tops present at the beginning of each cutting in irrigated treatment, was then investigated.

(i) Irrigated Plots.- The findings of Watson (1947a, 1956) and Davidson and Donald (in press) indicate that if water and nutrients are non-limiting, the rate of DMP of a crop depends largely on leaf area index.†

In the absence of leaf area and leaf weight an attempt is therefore made here to examine the rate of DMP of lucerne under irrigated conditions, in terms of dry weight of tops (DWT) present at the beginning of each period or cutting.

Fig. 33 shows the relation between DWT (as cwt/acre) and DMP (as cwt/acre/day) in subsequent periods of approximately 14 days, only the mean values being given. Curves of the same general shape showing the relation between crop growth and LAI have been obtained by Watson and Davidson and Donald.

It is clear from Fig. 33 that DMP reaches a maximum when DWT is between 10 and 15 cwt/acre, and that there was a reduction in DMP by 70 per cent. when DWT reached to 30 cwt/acre. If the curve drawn (Fig.33) is taken as a correct representation of the relation between DMP and DWT,

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* The term 'tops' is referred here to all above ground parts of the plant and will be referred to as "DWT".

† Introduced by Watson (1947a) and defined as the ratio of the area of the leaves to the area of the ground surface. It is usually denoted as LAI.

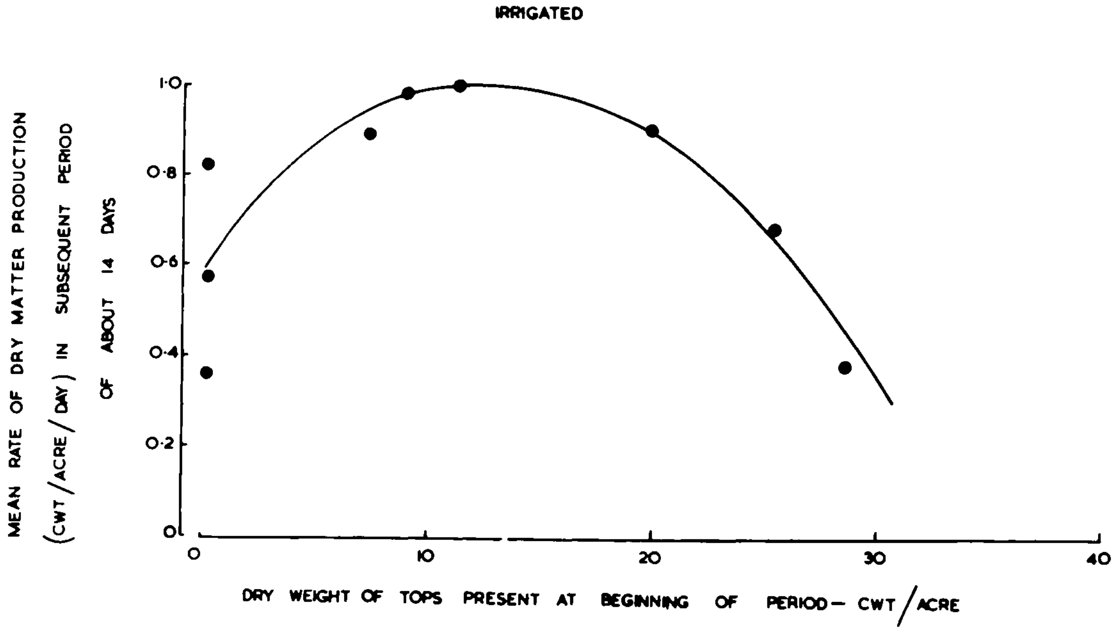

Fig. 33. Relation of mean rate of dry matter production in subsequent period of about 14 days and dry weight of tops present at the beginning of the period, for the 9 cuttings.

it shows that there was a range of DWT between 10 and 15 cwt/acre when DMP varied only slightly with change in DWT.

It is of interest to note that the curve (Fig. 33) showing the relation between DMP and DWT does not originate from zero. The explanation of this behaviour is probably that the lucerne was cut 1 or 1½ inches above the ground level, so that a certain amount of material was in fact present at the beginning of the period and it was therefore not zero. However, this should not make much difference to the general shape of the curve. No further analysis is possible in the absence of DMP data when DWT was zero.

(ii) A Comparison between the Growth Rate in Non-irrigated and Irrigated Plots.- Having failed to obtain a satisfactory correlation between DMP and various environmental factors and W in non-irrigated plots, it is proposed to see whether the low DMP in non-irrigated plots is related to:

(1) the amount of available water stored in the soil (0-66 in.) at the beginning of each cutting (Ws - n).

(2) the amount of irrigation and rain (In + R).

For this analysis the curve (Fig. 33) has been taken to represent the mean rate of growth under irrigation. The DMP (cwt/acre/day) of non-irrigated plots for each particular cutting was plotted against DWT at the beginning of each period.

The difference between the rate of DMP with and without irrigation was obtained for the particular amount of DWT present at the beginning of the period. The values thus obtained are taken as the deficit in rate of growth (cwt/acre/day) in non-irrigated plots as compared with growth under irrigation. Thus the deficit* in rate of growth for 7 cuttings was

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* This will be referred to as "dt".

obtained.

The deficit dt, In + R (in.) for each cutting and Ws - n at the beginning of each cutting are given in Table 20. Multiple regression analysis showed that I + R has a significant influence (P = 0.5) in decreasing dt while Ws - n has relatively insignificant effect, i.e. the dt is least when In + R is greatest, while Ws - n is unimportant.

Since the time intervals between each cutting were not uniform, it was decided to examine the effect of In + R on dt on a daily basis. In + R has therefore been converted to in./day for each cutting. Table 21 gives dt (cwt/acre/day), In + R (in./day) and Ws - n (in.). Multiple regression analysis showed that In + R (in./day) has an effect which would be significant only at about 10 per cent. level, while Ws - n is of no significance.

On the assumption that Ws - n had no significant effect on dt, Fig. 34 A is presented to show the effect of In + R on dt. dt is plotted against In + R. Actual values of dt are shown. The calculated regression is,

$$Y = -2.294\ X_1 + 0.631$$

where Y = dt (cwt/acre/day)

X_1 = In + R (in./day).

It is evident from Fig. 34A that dt continues to decrease as the amount of In + R (in./day) increases. Extrapolation indicates that when In + R reaches to the value of about 0.234 in./day dt will be reduced to zero.

It is realised that the relationships obtained here between dt,

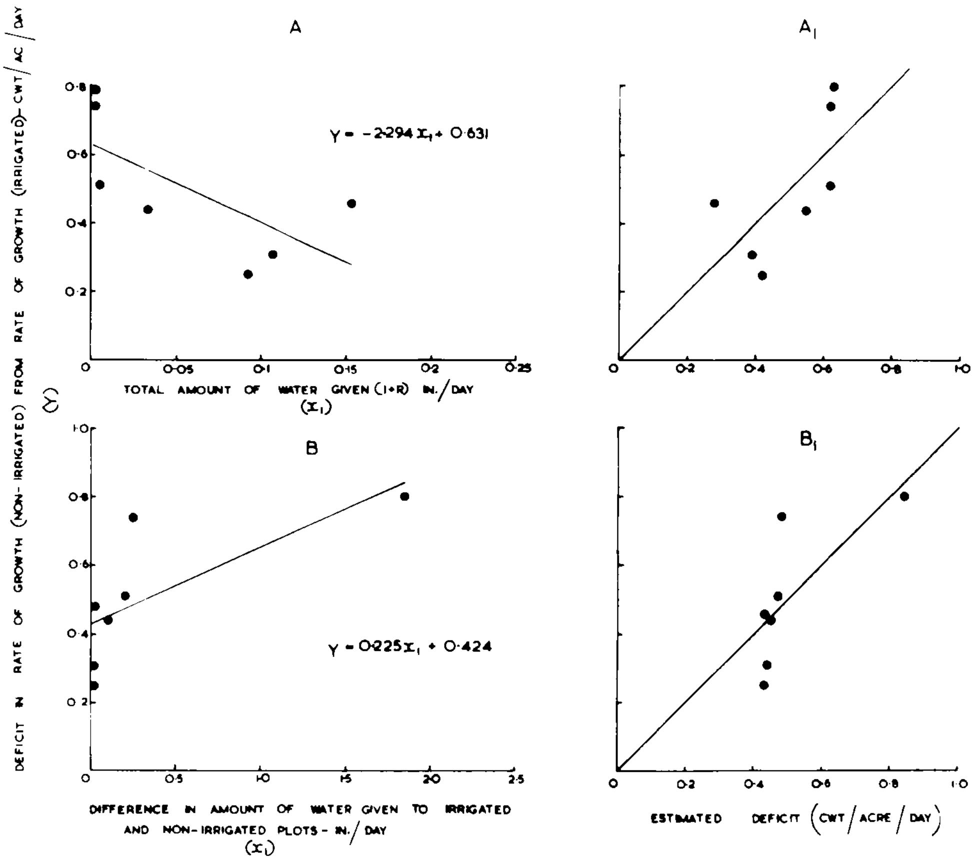

Fig. 34. Deficit in rate of growth in non-irrigated plots related to:

34 A. Total amount of water received by non-irrigated plots;

34 B. Additional water given to irrigated plots.

34 A, & 34 B, show comparisons between recorded deficits and those estimated from the equations of Figures 34A & 34B. The lines of perfect agreement are shown.

Table 20

Relation between the Deficit in Growth Rate in Non-irrigated Plots from the Rate of Growth of Irrigated Plots, Irrigation + Rain and the Amount of Available Water Stored in the Soil at the beginning of the Period

(Non-irrigated Plots)

INTERVAL		Deficit in Growth Rate in Non-irrigated Plots (cwt/acre/day) Y	Irrigation + Rain (in.) X_1	Amount of Available Water Stored in the Soil (in.) X_2
Harvest	Cutting			
I	1	0.25	2.03	6.10
	2	0.80	0.05	3.77
II	1	0.31	1.50	1.12
	2	0.51	0.07	0.99
	3	0.46	2.14	0.27
	4	0.74	0.05	0.28
III	1	0.44	1.37	0.10

Analysis of Variance

Variation	d.f.	S.S.	M.S.	V.R.	
Due to Y	6	0.251500			
Regression on X_1 and X_2	2	0.165749	0.082875	3.865	N.S.
Regression on X_1 alone	1	0.164306	0.164306	7.65	X
Additional for additional of X_2 to regression on X_1 alone	1	0.001443	0.001443	0.0673	N.S.
Residual about regression on X_1 and X_2	4	0.085751	0.02144		

Table 21

Relation between the Deficit in Growth Rate in Non-irrigated Plots from the Rate of Growth of Irrigated Plots, Irrigation + Rain and the Amount of Available Water Stored in the Soil at the beginning of the Period

(Non-irrigated Plots)

INTERVAL		Deficit in Growth Rate in Non-irrigated Plots (cwt/acre/day) Y	Irrigation + Rain (in./day) X_1	Amount of Available Water Stored in the Soil (in.) X_2
Harvest	Cutting			
I	1	0.25	0.092	6.10
	2	0.80	0.002	3.77
II	1	0.31	0.107	1.12
	2	0.51	0.005	0.99
	3	0.46	0.153	0.27
	4	0.74	0.003	0.28
III	1	0.44	0.034	0.10

Analysis of Variance

Variation	d.f.	S.S.	M.S.	V.R.	
Due to Y	6	0.25150			
Regression on X_1 and X_2	2	0.12459	0.06230	1.965	N.S.
Regression on X_1 alone	1	0.11624	0.11624	3.666	N.S.
Additional for additional of X_2 to regression on X_1 alone	1	0.00835	0.00835	0.260	N.S.
Residual about regression on X_1 and X_2	4	0.12691	0.03173		

In + R, and Ws - n are based on only 7 sets of values. Nevertheless, the results seem to indicate that with more data the relationship between dt, In + R and Ws - n may be confirmed.

Fig. 34 A; shows the actual value of dt and estimates dt from the equation. A line is drawn at 45° (100 per cent. correlation) to indicate the extent of the departure from the perfect relationship.

(iii) Relations between the Amount of Water added to the Irrigated Plots and the Amount by which the Yield of the Non-irrigated Plots fell below that of the Irrigated Plots.- Following the suggestion of Schofield (1950) that if water use from non-irrigated plots had not fallen short of that of irrigated plots, irrigation could not have increased the water uptake because it could not have increased the water use and yield, an attempt was made to relate the amount of water added to the irrigated plots and the amount by which the yield of the non-irrigated plots fell below that of the irrigated plots.

Table 22 gives the deficit dt, (cwt/acre/day), Id*(in./day) and Wd† (in.). The value of Id (in./day) is obtained by subtracting the total amount of irrigation which had to be added occasionally to the non-irrigated plots (in./day) from the total amount of irrigation given in the irrigated plots (in./day) for each period. Similarly the value Wd (in.) is obtained by subtracting the available water stored in the soil of the non-irrigated plots (Ws - n) from the available water stored in the soil of the irrigated

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* Id = I - In

† Wd = Ws - Ws - n

Table 22

Relation between the Amount of Water added to the Irrigated Plots and the amount by which the Yield of the Non-irrigated Plots fell below that of the Irrigated Plots

INTERVAL		Deficit in growth rate in non-irrigated plots (cwt/acre/day) Y	Difference in amount of water given to irrigated and non-irrigated plots (in./day) X_1	Difference in amount of available water stored in irrigated and non-irrigated plots (in.) X_2
Harvest	Cutting			
I	1	0.25	0.006	0.72
	2	0.80	1.839	1.43
II	1	0.31	0.016	2.97
	2	0.51	0.197	2.69
	3	0.46	0.000	2.86
	4	0.74	0.253	1.79
III	1	0.44	0.099	3.75

Analysis of Variance

Variation	d.f.	S.S.	M.S.	V.R.	
Due to Y	6	0.25150			
Regression on X_1 and X_2	2	0.138146	0.06907	2.437	N.S.
Regression on X_1 alone	1	0.135289	0.135289	4.774	N.S.
Additional for additional of X_2 to regression on X_1 alone	1	0.002857	0.002857	0.1008	N.S.
Residual about regression on X_1 and X_2	4	0.113354	0.028339		

plots (Ws) at the beginning of the period. Multiple regression analysis shows that the negative effect of Id on dt would only reach significance at the 7 per cent. level while Wd has no significant effect at all.

On the assumption that Wd had no effect on dt, Fig. 34 B was prepared to show the effect of Id on dt. Actual values of dt are plotted against Id. The regression equation is:

$$Y = 0.225\, X_1 + 0.424$$

where Y = dt (cwt/acre/day)

X_1 = Id (in./day)

It is evident from Fig. 34 B that dt continues to increase as Id increases i.e. as more water is applied in the irrigated plots compared with the non-irrigated plots. Extrapolation suggests that dt will reach to one when Id will be 2.55 in./day.

Fig. 34 B_1 shows the actual values of dt and estimates of dt from the equation. A line is drawn at 45° (100 per cent. correlation) to indicate the extent of the departure from the perfect relationship.

(i) <u>Growth Rate of Irrigated Lucerne</u>

The cumulative yield of dry matter of harvests I, II and III have been plotted against time (Fig. 35). Since no record of DMP at the outset of each harvest was obtained, it has been assumed that at the beginning of every harvest the DMP was zero. This assumption may not be true in the strict sense but it was thought that even small amounts of DMP occurred at the outset of each harvest; such amounts would not be great enough to alter the general slope of the curve for that harvest.

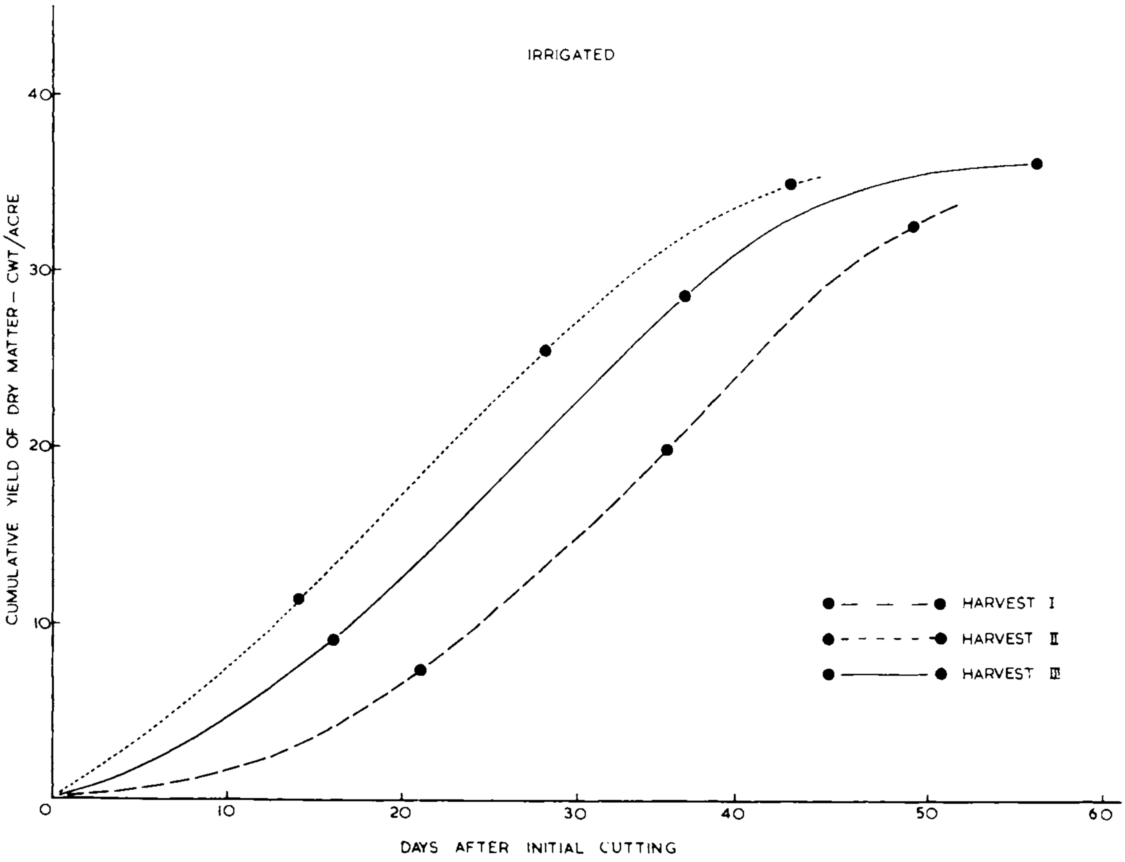

Fig. 35. Dry weight increase of irrigated lucerne for each of the three harvests.

In order to compare the growth curves of three harvests, the middle curve (Fig. 35) of harvest III was taken as a reference, since this was found to be more complete than the others. It is clear from the growth curve of harvest III in this figure that a dry weight of 20 cwt/acre was reached on day 27. Harvests I and II took about 35 and 22½ days respectively to attain the same amount. If the growth curves of harvests I and II are superimposed on the growth curve of harvest III, they all lie on one line from about 10 to 33 cwt/acre. In the process of superimposition the curves of harvests I and II were shifted backward and forward by 8 and 4¾ days respectively. The results indicate that the rate of growth of the three harvests was different at the outset of their respective harvests, but once the DWT reached approximately to 10 cwt/acre, their rate of growth is approximately the same till the DWT reached about 33 cwt/acre. In other words their rate of growth from 10 to 33 cwt/acre is independent of the seasonal conditions encountered.

Lack of data, particularly at the later part of the curves, makes it difficult to determine the slope of the curve at the end of the harvest. Extrapolation suggests that all will attain the same yield, indicating that the course of dry weight increase of all the three harvests will be similar once the DWT reach to 10 cwt/acre.

It is clear from the growth curve of harvest III (Fig. 35) that the rate of growth was at a maximum value when the DWT were 10 to 30 cwt/acre. Harvests I, II and III took approximately 20.7 (45.0 - 24.3), 20.3 (33.0 - 12.7) and 20.6 (37.6 - 17.0) day respectively to increase from 10 to 30 cwt/acre. The rate of growth during the period becomes for

Harvest I = 0.966 cwt/acre/day
" II = 0.985 " " "
" III = 0.971 " " "

This suggests that the rate of growth from 10 -30 cwt/acre is identical.

(j) Growth of lucerne in second year

The amount of dry matter produced (cwt/acre) at each cutting for each plot and the mean values for irrigated and non-irrigated plots for harvests IV and V respectively are given in Table 23. Fig. 36 shows the cumulative yield of dry matter (cwt/acre) against time. The analysis of variance indicates that the difference in dry matter production (cwt/acre) between irrigated and non-irrigated plots is significant ($P = < 0.01$).

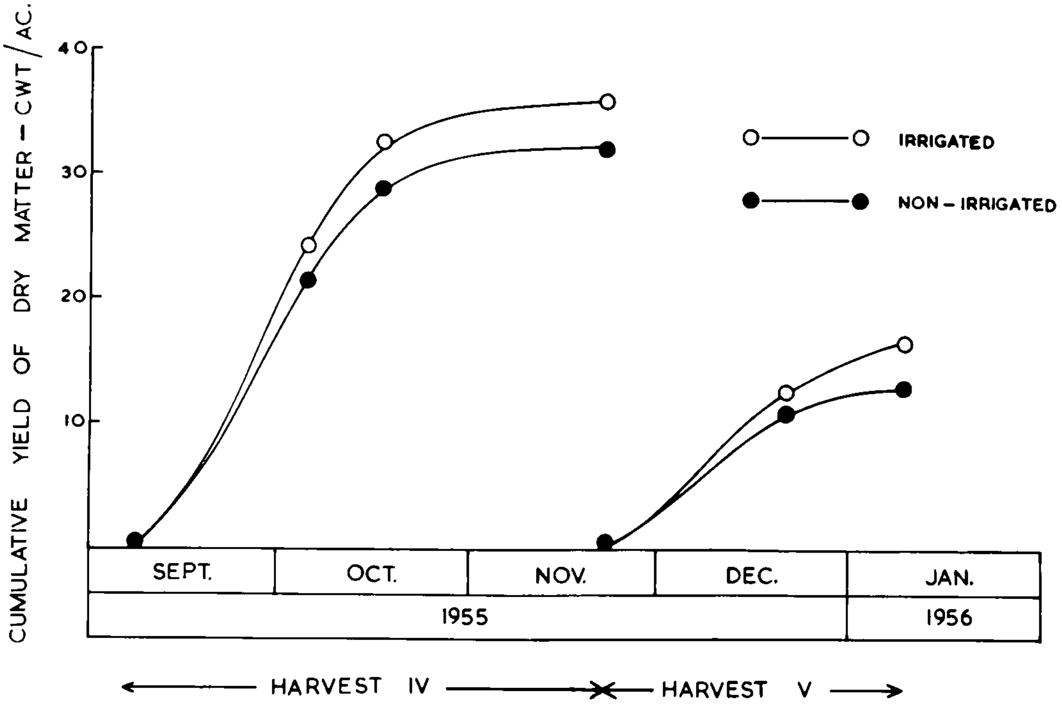

Fig. 36. **Dry weight increase of irrigation (previously irrigated) and non-irrigated (previously non-irrigated) lucerne in the second year.**

Table 23

Yield of Dry Matter - cwt/acre at each cutting (second year)

Harvest - IV

Irrigated Plots			Non-irrigated Plots		
Plot	Yield	Mean	Plot	Yield	Mean
First Cutting					
A	22.70		C	22.74	
B	24.76		E	22.54	
D	24.74	24.20	F	20.46	21.32
G	24.18		I	24.40	
H	22.70		K	19.14	
J	26.09		L	18.65	
Second Cutting					
A	7.26		C	6.17	
B	7.10		E	8.25	
D	10.47	8.28	F	5.43	7.48
G	9.30		I	8.16	
H	8.60		K	10.93	
J	6.99		L	5.95	
Third Cutting					
A	7.83		C	4.27	
B	2.74		E	0.46	
D	2.67	3.34	F	7.16	3.22
G	2.34		I	2.33	
H	2.08		K	0.49	
J	2.36		L	4.59	

Table 23 (Cont'd)

Harvest - V

First Cutting

Irrigated Plots			Non-irrigated Plots		
Plot	Yield	Mean	Plot	Yield	Mean
A	14.82		C	11.02	
B	14.02		E	10.78	
D	13.60	12.64	F	10.10	11.00
G	11.75		I	13.81	
H	12.79		K	9.47	
J	8.87		L	10.82	

Second Cutting

Plot	Yield	Mean	Plot	Yield	Mean
A	7.81		C	3.65	
B	0.93		E	1.44	
D	1.30	3.76	F	2.70	2.11
G	3.38		I	1.26	
H	2.50		K	1.58	
J	6.64		L	2.00	

Analysis of Variance

	d.f.	S.S.	M.R.	V.R.	
Total	59	3427.74			
Irrigation	1	30.39	30.39	7.57	XX
Cuttings	4	3183.92			
Irrigation x Cuttings	4	12.79	3.20		N.S.
Residual	50	200.64	4.02		

(k) Water Use by Irrigated Lucerne in Relation to Available Water.

Butler and Prescott (1955) have suggested that the relationships between evapotranspiration, evaporation from a free water surface and the available water can be expressed in the form (using their own symbols):

$$dI_{tr}/dW = c\,(2.4 - I_{tr})$$

where I_{tr} = $E_{tr}/E_W^{0.75}$

= 2.4 when available water is no longer limiting.

c = 0.119 for wheat

= 0.103 for pastures.

E_{tr} = Evapotranspiration (in./month)

E_W = Evaporation from a free water surface (in./month)

W = Stored water plus rainfall

= Available water

They found that the values of the index ($E_{tr}/E_W^{0.75}$) range from 0.86 to 2.07 for wheat and 0.16 to 1.69 for pastures.

A similar attempt is made to examine the relationship between water use (Wi) by irrigated lucerne, evaporation from a free water surface (Ew) and the total available water (Wa) during the period. Here Wa includes:

(i) The amount of available water stored (in.) to a depth of 66 inches at the beginning of the period (Ws).

(ii) The amount of water applied by irrigation (in.) during period (I) and

(iii) the amount of rainfall (in.) during the period (R).

Butler and Prescott (1955) have expressed available water on a monthly basis. The amount of available water reported ranges from 3.94 to 12.00 and 1.55 to 11.62 (in./month) for wheat and pastures respectively.

It is clear from Table 4 (Appendix D) that the total available water (Wa) in the present experiment ranges from 14.60 to 55.63 in./month, values which are clearly in excess of the amount of water which can possibly be held by the soil. There also does not seem to be any logic in expressing Wa on a monthly basis if it is proposed to compare periods of different durations. Hence it is proposed to express Wa (in.) during each period.

Prescott's monthly index K has been calculated for the present data (Table 5, Appendix D) by using the formula $Wi/_{E_W}0.75 = K$ (after Prescott 1949) where Wi = water use by lucerne (in./month)

E_W = Evaporation from a free water surface (in./month).

In Fig.37 $Wi/_{E_W}0.75$ is shown against Wa (in.). It becomes evident from the figure that the values of $Wi/_{E_W}0.75$ are approximately constant (2 values being divergent) in spite of slight differences in Wa. However, it can be said that as intended, irrigation was able to maintain K at a fairly uniform level for most part of the experimental period.

The lack of data at lower and higher levels does not permit the drawing of a smooth curve (Fig. 37) to fit the data. However, it is reasonable to assume that when the value of Wi is zero, K will be zero.

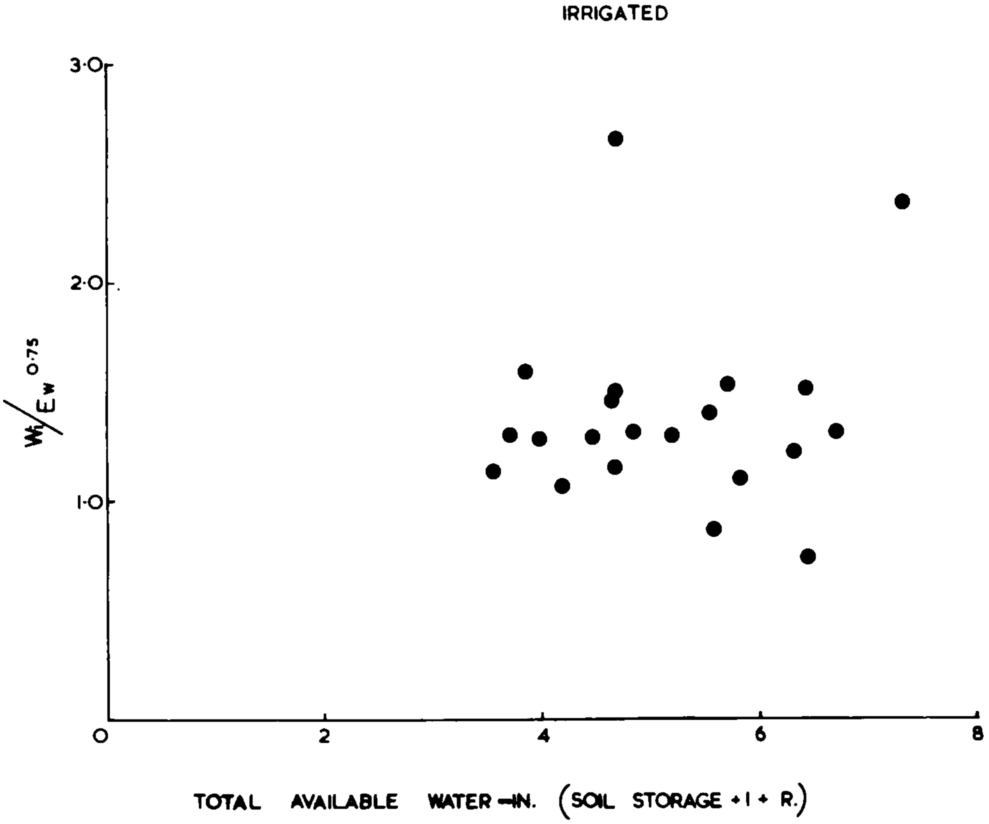

Fig. 37. The values of $Wi/_{Ew}$ 0.75 are plotted as a fraction of total available water. Note that the values of $Wi/_{Ew}$ 0.75 are approximately constant.

At the same time when Wa is zero, Wi is zero. In other words the curve showing the relation between K and Wa should pass through zero.

However, the lack of data at the lower end of the scale in the present experiment makes it impossible to verify independently the interpretation put forward by Butler and Prescott.

(1) Water Use by non-irrigated Lucerne in relation to available water stored and Irrigation plus Rain

It has already been shown that in the present experiment W from non-irrigated lucerne was found to depend on Ws - n as well as on In + R. An attempt has therefore been made to obtain the relation between Wn, E_W, In + R, and Ws - n at the beginning of the period.

Table 6 (Appendix D) shows weekly Wn (in./day), E_W (in./day) and value of K* for each period. A multiple regression analysis of K, In + R and Ws - n (Table 7, Appendix D) showed that K, In + R and Ws - n are all significantly related ($P < 0.001$) and are interdependent on each other.

Fig. 38 shows the effect of In + R and Ws - n on K. The isopleths of K drawn are based on the regression equation:

$$Z = 6.36X + 0.168Y$$

where $Z = K = Wn/E_W^{0.75}$

X = Irrigation + Rain (in./day) = In + R

Y = Amount of available water stored in the soil at the beginning of the period = Ws - n

The experimental values of K are also plotted and appear to fit reasonably

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* $K = Wn/E_W^{0.75}$ (after Prescott 1949).

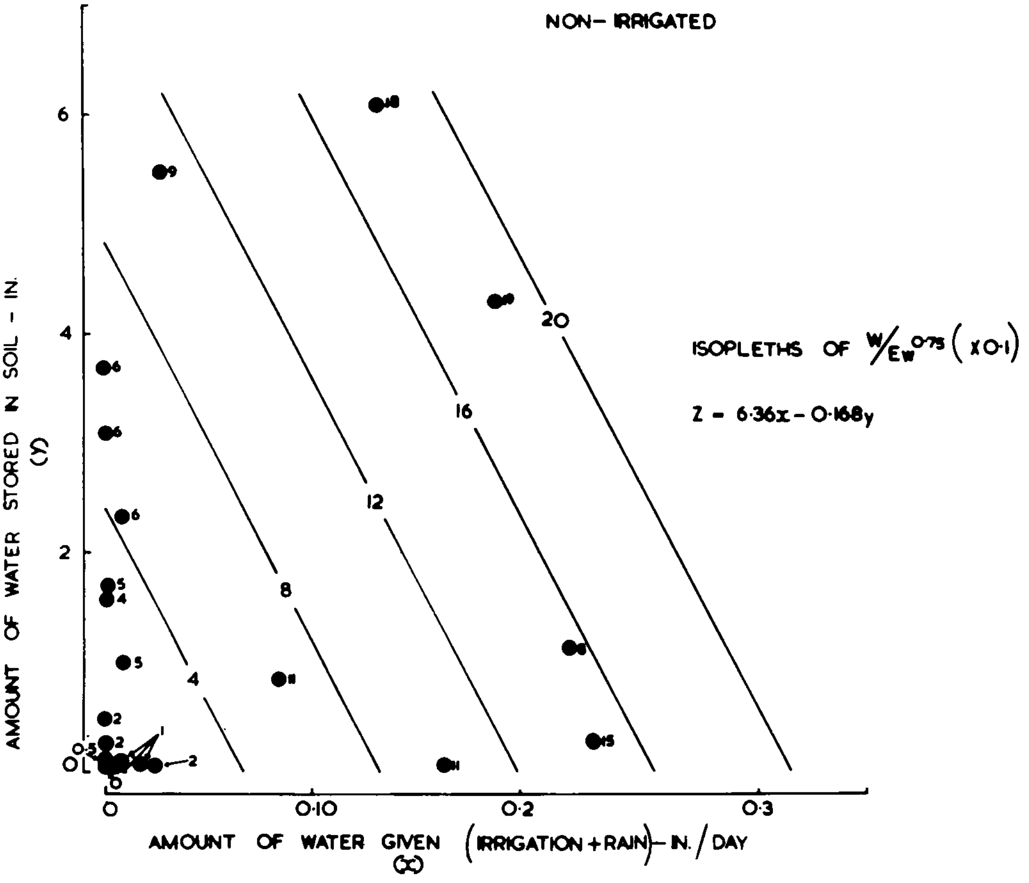

Fig. 38. Relation between $W/_{Ew}$ 0.75, the amount of available water stored in the soil and the amount of water given (irrigation plus rain). Experimental values of $W/_{Ew}$ 0.75 (X 0.1) are plotted.

well the isopleths drawn from the equation (2 values being divergent).

Nevertheless, Fig. 38 does give a general picture of dependence of K on In + R and Ws - n. It is suggested that if Ws - n is known, the above diagram may be used as a rough guide to assess the amount of water (in./day or even in./week) required to maintain at a particular K.

(m) Comparison of Penman's Potential Transpiration with actual Water Use Data obtained from the Irrigated Lucerne

The direct measurement of soil moisture for calculating the amount of water used or the amount of water required for irrigation, besides being time-consuming and laborious, is not entirely satisfactory. Consequently, the attention of many investigators has been directed to the estimation of evaporation or transpiration from more easily measured climatic data.

The important features of Penman's estimates are:

(1) They are based on standard meteorological parameters (not requiring any special measurements).

(2) They have a firm physical basis, taking into account all the important relevant factors while eliminating temperature and humidity at the surface of the vegetation, which are difficult to measure and are generally not understood.

It is proposed to test the estimated values of Penman's Potential Transpiration (E_T) by comparing with the actual water use data Wi obtained for the irrigated lucerne.

Penman (1948) suggested that evaporation from an open water surface (E_0) can be calculated from the expression: (using his own symbols)

$$E_0 = \frac{\Delta H_0 + 0.27\ E_a}{\Delta + 0.27} \quad \text{mm/day} \ \ldots\ldots\ldots\ldots \ (1)$$

$$= \frac{\Delta(0.95\ R_C - R_B) + \gamma E_a}{\Delta + \gamma} \quad \text{mm/day}$$

This formula (1) has been used throughout to calculate E_0. A key to the symbols is given on pages 164 and 165.

Evaporation from a soil with vegetation (E_T) was estimated by multiplying E_0 by an empirical reducing factor. This empirical factor was obtained from experiments at Rothamsted with a number of cylinders, half of which were filled with water, the others carrying a cover of short grass. This factor was found to vary for S.E. England from 0.6 inches in the four mid-winter months to 0.8 in the four mid-summer months. These factors were claimed to be sufficiently accurate in field experiments on irrigation of sugar beet (Penman 1949).

Later, in 1951, Penman and Schofield discussed the influence of diffusion resistance in the stomata, and Penman (1952), on the basis of these considerations, suggested that E_T can be estimated from the expression: (using his own symbols)

$$E_T = \frac{\Delta H_T + \gamma E_a}{\Delta + \gamma / SD} \quad \ldots\ldots\ldots\ldots\ldots \quad (2)$$

where

$$H_T = 0.80 R_C - R_B$$

$$R_C = R_A \left(0.25 + 0.54\ {}^{n}/_{N}\right)$$

$$R_B = \sigma T_a^4 \left(0.56 - 0.09 \sqrt{e_d}\right) \left(0.10 + 0.90\ {}^{n}/_{N}\right)$$

$$S = \frac{L_n}{L_n + L_s}$$

$$D = \frac{N}{24} + \frac{a}{b} \cdot \frac{1}{\pi} \operatorname{Sin} \frac{N\pi}{24}$$

$$a/b = \frac{(T_a \text{ max.} - T_a \text{ min.})/2}{T_a \text{ mean} - T_d}$$

This formula (2) has been used throughout to calculate E_T. A key to the symbols is given on pages 164 and 165.

Penman (1952) uses 0.16 cm as a probable value of L_s in the calculation of water use for lucerne in S.E. Australia, and this value has been adopted for these calculations.

For calculating E_a, Penman (1956) now uses a new expression which is, in fact, a compromise between measurements from a small tank and estimates from an infinite surface. Hence for the present calculation of E_a, Penman's new expression

$$E_a = 0.35 \left(0.50 + \frac{U_2}{100}\right) (e_a - e_d)$$

has been used. A key to the symbols is given on pages 164 and 165.

Symbols Used (after Penman 1952) Unit

T_a = Mean air temperature $\left(\frac{\text{Max.} + \text{Min.}}{2}\right)$ . . . . . . °F

T_d = Mean dew-point temperature . . . . °F

e_a = Saturation vapour pressure at mean air temperature in.Hg.

e_d = Saturation vapour pressure at dew-point temperature in.Hg.

Δ = Slope of saturation vapour pressure curve at T_a . . in.Hg/°F

U_2 = Mean wind speed at 2 meters . . . . miles/day

n = Mean duration of actual bright sunshine . . . . hours/day

N = Mean duration of maximum possible bright sunshine . hours/day

R_A = Incoming radiation . . . . equiv.mm/day

R_C = Incoming short wave radiation per day

= $R_A\,(0.25 + 0.54\ ^{n}/_{N})$ . . . . equiv. mm/day

R_B = Outgoing long-wave radiation per day . . . . equiv. mm/day

= $\sigma T_a^4\,(0.56 - 0.09\sqrt{e_d})\,(0.10 + 0.90\ ^{n}/_{N})$

σ = Stefan's constant

S = Stomatal factor

$$= \frac{L_a}{L_a + L_s}$$

$$L_a = \frac{0.65}{1 + \frac{U_2}{100}}$$

L_s = 0.16 cm

D = Day length factor

$$= \frac{N}{24} + \frac{a}{b} \cdot \frac{1}{\pi}\ \text{Sin}\ \frac{N\pi}{24}$$

Unit

$\frac{a}{b}$ = $\frac{(T_a \text{ max.} - T_a \text{ min.})/2}{T_a \text{ mean} - T_d}$

γ = constant of the wet and dry bult psychrometer

= 0.27

E_a = An intermediate expression obtained in calculation . mm/day

= $0.35 (0.5 + \frac{U2}{100}) (e_a - e_d)$ after Penman (1956)

H_O = Heat budget at open water surface . . . . equiv.mm/day

= $0.95 R_C - R_B$

H_T = Heat budget at plant surface . . . . equiv.mm/day

= $0.80 R_C - R_B$

E_O = Evaporation from open water surface . . . . . . mm/day

= $\frac{\Delta H_O + \gamma E_a}{\Delta + \gamma}$

E_T = Potential transpiration . . . . mm/day

= $\frac{\Delta H_T + \gamma E_a}{\Delta + \gamma / SD}$

E_T' = Potential Transpiration estimated taking SD = 1

= $\frac{\Delta H_T + \gamma E_a}{\Delta + \gamma}$ . . . . mm/day

Wi = Water use observed . . . . mm/day

E_W = Evaporation from free water surface observed mm/day

Table 1 (Appendix E) gives the sources of all the meteorological data (average parameters for each cutting) which served as a basis for these calculations. Table 2 (Appendix E) gives the values of H_O, H_T, E_O, E_T, E_a, E_W and Wi (all in mm/day) and also the ratios of Wi/H_O, Wi/H_T, E_T/E_O, E_T/E_W, E_T/Wi, E_O/E_W, Wi/E_O, Wi/E_W, and Wi/E_a.

Since weekly Wi data was available weekly E_T was compared with weekly Wi. Table 3 (Appendix E) gives the weekly meteorological data (average parameters) which served as a basis for these calculations. It will be clear from Table 24 that there is no advantage in estimating E_T on a weekly basis over fortnightly or three weekly bases. Table 4 (Appendix E) gives the weekly values of H_O, H_T, E_O, E_T, E_a, E_W and Wi (all in mm/day) and also the ratios of Wi/H_O, Wi/H_T, E_T/E_O, E_T/E_W, E_T/Wi, E_O/E_W, Wi/E_O, Wi/E_W and Wi/E_a. Nevertheless, for the present study the estimates of 21 periods will be examined.

Examinations of Tables 2 and 4 (Appendix E) suggest:

(1) Although Penman's estimate of evaporation from open water surface (E_O) underestimates the actual evaporation from a free water surface (E_W), on the whole the estimate is fairly good.

(2) The individual ratios E_O/E_W are reasonably constant. It should be noted that E_O underestimates particularly at high values of E_W. The main reasons for these discrepancies are that in the shallow tank heat exchange with the air takes place at both faces while evaporation from infinite open water surface only occurs at the upper surface.

Table 24

Comparison of Penman's Potential Transpiration (E_T) obtained from (a) data for the 9 inter-cutting periods and (b) weekly data

Period (inclusive)	E_T (mm/day)	Period (inclusive)	E_T (mm/day)	Mean (mm/day)
1954, Nov. 23 to Dec. 14	3.93	1954, Nov. 23 to 26	4.00	3.95
		27 to Dec. 7	4.00	
		8 to 14	3.84	
15 to 28	4.98	15 to 21	4.29	4.38
		22 to 28	4.47	
29 to 11 Jan. 1955	4.28	29 to 4 Jan. 1955	4.43	4.31
		5 to 11	4.18	
12 to 25	4.50	12 to 18	4.47	4.61
		19 to 25	4.74	
26 to Feb. 8	4.56	26 to Feb. 1	4.23	4.36
		2 to 8	4.49	
9 to 22	3.48	9 to 15	3.45	3.55
		16 to 22	3.64	
23 to Mar. 8	3.08	23 to Mar. 1	3.42	3.04
		2 to 8	2.66	
9 to 30	2.46	9 to 15	2.60	2.49
		16 to 22	2.70	
		23 to 30	2.16	
31 to Apr. 19	1.77	31 to Apr. 5	1.90	1.75
		6 to 12	1.98	
		13 to 19	1.38	

(3) Penman's estimate of E_a on the whole gives fairly good estimates of Wi.

(4) Estimated E_T is always less than E_O. This is expected as H_T is less than H_O and SD is less than 1. The results support the views of Penman (1952 and 1956) that potential transpiration (E_T) of a short green cover cannot exceed the evaporation from an open water surface (E_O), exposed to the same weather.

(5) Throughout the experimental period the calculated potential transpiration (E_T) was consistently lower than the observed transpiration, or water use (Wi), two periods (periods 2 and 9) being exceptions. It has already been pointed out that water use data of period 1 is suspected to have been overestimated and there is a corresponding low value of water use in the second period. The factors leading to the overestimation of water use in period 1, however, are not easily understood. No seasonal trend of water use could be found except that in the last four periods water use was higher compared to E_T than for the preceding periods.

(6) The ratio E_T/E_O is consistently lower than the observed ratio Wi/E_O. According to Penman (1952) low values of E_T/E_O were due to the neglect of field factors such as : (1) the roughness of an area of natural vegetation cover as compared with an area of short grass (2) air movement within the crop resulting in increased ventilation, (3) a reflection coefficient less than the value $r = 0.20$ and (4) evaporation of intercepted rain water. It was suggested that incorporation of any of these factors would increase the calculated ratio

of E_T/E_O. It can be seen that the first two factors would increase E_a and the third would increase H_T.

(6) The ratios of Wi/E_O (mean ratio = 0.92) are in general higher for the lower value of E_O towards the end of the growing season than they are for higher values of E_O at the beginning. This is not in accord with Penman's (1948) arguments. However, it can be shown that Penman's (1948) formula (with f = 0.92) gives a good estimate of water use which is slightly higher than those Penman has given for S.E. England summer (f = 0.80).

Having found that Penman's estimates of potential transpiration underestimate the actual transpiration obtained from the irrigated lucerne and that Penman's estimates of E_O gave fairly good estimates of E_W and Wi, the 1952 formula for the calculation of evaporation from vegetation was then examined.

Penman's formula for evaporation from an open water surface is

$$E_O = \frac{\Delta(0.95\,R_C - R_B) + \gamma E_a}{\Delta + \gamma}$$

and for evaporation from the soil covered by vegetation is

$$E_T = \frac{\Delta(0.80\,R_C - R_B) + \gamma E_a}{\Delta + \gamma}$$

The principal differences between 1948 and 1952 formulae are (1) the different reflection coefficient of a vegetation surface (0.20) and for open water surface (0.50) and (2) the stomatal and day length factors S and D.

Penman introduced the factor SD to account for firstly, the influence of diffusion resistance in the stomata if open and secondly, the influence of the closing of the stomata during the night.

Since there is some considerable doubt as to the very nature of and the value of SD (Penman 1956), E_T was then calculated using a value SD = 1. (E_T').

Hence

$$E_T' = \frac{\Delta(0.80\ R_C - R_B) + \gamma\ E_a}{\Delta + \gamma}$$

Tables 5 and 6 (Appendix E) give the values of E_T', and the ratios of E_T'/E_O, and E_T'/W_i for 9 periods and 21 periods respectively. Fig. 39 shows the values of E_T and E_T' plotted against Wi. The lines of perfect agreement are shown. It will be clear from the above tables that the ratio of E_T'/E_O is almost constant and the value (f = 0.82) agrees fairly well with the value given by Penman (1948) for S.E.England in summer (f = 0.80).

The use of E_T' improves very considerably the estimate of water use (Fig. 39); the mean ratio E_T'/W_i becomes 0.96, as compared with 0.73 when the SD factors are incorporated into Penman's equation; furthermore the variability seems to be reduced.

The ratio of W_i/E_T' (mean ratio = 1.11) is the same as the ratio of W_i/H_T (mean ratio = 1.17), suggesting that H_T also gives a good measurement of transpiration loss from the plant and that Penman's estimation of total amount of ~~heat~~/budget available at plant surface seems reasonably accurate.

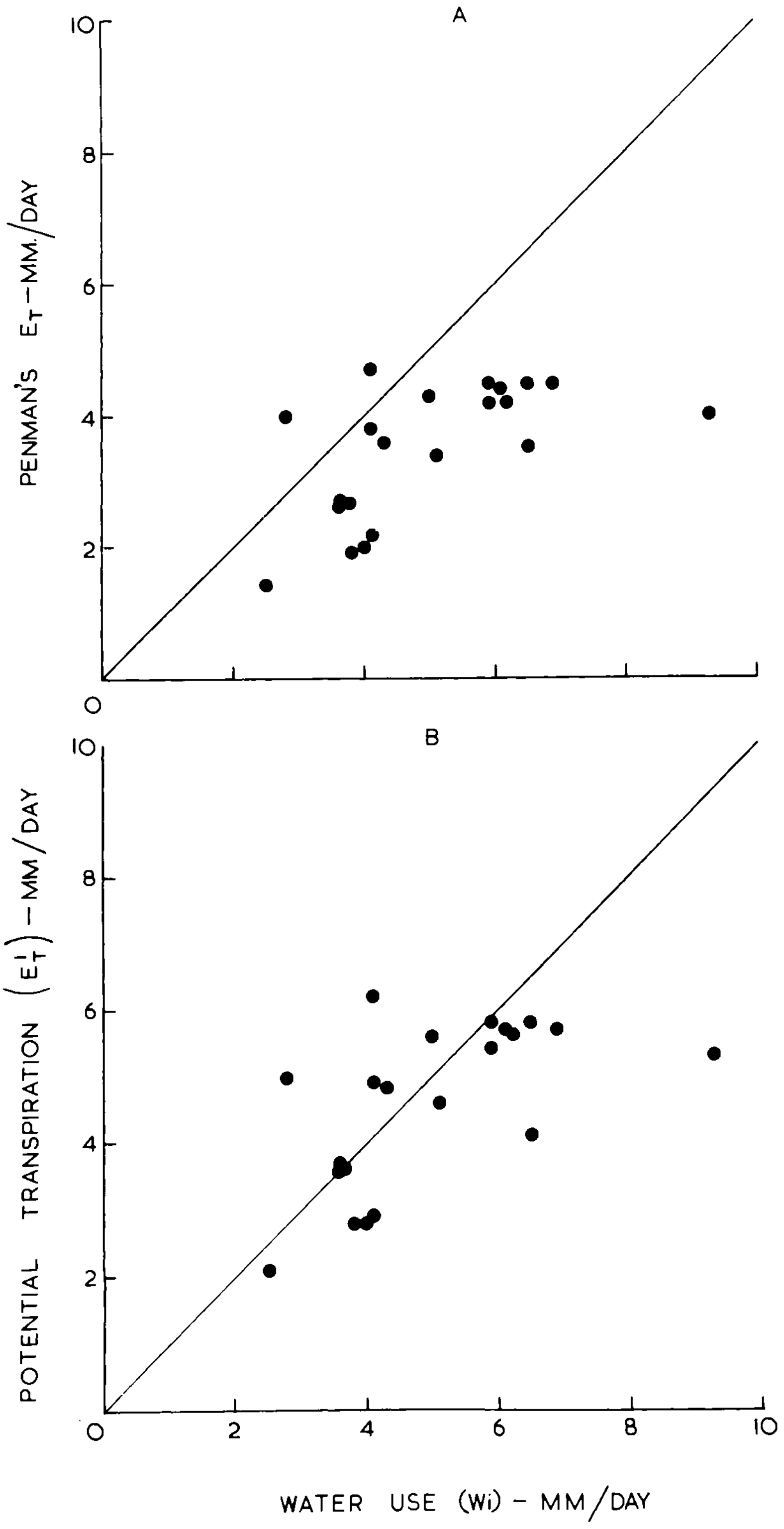

Fig. 39. Comparison of:-
(A) Penman's E_T
(B) Potential transpiration $(E_T^{\prime})$
with actual water use.

DISCUSSION

(a) Soil Temperature

A satisfactory record of soil temperature is extremely cumbersome to present inasmuch as the temperature varies with both depth and time, as pointed out by Richards, Hagan and McCalla (1952). Although the presentation of the temperature data is largely determined by the nature of the investigation and the information required, Callendar and McLeod (1896) and Hann (1906) were probably the first to present the soil temperature in isotherms against depth and time. The diagram presented by Callendar and McLeod of data collected from March 1895 to April 1896 shows the effects of daily mean air temperature, rainfall and the depth of snow on the ground on the temperature of the soil to a depth of 110 inches. However, no studies seem to have been made on the effect of rain, irrigation and daily mean air temperature on soil temperature at various depths under irrigated and non-irrigated conditions. Hence the main purpose of presenting the data in diagrammatic form (Fig. 9) is to show the distribution of temperature at various depths with time in relation to the effect of rain, irrigation and air temperature.

In this discussion of soil temperature, it should be realised that the soil temperatures recorded are not the daily, or weekly means, but are the temperatures taken at a given time in each week. Consequently the values of temperatures obtained here will not be exactly the same as the daily mean value of the soil temperature based on the average of the maximum and minimum values. The importance of time of observations of soil temperature was pointed out by Keen (1931 p.306) and Daubenmire (1947 p.173). Daubenmire has stated that any reference of soil temperature is of limited significance unless the time of observation and depth at which it is made are specified.

It is also to be noted that the accuracy of this type of thermistor in measuring the changes of soil temperature is ± 0.2°C.

(i) Effect of Rainfall. Although there are some differences of opinion on the effect of rainfall on soil temperature, there is ample evidence (Baver 1956 p.383, Bouyoucos 1913, Franklin 1919, Keen and Russell 1921, Keen 1931 and Smith 1929) to indicate that rainfall has a definite modifying effect on soil temperature, promoting both cooling and warming, depending on season and soil conditions. As rainwater penetrates the soil there is a tendency for the temperature of the rainwater and the soil to come into equilibrium (Geiger 1950 and Keen 1931); consequently the temperature will be lowered in winter to the depth of penetration of rainwater.

The data of 10.5.55 and onwards (Figs. 11 and 12) clearly show the cooling effect resulting from the percolation of winter rain. As the winter rain proceeds and more and more water infiltrate to deeper layers, the temperature at different depths in both plots becomes more and more uniform. The results indicate that percolation of winter rain has an effect tending to equalise the temperature of the whole soil profile. It is evident from the data for 5.10.55 (Fig. 12) that by this time there is virtually no temperature gradient.

(ii) <u>Highest and Lowest Temperatures.</u> Soil is a complex material; far from being solid it is a delicately balanced three-phase system, including solid matter, air and water ~~and~~ both free and fixed. The nature of soil temperature variations cannot therefore satisfactorily be considered without a detailed study of the effects of temperature changes upon the water associated with soil particles.

Water has a very important effect on the thermal conductivity of soil materials both on account of its high specific heat and because of its influence on structure. It can be inferred from the results of various investigators (Kersten 1948, Patten 1909, Shanklin 1922, Shannon and Wells 1947, and Smith 1939) that any increase in moisture content results in an increase in conductivity consequent upon better thermal contact between soil grains produced by the moisture film and this suggests that the rate of change in conductivity should be greater at higher moisture contents. With further addition of water however, the temperature of the soil will respond more slowly, in spite of better conductivity, due to the high heat capacity of water which is almost five times that of dry soil. So between the extremes of dry and wet soil there is a range of moisture contents where the specific heat of the moist material per unit volume increases less rapidly than the conductivity and within this range the maximum conduction of heat and the greatest temperature rise for a given application of heat occurs. This moisture content is, however, different for each soil (Patten 1909). The increase in heat conductivity is most rapid at the lower moisture content range (Baver 1956 p.377). Crawford (1952) believes that soil moisture influences the radiation, evaporation, specific heat, thermal conductivity and diffusivity, and heat capacity of soil.

Since in this experiment no records were obtained of the relation between moisture content, conductivity and specific heat either under field conditions or under laboratory conditions, no quantitative estimate can be made of the effect of moisture content on the difference of temperature between the two treatments. However a qualitative estimate will be attempted as far as available data will permit.

In view of this, the temperature records have been examined to determine whether the highest temperature differences obtained in the two treatments can be ascribed to (1) moisture content difference, (2) vegetative cover, and (3) slope of the plot.

(1) Moisture content difference.- Table 5 shows the highest temperature and the relevant moisture contents at various depths. The moisture contents for various depths were obtained from the pF-moisture content curve, and the moisture content at permanent wilting percentage is also shown for various depths.

It is evident from Table 5 that the moisture content varies quite considerably in the two treatments at 6, 12, 24, 36, 48 and 60 inches depth. The moisture content in the non-irrigated plot, as expected, is always lower than in the irrigated plot. It should be noted, however, that the highest temperatures were recorded at 6 inches depth in the irrigated plot on two occasions. On one occasion the moisture content of the irrigated plot was lower while in another it was higher than in the non-irrigated plot. The moisture content in the non-irrigated plot at 24, 36 and 48 inches is approximately at wilting point when highest temperatures were recorded at these depths, while the moisture content at 60 inches is slightly higher than wilting point but is lower than the moisture content at 60 inches in the irrigated plot.

It is evident from Tables 25 and 26 that the moisture content of the non-irrigated plot is consistently lower than that of the irrigated plot. Table 25 gives the moisture content and temperature of the irrigated plot at various depths on the day when highest temperatures were recorded in the non-irrigated plot. Similar data for the non-irrigated on the day when highest temperatures were recorded in the irrigated plot have also been given (Table 26). It is of interest to note that the temperature of the irrigated plot is lower than that in the non-irrigated plot at all depths. On the other hand, the moisture content of the irrigated plot on the day when the highest temperatures were recorded, was consistently higher than the moisture content of the non-irrigated plot at all depths. It is also of interest to note that when highest temperatures were recorded in the irrigated plot the non-irrigated plot had an even higher temperature.

Although the data do not permit a critical and satisfactory examination of the effects of moisture content on the temperature differences obtained in the two treatments, it is, however, fairly clear that in the present investigation the soil of the irrigated plot is colder than that of the non-irrigated plot. It can be said that the cold nature of wet soil is due to the higher heat capacities than that of dry soil (Baver 1956 p.370). Similarly, reports have been given by Smith, Kinnison and Carns (1931) that irrigation reduces the soil temperature, the

Table 25

Moisture content of non-irrigated and irrigated soils at times at which highest temperatures were recorded in non-irrigated plots

Experimental Period

Depth (in.)	Non-Irrigated Plot		Irrigated Plot	
	Temp. (°C)	Moisture* (%)	Temp. (°C)	Moisture* (%)
6	31.2	8.2	23.2	12.7
12	28.6	11.2	22.0	14.2
24	26.3	19.9	20.0	22.5
36	24.2	17.7	19.2	21.4
48	23.0	16.9	19.4	19.2
	23.0	16.9	19.4	19.0
60	21.6	16.5	18.3	17.3
	21.7	15.5	18.4	17.2
	21.7	15.5	18.5	17.2
	21.7	15.3	18.8	17.2
	21.5	14.9	18.8	17.1
	21.5	14.7	18.7	17.1
	20.9	14.7	18.7	17.1

* Expressed as percentages of oven-dry soil

Table 26

Moisture content of non-irrigated and irrigated soils at times at which highest temperatures were recorded in irrigated plots.

Depth (in.)	Irrigated Plot Temp. (°C)	 Moisture* (%)	Non-irrigated Plot Temp. (°C)	 Moisture* (%)
6	23.9	8.0	26.4	6.7
	23.6	14.3	28.6	8.7
12	22.0	14.2	28.6	11.2
24	22.8	22.4	15.8	21.8
36	20.9	22.2	19.0	22.0
48	19.9	20.2	22.4	16.9
60	18.3	17.3	21.6	16.5
	18.4	17.2	21.7	15.5
	18.5	17.2	21.7	15.5
	18.8	17.2	21.7	15.3
	18.8	17.1	21.5	14.9
	18.7	17.1	21.5	14.7
	18.7	17.1	20.9	14.7

* Expressed as percentages of oven-dry soil

greatest reduction being at 1 foot and the lowest at 3 feet. They stated there that irrigation has the effect of lowering the temperature even when the water was either cooler or warmer than the soil, or when the temperature of the soil and water were nearly equal. For instance they found that in Arizona in the month of August when the water and soil temperature were nearly equal, the lowering was 3 °F. According to Richards, Hagan and McCalla (1952) Brookes (unpublished data) found that two weeks after an irrigation the daily maximum temperature just below the soil surface was lower on the irrigated plot. Jakobsen et al. (1953) have summarised their findings that in the absence of plant cover wet soil is about one degree colder than dry soil, at least in the dry early part of the summer. So it can be said that although under the same climatic conditions wet bare soil absorbs more solar energy than dry bare soil, wet bare soil is colder because five times as much heat is required to elevate the temperature of water contained in the pore space as would be required to heat an equivalent volume of dry soil.

The reduction in temperature in the irrigated plot compared with the non-irrigated plot in this experiment appears to be much higher than those reported by these workers. Smith, Kinnison and Carns (1931) have stated that the time taken fully to regain the loss under the influence of air temperature is two weeks or more, but in this experiment irrigation was given every week. Thus, the irrigation interval was insufficient to permit a full build up in temperature, and the temperature differences between the irrigated and non-irrigated plots increased every week. This may be one of the reasons for so great a temperature difference in the two treatments. Furthermore, the wet (irrigated) soil is covered with a dense vegetative growth of lucerne while the dry (non-irrigated) soil has a very sparse cover.

(2) Vegetative cover.- There is ample evidence that surfaces covered by vegetation are cooler than bare soil in summer, but warmer in winter (Richards, Hagan and McCalla 1952; and Russell 1950 p.329). According to Baver (1956 p.365) Wollny (1883) showed that the daily variation in soil temperature at a depth of 10 cm was 2° to 4°C greater under bare soil than under a grass cover and the influence of cover was greater the larger the number of sunny days. Wollny is also said to have observed that there was little difference between the effects of different crops if they provided the same amount of shading. Bouyoucos (1913) had shown that the conditions of cultivation - non-cultivation and sod (alfalfa sod) - have very distinct influences upon soil temperature, and he observed that during the months of June, July, August and September, 1912, the uncultivated plot was the warmest, the sod the coldest and the cultivated was intermediate. The highest average temperatures were recorded on July 9th with the following results:

7 in. uncultivated 77.80°F, cultivated 76.00°F, sod 69.45°F;
20 in. uncultivated 69.31°F, cultivated 69.00°F, sod 65.25°F.

Hojendahl (1953) also observed that in July 1951 the surface of bare soil was about 5°C warmer than that of the soil covered by oats. Similar temperature differences were also obtained between bare soil and the soil covered by wheat in the months of June and July 1952.

It is also evident that vegetation intercepts a part of the sun's rays, using the energy partly in assimilation, but mainly for evaporation. Geiger (1950 p. 285) from the data of Angstrom pointed out that a pasture 1 m high of meadow grass and Dactylis glomerata intercepted 80 per cent. of the solar radiation. The main effect of dense vegetative cover (Baver 1956 p. 365) is that by intercepting a considerable portion of the sun's radiant energy it prevents the soil beneath from becoming as warm as bare soil during summer, while in winter it acts as an insulating blanket reducing the rate of heat loss from the soil.

While discussing the amount of solar radiation intercepted by plant cover it should also be realised that its main effect is to alter the distribution of a given amount of heat either gained or lost (Geiger 1950, p. 287). The whole exchange of heat is at the boundary in the case of bare soil, while in the plant cover there is an air canopy within the foliage. Consequently, the soil covered by a crop receives less energy in the day time than bare soil. The vegetation also hinders the emission of heat rays from the soil at night. Furthermore, in the absence of appreciable wind, the higher humidity of air under vegetation increases the amount of heat needed to raise its temperature effectively. Thus on account of opposite influences of vegetation during the day and night, temperature fluctuates less widely under plant cover than where the soil is bare (Daubenmire 1947. p. 176). Russell (1950. p. 331) pointed out the efficiency of vegetation in reducing the fluctuation of surface soil temperature and that the thicker the vegetation the smaller the temperature fluctuations in the soil. Impressed by the marked influence of vegetation on soil temperature Crabb and Smith (1953) concluded that vegetation not only exerts a direct influence upon soil temperature, but also an indirect influence upon almost every other factor affecting soil temperature changes and hydrological factors. Thus it can be seen that the rate of loss of heat energy at night by re-radiation is retarded by plant cover, with the result that the nocturnal temperatures of both soil and air within vegetation characteristically do not drop as low as those of adjacent bare soil.

It should also be realised that the greatest fluctuation in the temperature of bare soil occurs at the ground surface, while this condition is reversed in the crop (Geiger 1950. p.291). In other words the highest and lowest temperatures occur in the ground surface of bare soil while in the plant-covered soil the peak fluctuations take place at the top surface of the plant and not on the soil surface.

(3) Slope of the plot.- Since the amount of radiation received per unit area is proportional to the cosine of the angle made between the perpendicular to the surface and the direction of the radiation, the radiation received per unit area decreases with an increase in this angle. In the present experiment plot G (irrigated) is completely flat while plot C (non-irrigated) has a slope of $3^{o}6''$ facing north. Plot C may be shown to receive about 2 per cent. more solar energy than plot G.

Conclusion. From the foregoing discussion it is clear that bare soil is warmer than covered soil in summer, while the soil of the non-irrigated plot is warmer than the soil of the irrigated plot; also that the temperature differences are highest at the surface layer and decrease with increase in depth. In this experiment there was always a dense vegetative cover of actively growing lucerne in the irrigated plot while in the non-irrigated plot there was virtually no vegetative cover at all. It is therefore reasonable to conclude that the low values of the highest temperature recorded in irrigated plots are due to irrigation as well as due to high plant cover. No comparable studies to the present investigation appear to be available in the literature.

(iii) Heat Penetration and Loss.- It is now possible to attempt to explain why the soils of the irrigated plot at the depth of 12, 24, 36, 48 and 60 inches lagged 1, 1, 1, 1, and 3 weeks respectively behind the non-irrigated plot at these corresponding depths.

(1) Since the irrigated soil has a dense vegetative cover, it receives less solar energy than the non-irrigated soil which is bare, with the result that the depth of penetration of heat waves will be much less in irrigated soils compared with non-irrigated soils. This is clearly illustrated by the isotherms (Fig. 9) penetrating downwards in the non-irrigated plot while in the irrigated plot very few isotherms penetrate downwards and the distance between them increases. No other comparable results are available of the effects of irrigation and natural rainfall conditions and also covered and bare soil on the penetration of heat.

(2) Vegetation considerably reduces the fluctuations of the temperature at the surface soil with the result that the penetration of heat will be much delayed and also that the amount of penetration will be much less in the covered soil.

(3) There will be much more evaporative cooling from an area of

vegetation than bare soil. Furthermore, the vegetation has a greater evaporating surface than that available for the bare soil.

(4) Constant irrigation will also reduce the fluctuations of temperatures of subsurface soil considerably in the irrigated soil.

Although the 6 inch soil of the non-irrigated plot lagged one week behind the irrigated plot in reaching the highest temperature (Figs. 13 and 14), it does not follow that 6 inch irrigated soil recorded a higher temperature than the 6 inch non-irrigated soil. On the contrary the 6 inch soil temperature of the irrigated plot was 6°C lower than the soil temperature of the non-irrigated plot at that depth. The possible reason for the discrepancy is:

(1) The lucerne was cut completely on 10.1.55 and hence both plots were bare for a few days. However, the irrigated plot had a complete cover within a week while the non-irrigated plot still had a very sparse cover. Consequently, the temperature of the 6 inch irrigated soil rose with the air temperature, and then gradually decreased due to cover and irrigation, while the temperature of the 6 inch non-irrigated soil went on increasing under the influence of air temperature etc. and reached its highest value on 28.1.55.

<u>Second Year</u>.- The data of the second year soil temperature of both plots show that the irrigated plot is still colder than the non-irrigated plot at all depths, 6 inch being the exception - an anomaly which is difficult to understand.

Before going into possible explanations it is to be noted that the resistance of the thermistors changes with time (Aitchison 1953). It has been reported that the magnitude of the apparent drift in soil temperature arising from this resistance change is of the order of 1°C per year. Since no calibration of thermistors could be done in the second season, the magnitude of drift in these thermistors is unknown.

In view of this, attempt will be made to put the following tentative reasons:

(1) Vegetative Cover

(2) Moisture Content Difference

(1) Vegetative Cover.- It has already been shown that vegetative cover has a considerable effect in reducing the soil temperature. It will be clear from Table 23 that vegetative cover (in terms of dry matter production cwt/acre) in non-irrigated plot is significantly ($P = < 0.01$) lower than that of the irrigated plot. This means that there will be less interception of solar energy in the non-irrigated plot compared with the irrigated plot. As a result the amount of solar energy available per unit area to heat the soil of non-irrigated plot will be more than that available to the soils of irrigated plot. No further analysis is possible in the absence of more extensive data, but it should be noted that, as already mentioned, the non-irrigated plot gets approximately 2 per cent. more solar energy than the irrigated plot as a result of the slope.

(2) Moisture Content Difference.- No significant differences in moisture at various depths in the two plots could be found.

From these considerations it may be suggested that the reasons for the higher temperatures being recorded in the non-irrigated plots at all depths except at 6 inches are firstly, the lesser plant cover and, secondly, the greater available solar energy.

(b) Use of Gypsum Blocks

In this section it is proposed to discuss the main errors involved in the use of gypsum blocks. It will be recalled that gypsum blocks were used to measure the pF of the soil water of the two treatments; the pF data thus obtained were then converted to moisture percentage by appropriate pF - moisture content curve.

The following are the main inherent weaknesses in the use of gypsum blocks:

(1) Hysteresis
(2) Sampling locations
(3) Block variations
    (i) Random variation
    (ii) Drift of calibration with time
(4) Soil salinity

(1) Hysteresis.- The tendency for a soil at a given soil moisture tension, to have a higher moisture content while the soil is drying than when the soil is wetting, is mainly due to the control exerted by the smaller pores on the removal of water from the larger openings during the drying part of the cycle. On rewetting, the larger pores hold water at lower tensions than for the corresponding moisture content in the drying cycle. The block itself is subject to this same phenomenon. In addition

the drying of the clay fraction in the soil causes shrinkage, which is not immediately reversed on wetting.

Realising these limitations the calibration of log R against pF (Fig. 3) was done on the drying part of the cycle, since the resistance of all blocks was intended to be taken three or more days after irrigation, at which time they would be on the drying part of the cycle. Richards (1949a) also pointed out that it is the drying curves that are of chief interest in practical agriculture, since the wetting process is usually of short duration.

In the present experiment the installation of the blocks was commenced in the first week of May 1954, and completed by the middle of August 1954. The lucerne was sown on 22nd September. During the period May to September the total rainfall was 10 inches. Under these conditions it can be inferred that the blocks had plenty of time to come to equilibrium to a tension equivalent to field capacity. This equilibrium would not have been reached if there had been no rain; Edlefsen and Anderson (1942) have shown "that even after one month, the plaster of paris block does not attain equilibrium if surrounded by soil the moisture content of which is in the lower quarter of the range of available moisture to plants". Since in the absence of vegetation water movement to the surface from the lower depths will be very low, little increment in tension will occur.

Since the irrigation and the summer rain water never penetrated below 2 feet in the irrigated plots there was no question of drying and wetting below this layer. The soil was always on a drying part of the cycle as a result of the extraction of soil moisture by the roots. Hence the error due to hysteresis in depths below 2 feet in irrigated plots will be negligible. The hysteresis might be quite serious in the top 2 feet due to the constant addition of water by irrigation. But even in irrigated plots it is suggested that the errors should not be considerable, because:

(1) The irrigation was always terminated by Thursday in three plots and by Friday in the other three plots; the block readings were taken on the following Tuesday. The blocks were thus given 84 hours to come to equilibrium to a tension corresponding to field capacity.

(2) If after 84 hours the block reading gave pF values of less than 2.9, the readings can be taken as reliable inasmuch as the sensitivity of the blocks does not start from 2.9. Furthermore, there are indications that errors due to hysteresis are highest below pF 2.9 and above pF 2.9 are considerably lower.

(3) If the blocks may be assumed to have come near to equilibrium with the tension corresponding to field capacity within 84 hours, and the subsequent block readings gave the pF values higher than 2.9, the readings obtained would be within the hysteresis loop of that group of blocks.

(4) If the blocks did not start from the equilibrium of tension corresponding to field capacity the error may then be considerable.

Further work is necessary to show how long a block will take to come to equilibrium to the tension of field capacity after irrigation under field conditions, and also the magnitude of hysteresis thereafter.

However, no further analysis is possible in the absence of more detailed data. It is certain that greater reliance may always be placed on gypsum block behaviour when the resistance readings are taken on the drying cycle.

In the non-irrigated plots there is no question of hystersis effect as the blocks were always on a drying part of the cycle except for the top 1 foot which was occasionally wetted by summer rain and irrigation. It is clear from the data in Appendices B_1 and B_2 that the pF of the soil water of the top 2 feet of the irrigated plots was for most of the time higher than 2.9. Hence it may be assumed that the diagram presented (Fig. 15) can be taken as a valid representation of soil moisture tension changes in the two treatments.

(2) <u>Sampling locations</u>.- In order to test the accuracy of calculating the amount of irrigation water to apply from tension data, Ashcroft and Taylor (1953) determined the coefficient of variability of moisture tension data in fields of potatoes and sugar beets with the location, with the characteristics of the individual blocks and with the combined location and block variation. They contended that the variability of the blocks themselves is a measure of accuracy of the blocks, while the combined location plus block variability is an estimate of the precision with which the moisture tension was actually measured. They concluded that the greatest source of variation results from the sampling locations, and suggested that this is due to uneven soil disturbances in installing the blocks, real differences

in soil moisture tension within the plots, caused by either uneven application of water or differential removal of water by a crop or by real differences in the soil itself.

The result of the present investigation supports the views put forward by Ashcroft and Taylor (1953), and Taylor (1955) that uneven distribution and uneven penetration of water contribute to the variability in pF readings (Appendix B1). It has already been mentioned that equal amounts of water could not be applied to all the six irrigated plots. Furthermore, the plots were watered over an interval of 2-3 days. The diagram (Figs. 7 and 8) of changes in soil-moisture tension in irrigated plots clearly indicates the effects of differences in time and amount of irrigation.

Since all precautions were taken to install blocks carefully it was thought that errors due to uneven disturbance of soil during installations would be small.

(3) Block Variation.- The results of Ashcroft and Taylor (1953) and Taylor (1955) indicate that there is a smaller source of variation among blocks themselves than between locations. It was suggested that this variation arises from two sources: viz. random variation among blocks and drift of calibration curve with time. Since in the present investigation the blocks were selected (see p.34) as suggested by Aitchison, Butler and Gurr (1951), it may be expected that the error caused by random variations among blocks would be at a minimum.

(ii) Drift of calibration with time. - Ashcroft and Taylor (1953) and Taylor (1953) suggested that drift in calibration curve with time is due to re-crystallisation of the gypsum in the blocks and cannot be eliminated. Taylor (1955) suggested that the magnitude of the change depends on the number of drying intervals and the number of days between each drying interval. Changes in calibration were greater in the wet range (low resistance value) than in the drier moisture range. There is no question of drift in calibration curves for the blocks used in non-irrigated plots, as for most of the time they were on the drying part of the cycle, 6 and 12 inches being the exception.

The drift in calibration curves of those blocks installed at 6, 12, and 24 inch depths in irrigated plots may result in error as they were alternately on drying and wetting cycles. However, very little is known about this drift with use under field conditions, particularly under irrigated lucerne.

(4) Soil Salinity.- Since the percentage of total soluble salts of the soil of the present experiment is less than 0.1 per cent., the effect of salt is taken as negligible (Aitchison, Butler and Gurr 1951).

(c) Calculation of Moisture Percentage from pF Data

There is no doubt that when gypsum blocks are used directly for measuring the moisture content in the field, the changes brought about by disturbing the soil could lead to a considerable error. Since the pF-moisture content relations are different for disturbed and undisturbed soil, a laboratory calibration of the gypsum block in terms of moisture content of a disturbed sample would not be suitable for field measurements.

In view of these, the best way to utilise gypsum blocks to measure moisture content in the field is either by direct field calibration, which had already been discussed, or by an indirect method.

The indirect method consists of two steps. The first is to calibrate the block resistance against pF and the second is to obtain the pF-moisture content relationship for an undisturbed soil of various depths. This is an involved way of making the measurements but it appears to be the only alternative to field calibration if reliable results are to be obtained in soil from gypsum blocks.

Bearing in mind these limitations in the use of gypsum blocks, the pF-moisture content relationship was obtained for undisturbed soil of various depths at a time when the soil down to the depth of 60 inches was wet to about the tension of field capacity. In order to examine whether the moisture percentages calculated from pF data agree or not with moisture percentages obtained from sampling technique, actual samples were taken in the present experiment at various depths on six occasions. It will be clear from Tables 27 and 28 that moisture percentages calculated from pF data provide a satisfactory basis for the calculation of water use.

The results of Taylor (1955) indicate that the possibility of reducing the coefficient of variability below 10 per cent. with gravimetric methods appears unlikely for field sampling of moisture in moist soils. Therefore any indirect method approaching this precision is an acceptable alternative in the field, and it is suggested that gypsum blocks come in this category.

Table 27

Comparisons of Moisture Percentages obtained from pF data and from direct sampling

Date	Irrigated Plots											
	Gypsum Blocks* Depth (in.)						Direct Sampling† Depth (in.)					
	6	12	24	36	48	60	6	12	24	36	48	60
22.11.54	10.6	11.3	25.2	25.7	25.7	21.5	9.5	11.3	27.1	26.6	24.5	21.0
14.12.54	11.0	9.2	21.9	22.5	24.8	21.5	10.7	8.9	20.3	23.2	25.1	21.0
28.12.54	10.9	11.9	22.0	21.6	23.4	20.1	15.0	15.0	24.5	20.9	23.8	20.8
5.10.55	12.6	14.2	23.6	24.6	24.5	19.5	10.9	13.4	27.4	25.2	24.7	21.4
18.10.55	10.5	11.6	22.7	22.5	20.9	17.8	11.2	9.3	24.5	22.9	20.4	16.8
10. 1.56	6.6	7.4	19.9	17.7	16.9	14.4	5.1	7.5	20.5	19.6	16.9	15.2

* Mean of 18 values

† Mean of 6 values

Table 28

Comparisons of Moisture Percentages obtained from pF data and from direct sampling

	Non-Irrigated Plots											
	Gypsum Blocks* Depth (in.)						Direct Sampling† Depth (in.)					
Date	6	12	24	36	48	60	6	12	24	36	48	60
22.11.54	11.2	11.1	24.9	25.1	22.8	21.5	9.5	11.3	27.1	26.6	25.5	21.5
14.12.54	7.1	8.1	21.6	23.2	22.6	19.7	7.0	8.0	22.3	23.1	24.5	21.0
28.12.54	6.8	7.5	20.4	20.5	21.3	18.1	6.8	7.7	19.6	23.2	21.6	18.2
5.10.55	12.8	13.5	23.6	24.6	24.5	19.4	10.9	13.4	27.4	25.2	25.0	19.9
18.10.55	10.1	11.5	22.7	21.6	21.3	17.3	11.2	9.3	23.5	23.0	21.0	16.6
10. 1.56	6.6	7.4	19.9	17.7	16.9	14.4	5.1	7.5	20.5	19.6	16.8	14.5

* Mean of 18 values

† Mean of 6 values

(d) Factors affecting Dry Matter Production

It is proposed to discuss the factors affecting the dry matter production of first irrigated and then of non-irrigated lucerne.

(i) Irrigated lucerne

The accumulation of dry matter is the net result of the total photosynthate produced in the leaves less the total respiratory loss in the entire plant. The rate of accumulation of dry matter may be expressed as the product of leaf area and net assimilation rate (Watson 1952), and any factor limiting the development of leaf area or net assimilation rate will thus have a limiting effect on the accumulation of dry matter. There is increasing evidence that variations in yield as measured by the accumulation of dry matter are largely defined by variations in leaf area (e.g. Watson 1952 and 1953) rather than variations in net assimilation rate.

Donald (1951, 1956) has emphasised the importance of light as a factor in plant environment and has stated that if nutrients and water are non-limiting the amount of light energy available per unit area is the sole factor determining the total yield of pasture, once a complete canopy has developed.

In a review of the influence of varying light intensity on the growth of herbage plants Black (1957) concluded that the growth of pasture species is primarily dependent on the quantity of light energy available rather than on the intensity. In a recent discussion of the significance of leaf area in pasture growth Donald and Black (in press) have stressed that light and light alone may become the factor governing the productivity of a pasture when nutrients and water supply are non-limiting.

Watson (1956) found a high correlation between yield of dry matter and leaf area index and reported that the rate of dry matter production in kale was increased to a maximum when the leaf area index (LAI - the ratio of leaf area to ground surface) had a value of about 3 and decreased to 50 per cent. when LAI fell to 5. Davidson and Donald (in press) have also found that the rate of dry matter production of tops increased to a maximum when LAI was about 4, falling by about 30 per cent. when LAI reached 8.7. Brougham (1956) has also pointed out that the rate of growth is related to the percentage of light intercepted by the herbage, and to leaf area.

In a sward each layer of leaves will receive less light than the layer above it. Thus it can be seen that each reduction of light means a lesser leaf efficiency (i.e. the rate of dry matter production per unit of leaf area will decline); each layer in the canopy makes a smaller net contribution of photosynthesis over respiration; and leaves deep in the canopy will have respiratory losses exceeding their photosynthetic contributions. Hence lower leaves heavily shaded by upper leaves will be in negative balance. Davidson and Donald (in press) have pointed out that all these effects depend on the light relationships within the sward and their influence on the balance of photosynthesis and respiration.

With these results in mind an attempt is here made to explain the relation obtained between the mean rate of dry matter production and dry weight of tops at the beginning of the period; leaf areas were not measured and dry weight of tops is used as the only available criterion.

The present results suggest that at DWT (dry weight of tops) of 10-15 cwt/acre (Fig. 33) the lower leaves were in equilibrium between photosynthetic gains and respiratory losses, and the sward as a whole had reached its optimum leaf area and hence optimum DWT for dry matter increment.

As the DWT increased beyond 15 cwt/acre there is a steady decline in the mean rate of dry matter production (DMP) in the ensuing period. It is suggested that the quantity of light available to the lower leaves of the canopy fell below the compensation point when the DWT rose above 15 cwt/acre and that the respiration rate of these leaves was then higher than their rate of photosynthesis. Nevertheless, the rate of photosynthesis of the whole plant will still be greater than its rate of respiration since it has enough leaves exposed to higher intensities of light in the upper layer of the canopy.

If the curve (Fig. 33) of the mean rate of DMP is extrapolated, the rate of DMP will be zero. when DWT reaches about 35 cwt/acre. This is in agreement with the presentation in Fig. 35 inasmuch as the growth curves of all three harvests flatten out at this same value of DWT. In Brougham's experiments it is probable that if the total herbage growth curves for each of the four starting dates (Brougham 1955) and the growth curves of total herbage defoliated at 1, 3 and 5 inches (Brougham 1956) were extrapolated, they all will flatten at the same level. It may also be inferred that in the present experiment when DWT reached 35 cwt/acre, the respiratory losses were in equilibrium with the photosynthetic gains.

It has already been mentioned that once the dry weight of tops (DWT) reached 10 cwt/acre the rate of growth seemed to be independent to a considerable degree of the seasonal conditions, within the limited range of conditions experienced. On the other hand the time taken by the lucerne in the Harvests I, II and III to reach 10 cwt/acre was approximately 24, 13 and 17 days respectively.

Three reasons for the difference in time taken by the lucerne in the three harvests to reach 10 cwt/acre may be put forward:

(1) The amount of available soil water at the beginning of the harvests.

(2) The number of lateral shoots per crown at the beginning of the harvests.

(3) Air and soil temperatures.

(1) <u>Total available water supply.</u>- From the data of Harris (1914) on corn, and Barnes (1936) on carrot, it can be said that an increase in water supply favours shoot growth more than root growth and vice versa. Hence, if water was limiting at the outset of harvests II and III, the time taken to reach 10 cwt/acre would have been more at these two harvests. Although the total available water (available water stored down to 66 inches + irrigation + rain if any) at the beginning of harvests II and III (Table 29) is less than that available at the beginning of harvest I, it appears safe to indicate that water was not limiting for harvests II and III and that the differences in time taken to reach 10 cwt/acre cannot be ascribed to the differences in the water supply.

(2) Number of lateral shoots.- Very commonly, the crown of a lucerne plant consists of three or sometimes four branches, in addition to the primary stem. After defoliation, several branches arise from adventitious buds which occur at the bases of the axillary branches. Therefore at the beginning of harvest II the number of stems per crown will be more than at the beginning of harvest I and similarly the plants during harvest III will have more stems per crown than in harvest II. This may partly explain why the plants in harvests II and III took less time than in harvest I to reach 10 cwt/acre.

(3) Temperature.- The data of Barnes (1936) on carrots and Brown (1939) on four different grasses show that increase in temperature results in an increase in shoot growth compared with root growth, and therefore lower root-shoot ratio. For example, the results given by Brown (1939) show that the dry matter (g) of herbage increased from 17.19 to 24.09 and dry matter of roots decreased from 9.13 to 4.63 when the temperature was increased from 70°F to 80°F with the result that root-shoot ratio was decreased from 0.53 to 0.19. Similar reports were observed for Canada blue grass, orchard grass and Bermuda grass (Brown 1939). However, it was not reported whether the same sort of behaviour will be obtained if the temperature is decreased from 80°F to 70°F.

If the results of Brown (1939) are taken as generally representative of the effect of temperature on shoot and root growth, it may explain why the lucerne in harvest II took less time than in harvests I and III to reach 10 cwt/acre.

Table 29

Probable environmental factors affecting the attainment of 10 cwt/acre in 3 harvests after initial cutting

Harvest	Time taken to reach 10 cwt/acre after initial cutting (Days)	Air Temperature during the period (°F) Max.	Min.	Mean	Ave. Soil Temperature (0-66 in.) (°F)	Total available water at the beginning of the harvest (in.)
I	24	78.82	58.01	68.42	18.3	7.32
II	13	85.59	63.34	74.47	19.8	5.69
III	17	76.90	57.61	67.26	18.9	3.97

Immediately after defoliation, the carbohydrate contents of roots of grasses decreases rapidly for about a week or ten days and then increases for about four weeks, when it reaches the original level (Sprague 1952). In lucerne, according to Grandfield (1935) there was a rapid decline in carbohydrate after defoliation and it reached the minimum in 20 days. This rate of decrease and the point of minimum storage will, of course, depend on many factors particularly on temperature (air and soil), the amount of plant growth or leaf area and rate of growth.

General conclusions.- In the absence of more detailed data, the following conclusions may be reached: (see Table 29)

(1) The lucerne in harvest II took less time to reach 10 cwt/acre than in harvests I and III because:

(a) both mean air temperature and mean minimum temperature were higher.

(b) average soil temperatures were higher.

(2) The lucerne in harvest II took less time than in harvest I because, in addition to the above factors, it may initially have had more numbers of lateral shoots.

(3) The lucerne in harvest III took less time than in harvest I, also because of the higher number of lateral shoots initially present.

(ii) Non-irrigated lucerne

Under the conditions of the experiment it is reasonable to assume that any additional growth in the irrigated plots compared with the non-irrigated plots is due to the amount of water given to the irrigated plots (see graph of Fig. 34B). The present hypothesis does not, however, assume that unit amount of water is necessary to increase unit amount of dry matter in both treatments. It is realised that the deficit in growth and growth-rate will be a function of the age of the plant at which it is cut, and also at which stage the irrigation was applied.

It is known that once the plant has wilted or severely wilted, it will never regain its initial physiological condition even after irrigation and cannot be compared with a plant which has never wilted and was growing under a plentiful supply of water. Meyer (1956) has stated that "In general, the longer that severe internal water deficits persist in a plant during its growing season the more <u>dwarfed</u> or <u>stunted</u> growth for that season will be. Herbaceous plants never attain their usual stature during a growing season which is characterised by pronounced drought".

If the straight line drawn in Fig. 34B is taken as a true representation of the empirical relationship between deficit in growth rate and the difference in the amount of water given to irrigated and non-irrigated plots, it shows that when the difference in the amount of water applied is zero, the deficit is 0.424 cwt/acre/day. It is suggested that this is due to the past history of the plant - in other words is a consequence of the number of wilting periods experienced. No comparable results seem to be available in the literature.

(iii) <u>Growth of lucerne in the second year</u>

The data of dry matter production in harvests IV and V (Table 23) of irrigated and non-irrigated plots show that there are significant differences ($P = < 0.01$) in yield at each cutting in both harvests; irrigated plots always gave higher yields than non-irrigated plots. An examination of water use (Table 30) and efficiency of water use (Table 31) data of both harvests suggests that there are no significant differences in water use and efficiency of water use between the two plots.

Nevertheless, in the absence of more detailed data it is proposed to discuss the differences in yield of dry matter production in terms of:

(1) Shoots
(2) Roots

(1) Shoots.- Although it was found that there was no significant difference in the number of plants per unit area at the end of harvest V (Table 10) it is highly probable that the number of lateral shoots/crown was much more in the irrigated plots than in the non-irrigated plots and this was actually observed at the start of harvest IV. The early differences in yield between the two plots are understandable but the differences in the final yield of harvests IV and V are not easily understood, since a period of some five months had elapsed in which both treatments were plentifully supplied by natural rainfall.

(2) Roots.- The amount of injury caused by the direct and indirect effects of prolonged water deficits will depend on the prevailing weather and the duration and the severity of water stress. There are definite indications that root hairs die as a result of a deficiency of water even when the plants are maintained for only a few days in a condition of

Table 30

Amount of Water Use - in./acre at each cutting

(Second Year)

Harvest - IV

First Cutting

Irrigated Plots			Non-Irrigated Plots		
Plot	Water Use	Mean	Plot	Water Use	Mean
A	6.03		C	6.68	
B	5.76		E	5.22	
D	6.85	6.31	F	5.62	5.90
G	7.44		I	5.70	
H	5.70		K	5.27	
J	6.08		L	6.93	
			Second Cutting		
A	2.95		C	2.63	
B	3.61		E	3.87	
D	2.55	3.17	F	3.80	3.90
G	2.15		I	4.72	
H	3.87		K	5.25	
J	3.87		L	3.15	
			Third Cutting		
A	7.13		C	7.05	
B	7.19		E	7.38	
D	7.14	6.89	F	7.30	6.81
G	6.78		I	6.54	
H	6.29		K	6.40	
J	6.73		L	6.21	
			Harvest V		
			First Cutting		
A	1.94		C	1.84	
B	1.66		E	1.75	
D	1.64	1.83	F	1.53	1.58
G	1.83		I	1.29	
H	2.39		K	1.33	
J	1.50		L	1.77	
			Second Cutting		
A	0.78		C	0.63	
B	0.61		E	0.61	
D	0.65	0.65	F	0.58	0.63
G	0.63		I	0.58	
H	0.58		K	0.58	
J	0.65		L	0.77	

Table 31

Efficiency of Water Use - cwt/acre per inch of water used

(Second Year)

Harvest - IV
First Cutting

Irrigated Plots			Non-Irrigated Plots		
Plot	Efficiency of Water Use	Mean	Plot	Efficiency of Water Use	Mean
A	3.76	3.87	C	3.40	3.66
B	4.30		E	4.32	
D	3.61		F	3.64	
G	3.25		I	4.28	
H	4.00		K	3.63	
J	4.29		L	2.69	

Second Cutting

A	2.46	2.82	C	2.35	1.94
B	1.97		E	2.13	
D	4.11		F	1.43	
G	4.33		I	1.73	
H	2.22		K	2.08	
J	1.81		L	1.89	

Third Cutting

A	1.10	0.48	C	0.61	0.47
B	0.38		E	0.06	
D	0.37		F	0.98	
G	0.35		I	0.36	
H	0.33		K	0.08	
J	0.35		L	0.74	

Harvest - V
First Cutting

A	7.64	7.01	C	5.99	7.12
B	8.45		E	6.16	
D	8.29		F	6.60	
G	6.42		I	10.71	
H	5.35		K	7.12	
J	5.91		L	6.11	

Second Cutting

A	10.01	5.57	C	5.79	3.38
B	1.52		E	2.36	
D	2.00		F	4.66	
G	5.37		I	2.17	
H	4.31		K	2.72	
J	10.22		L	2.60	

permanent wilt (see Meyer 1956; Loustalot 1945) and that root systems of plants in soil allowed to dry down to permanent wilting showed decreased capacity to absorb water and did not regain their full absorbing capacity until several days after the soil was wetted to field capacity (Kramer 1950, 1956).

It is expected that under the conditions of the experiment there must have been serious injury to the root hairs during the Adelaide summer inasmuch as the pF of the soil water for about five months of the whole profile was greater than 4.20 (Fig. 15). Although the recovery and resumption of root elongation may occur completely during winter, it is unlikely that the percentage of roots exposed to unit volume of soil was the same in both plots particularly in the top 66 inches. While excavating the roots on January 11th, 1955 (see p. 66) it was observed that the tap root was branched more than it appeared to be at the end of the second year (see photograph 8).

Nevertheless, since there is no difference in water use and efficiency of water use the difference cannot be due to the dying of roots, at least not in the top 66 inches.

However, the previous treatment has had some effect on the plants or roots of the non-irrigated plot that had a residual effect in the second year (Fig. 36). It is suggested that either the roots below 66 inches have more absorbing surface or deeper depth of penetration in irrigated plots than in non-irrigated plots.

(e) Factors affecting Water Use

It is proposed to discuss the factors affecting water use of first irrigated and then of non-irrigated lucerne.

(i) Irrigated lucerne

(1) Mean Amount of Herbage Present.- The fact that the rate of water use was approximately the same (Table 19 particularly in harvest III) even when the mean dry weight of herbage present was 4.6, 18.9 and 32.4 cwt/acre suggests that the water use is independent of plant height and plant cover. Hagan and Peterson (1953) also found that an alfalfa-grass mixture produced 3.72 and 10.30 tons/acre with two and five weeks' clipping while ladino clover grass mixture produced 5.59 and 8.00 tons/acre when cut at two and five weeks' intervals; notwithstanding these large differences in yield they could not find any detectable differences in consumptive-use rates. Aslyng and Kriestensen (1953) have also found that cutting lucerne and clover grass at different frequencies has practically no effect on evaporation and that the total evaporation during the experiment was practically the same at the individual locations irrespective of the variety and size of crops .

It is highly probable that the transpiration of lucerne for the short period immediately after the defoliation and before new leaves are formed is lower than that of lucerne with a fully developed leaf system, but these periods (only two to three days in the present experiment) are quite transitory when lucerne is growing fast in the Adelaide summer, and it is suggested that this would not affect the general conclusion.

When the present results are examined in relation to the views of Penman (1956), Schofield (1952) and Thornthwaite (1948) and are compared with the results of various workers (including Halkias, Veihmeyer and Hendrickson 1955) it becomes evident that when water is non-limiting the plant acts as a conducting channel for water between the soil and the atmosphere above, and the water use by actively growing plants completely covering the ground is largely independent of the plant.

(2) Environmental conditions.- The present results have shown that the mean rate of water use (Wi) by irrigated lucerne is related to mean solar radiation (R_C), mean air temperature (T_a), mean evaporation from a free water surface (E_W)* and mean saturation deficit (s.d.). However, it must be realised that the relation of Wi to any single factor such as with R_C, or T_a or E_W or s.d. is complicated by the close correlation between component factors; all the factors are inter-dependent although the degree of dependence may vary. Because of the influence of other components it is unreasonable to expect a clear relationship between Wi and R_C or T_a or E_W or s.d. Nevertheless, an attempt is here made to ascertain which of these components are satisfactory and closely related to Wi.

(1) Solar Radiation (R_C).- The present results have shown that there is a positive relation between Wi and R_C. Schofield and Penman (1948) have suggested a close relation between evaporation and the amount of R_C incident upon the vegetated area. Impressed by the effect of R_C on evaporation Schofield (1952) went so far as to state that the maximum rate

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* It is realised that E_W is not an environmental factor but since it gives the integral effect of a number of environmental factors, it is included here.

of water loss (potential transpiration) from plants depends almost entirely on meteorological conditions, primarily incident solar radiation - R_C and scarcely at all on the nature of the vegetation, so long as it is in a stage of vegetative growth and effectively covering the soil. It should be noted that Schofield's analysis assumes an adequate supply of water to the roots.

Since evaporation requires energy to supply the latent heat of vaporisation, various workers (Briggs and Shantz 1916a, 1916b; Baver 1954) have reported a close positive relation between transpiration and solar radiation.

According to Miller (1938. p.458) the accelerating effect of radiation on transpiration is due to:

(1) Higher temperature of leaves.

(2) Greater permeability of protoplasm as suggested by the work of Iwanoff and Thielmann.

(3) Imbibitional changes in the cell-wall colloids.

However, Martin (1935) reported that the accelerating action of radiation is due largely to its heating effect and that the change of permeability plays a minor role. He believed that any change of permeability that may occur under the conditions of his experiments would be either small in comparison with the heating effect or directly proportional to the intensity of radiation.

It is reasonable to conclude that solar radiation influences transpiration almost solely by maintaining the leaf at a higher temperature, resulting in a higher vapour pressure of the evaporating surface and that permeability changes will be negligible.

It is to be noted that the important point is not how much solar radiation (R_C) is available but how much total energy (H_T)* is available for evaporation. Water use data is therefore likely to be more closely related to H_T, because it takes into account both back radiation (R_B)* and reflection. Since R_B is likely to be large if R_C is large (higher temperature and clear skies), H_T will not be proportional to R_C; hence it might be expected that H_T would give a better measure of energy available for evaporation than R_C. However, an examination of the present Wi data shows that the correlation coefficient of Wi with H_T is 0.5114 which is significant at 2 per cent. level, while with R_C (see p. 138) it is 0.5030 which is significant also at 2 per cent. level. Although the present result shows that the Wi is related to R_C or H_T to the same degree it is certain that Wi should be more closely related to H_T than to R_C.

However, there is positive evaporation at R_C or $H_T = 0$. i.e. evaporation will be greater than zero even when H_T or R_C is zero (e.g. see de Vries and van Duin, and Milthorpe, personal communication). Since energy required for evaporation can come fro the radiation currently incident on the leaf or from the surrounding air, evaporation can continue in the absence of incident radiation ($H_T = 0$, or even negative).

(2) Mean Air Temperature.- It is clear from Fig. 25 that water use between 60°F and 80°F is increasing at approximate rate of 0.007 in./°F increase in temperature.

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* For calculation of H_T and R_B see p. 163.

Since:

(1) Because of rapidity of exchange with the air, the temperature of the leaf rarely differs from air temperature by more than 5°C and is likely to be higher than air temperature (particularly in clear direct sunlight) and lower when radiation is low or absent.

(2) The vapour pressure of the leaf follows leaf temperature, i.e. is equal to the saturation vapour pressure of water at the same temperature.

(3) Because the air is not saturated, the vapour pressure of the air does not change very greatly,

the present positive relationship between Wi and the mean air temperature can best be explained in terms of difference in vapour pressure and the increase in Wi at higher temperature is due to the relatively greater vapour pressure increase inside resulting from the heating of the leaf.

It is evident that a rise in temperature of the leaf alone or of the leaf and air markedly increases the rate of transpiration. It is highly probable that within the narrow range of temperature (e.g. between 60°F - 80°F), the relationship may be of linear type. There are other elements, for example, such as wind, lag of air temperature behind solar radiation (Prescott 1943) the it is very difficult to generalise as to the nature of the curve, particularly when the data are obtained under field conditions. Considering all these limitations and notwithstanding the standard error of the estimate (± 0.047) the present data fit a straight line reasonably well.

General Conclusions.- The present relationships obtained between Wi and mean air temperature, evaporation from free water surface and saturation deficit have shown that either mean air temperature, E_W or s.d. can be taken as a reliable measure of water use by irrigated lucerne.

Saturation deficit and evaporation from free water surface both give a measure of the evaporating power of the air; Prescott (1949) has shown that these are related to water use. In the present experiment a very good relation is found between water use by irrigated lucerne and Prescott's "moderate" water use using both types of values i.e. evaporation from a free water surface (see Fig. 27) and saturation deficit (see Fig. 28). Nevertheless, the ideal dimensions of a standard evaporating surface (Penman 1956) are still a matter of controversy, and since saturation deficit is easily measured, this latter measurement may be preferred.

Since the present result is supported by Prescott's classification of plants with a typical water use constant, the present relationships between water use and evaporation from free water surface or saturation deficit may be regarded as typical for lucerne with an ample supply of water.

Although the mean air temperature and water use curve shows a satisfactory fit, it is not associated with a theoretical model and hence cannot be given any general significance.

(ii) Non-irrigated lucerne.-

Water use by irrigated lucerne was related to other environmental factors, because:

(1) Water was non-limiting

(2) There was an effective plant cover, and

(3) Plants were growing actively.

This suggests that water use by non-irrigated lucerne (Wn) will not be directly related to any other environmental factors.

Although the present data of Wn has clearly shown that it is dependent on the amount of available water stored (Ws - n) and irrigation plus rain (In + R), the magnitude of dependence varies. Wn is more dependent on the external supply of water than on Ws - n. This may be because:

(1) Whenever irrigation was given or rain fell, penetration of water is confined to shallow depths.

(2) The concentration of roots is maximal in the top 24 inches.

(3) Surface evaporation as well as plant transpiration occur.

The low dependence of Wn on the amount of available water stored may be because,

(1) At deeper layers the rate of absorption of water by roots is limited by the rate of movement of water through the soil to the roots, in turn dependent on tension gradient and the capillary conductance.

(2) The capillary conductance decreases and the tension gradient increases as the moisture content decreases.

(3) Although unsaturated permeability is not negligible in the moisture range above the wilting range (Richards and Wadleigh 1952) there is conclusive evidence that moisture will not move from root-free soil at a moisture content below field capacity at a rate adequate to supply

roots in adjacent soil at distances of the order of a number of centimeters.

(f) Comparison of Penman's Potential Transpiration with actual water use data obtained from the irrigated lucerne

It will be clear from Fig. 40 that Penman's E_T gave values of water use which were lower than those recorded for irrigated lucerne. Cumulative E_T has been plotted against time for the three harvests, and the actual amount of cumulative water use (Wi) for three harvests is also shown. Prescott's "moderate" water use ($Wi = 1.2\ E_W^{0.75}$) data (cumulative) has also been plotted, and is seen to fit the present data better than does Penman's E_T.

It is proposed to discuss Penman's E_T under two sections:

(i) The probable reasons for the consistent under-estimation of water use by irrigated lucerne in the conditions of the present experiment.

(ii) The probable limitations of the formula itself.

(i) The following reasons may be put forward for the low values of E_T found in this experiment:

(1) Penman's formula assumes an infinite vegetative surface (closed, level cover of vegetation of considerable horizontal extent), with adequate soil moisture. The present data were obtained from the six separate plots, each of one twentyninth of an acre, although they had adequate soil moisture at all times. As the summer proceeded the surrounding soil became less and less vegetated i.e. there was really a decrease in plot size from an infinite size to one of small dimensions. In these circumstances evaporation from these plots will be higher than

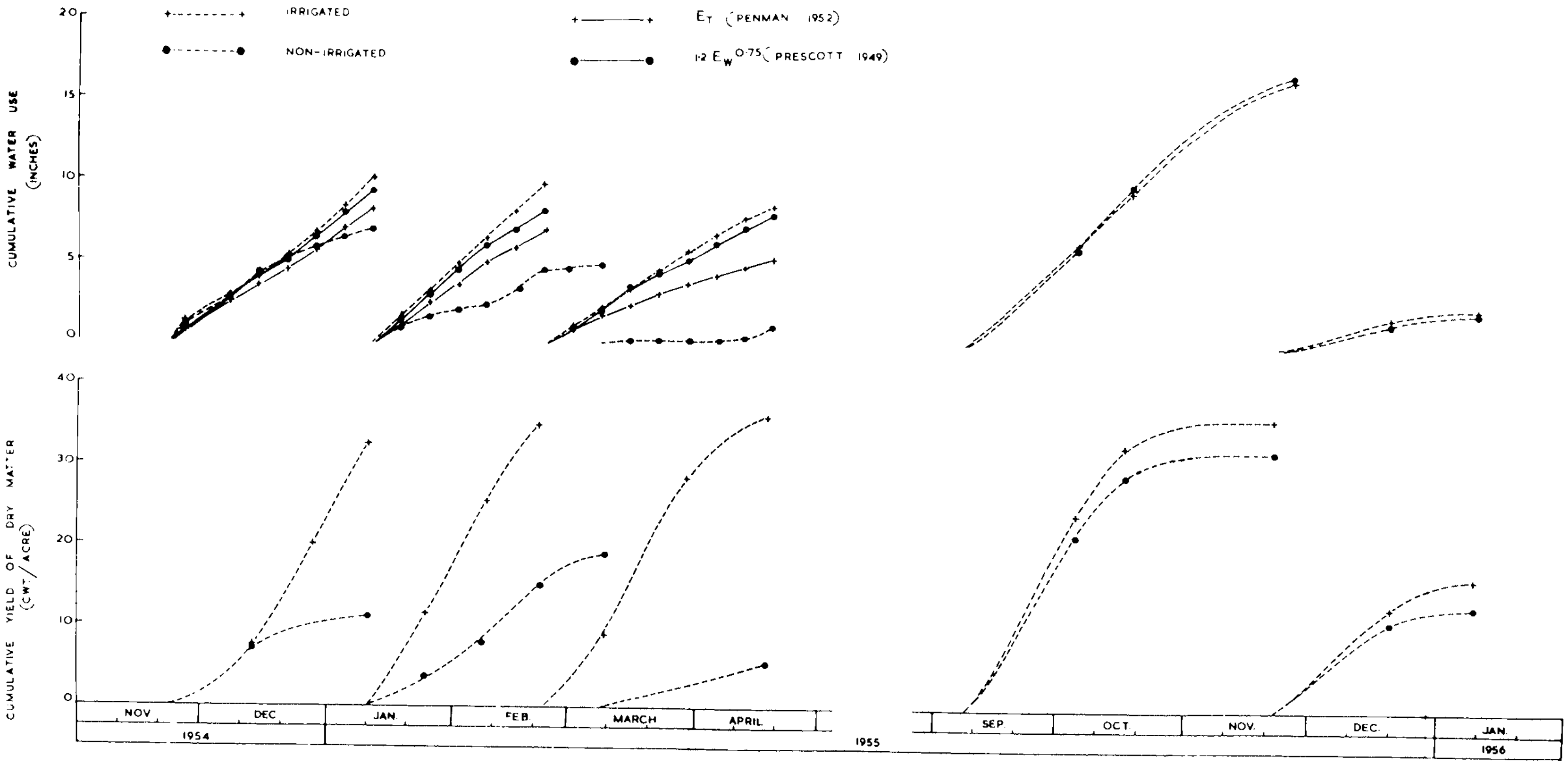

Fig. 40. Dry weight increase and water use of irrigated and non-irrigated lucerne.

from an infinite surface. The increase in the ratio of Wi/E_0 with time probably indicates the effect of the surrounding soil becoming less and less vegetated (Table 4, Appendix E).

(2) Furthermore, four quadrats each of 5 x 5 links were cut to take the yield data from each plot. Hence vegetation within the plot itself is not homogeneous. Penman (1948) went so far as to suggest that plants that project above the surrounding vegetation will have more favourable conditions for heat and vapour exchange with the air than those within homogeneous vegetation. Under these conditions the measured transpiration will be higher than the computed E_0. Hence there will be more evaporation from the plots than if it has been completely homogeneous.

(3) Although the total hours of sunshine and duration of bright sunshine are independent of the size of the plot, the temperature and the vapour pressure regime over the experimental plots will definitely be different from that which would hold if they were surrounded by an infinite surface of vegetation with an ample supply of moisture.

It should, however, be pointed out that the measured water use data is not likely to have been overestimated; firstly, no percolation of irrigation or rain water below 2 feet was observed and, secondly, water was applied through 'soakit' hoses lying on the soil surface and there was therefore very little chance of water being evaporated directly from leaves.

(ii) The following reasons may be put forward to indicate that Penman's (1952) formula is not yet a working equation:

(1) In Penman's hypothesis, the plant leaf is treated as a system discharging water vapour through the stomata in an impervious cuticle, and when the stomata are closed, water vapour discharge from the leaf is considered to cease. In fact it has been shown that in some species (e.g., Antennaria dioica, Calluna vulgaris), the closing of stomata may only reduce transpiration to 5-10 per cent. of the original value and in some species (e.g., Pinguicula vulgaris) the cuticular transpiration may amount to 25-40 per cent. of the total (Hygen 1953). Curtis and Clark (1950, p.187) have stated that "there is some loss of water also through the cuticle; when the stomata are open this cuticular loss is probably usually much less than 10 per cent. of the total but may, in exceptional cases such as thin, shade-grown leaves, be as high as 25 per cent.". Stalfelt is quoted by Curtis and Clark (1950, p.187) as having found the cuticular transpiration in birch (Betula pubescens) leaves with wide-open stomata (8μ in diameter) to be about 3 per cent. of stomatal transpiration, whereas that from similar leaves with the stomata nearly closed (only 1μ in diameter) was about 4.5 per cent. Meyer and Anderson (1952, p.126) have stated that "Even in leaves which are heavily coated with cutin, some cuticular transpiration occurs, possibly largely through tiny rifts in the cutin layer. In most species of plants of the temperate zone less than 10 per cent. of the foliar transpiration occurs through the cuticle, the remainder being stomatal transpiration". All these results indicate that there will be a considerable flux of water into and out of the leaf independent of stomatal control.

(2) It was assumed (Penman and Schofield 1951) that the stomata are fully open from half an hour before sunrise to half an hour after sunset. There does not seem to be any literature to support this assumption. The opening of the stomata depends not only on the light but also on the daily pattern of environmental factors. Such universal assumptions do not appear to be satisfactory. Although his methods are open to question, Loftfield (1921) has found that there is a great variation in the behaviour of the stomatal aperture of the different leaves of the same plant and even on the same leaf. The stomata on the upper surface may behave differently from those on the lower. Not all the stomata on a plant are necessarily open at the same time, and different stomata may differ markedly in their degree of opening at the same time. He has also found that in alfalfa, stomata situated on the lower surface open more slowly and close earlier than those on the upper. On the other hand, in the present experiment it was found that stomata of the upper epidermis open more slowly and close earlier than those on the lower.* Loftfield also found that in alfalfa stomata open in 2 to 6 hours after daylight, remain open from 3 to 6 hours, and then gradually close during a period about twice as long as that required for opening. In the present experiment (8.4.1955)† opening of the stomata was noted at 0500 hours in the lower epidermis and reached maximum between 1200 to 1500 hours. Some stomata were still open at

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* Measurements obtained by the "infiltration" method, in which the diffusion into the leaf, of liquids of different surface tensions and wettabilities is noted.

† Sunrise at 0602 hours.
Sunset at 1732 hours.

1800 hours and no stomata open at 2100 hours. No stomata of the upper epidermis were open at 0600 hours and partial opening was observed at 0900 hours and reached the maximum between 1200 to 1500 hours. No stomata were found open at 1800 hours. No closing of the stomata either of the upper or lower epidermis was observed during the day.

(3) The assumption that during the night ($L_s = \infty$) the stomata are completely closed and that there is no other way for water to pass through the epidermis is certainly not true for lucerne. Partial opening of the lower epidermis at 0100 hours on 8.4.55 was observed. Nocturnal opening of the stomata of lucerne was also observed by Loftfield (1921). In fact, this was one of the reasons why Penman (1952) indicated that lucerne was not a good test crop. There is definite evidence that nocturnal opening of stomata does occur in other species (e.g. <u>Tradescantia</u> sp., <u>Pisum sativum</u>, <u>Phaseolus vulgaris</u>, <u>Nicotiana tabacum</u> - Desai 1937) and that high temperatures, especially at night, appear to be associated with this phenomenon. (Meyer and Anderson 1952, p.155). A reduced partial pressure of oxygen in the intercellular spaces as a result of night respiration may sometimes induce nocturnal opening of the stomata (Meyer and Anderson 1952, p.155). However, the amount of opening in the night may not be great and the additional stomatal conductance relative to cuticular conductance would be small.

(4) There is indeed no <u>a priori</u> reason for using $L_s = 0.16$ but the value to be assigned to L_s may be calculated from the geometry and population[1] of stomata as given by Penman and Schofield (1951); this value was used by Penman (1952) himself in his study of water use by lucerne at Griffith, N.S.W., Australia.

(5) The fact that the value of potential transpiration E_T' (i.e. by taking SD as 1) gave a better fit to water use data suggests that the values of SD calculated by Penman's (1952) formula are too low and that the theoretical treatment of SD is not yet adequate. Businger (1956) has given data which show an empirical value for SD of 0.92, little different from 1.

(6) Finally there may be a fundamental oversight involved in the use of an equation based on energy balance, as pointed out by de Vries and van Duin (1953), who state "In applying the energy balance concept to a surface carrying a vegetation it must be remembered that the absorption and emission of radiation and the exchange of heat and water vapour between plants and air take place in a layer with a certain vertical extension and not at a geometrical surface as in the case of level ground. So far - to our knowledge - there exists no theory that describes the heat and vapour economics in such a layer".

If the present relations between Wi/E_T' and E_T'/E_O are taken as a true representation of the relation between water use, evaporation from open water surface and estimated potential transpiration (i.e. by taking SD as 1), it appears that plant surface loses water as an open water surface (with a different reflection coefficient) at an unknown temperature depending upon the prevailing weather. Penman (1956) himself has stated "Under ideal conditions transpiration is dictated by prevailing weather and that the plant can be regarded as a passive channel between the water in the soil and the atmosphere above".

The following reasons may be put forward for the discrepancies between Prescott's relation of water use and Penman's E_T.

(1) Penman assumes that there is a constant relationship between transpiration and evaporation from open water surface. The present relationship between Wi and E_0 does not support this. It was found that the ratios of Wi/E_0 (mean ratio 0.92) are in general higher for the lower value of E_0 towards the end of the growing season, than they are for higher values of E_0 at the beginning.

(2) Prescott has given evidence for taking $Wi/E_0{}^{0.75}$ (substituting E_T for E_0) as a constant and not Wi/E_0 as a constant.

The overall effect of the differences between Penman's and Prescott's treatments is that Prescott's calculations fit the present water use data better than do Penman's, and give a more reliable estimate of water use by irrigated lucerne in Adelaide summer conditions.

SUMMARY

The aim of the studies here reported was to determine the effect of a number of environmental factors on the water use and the growth of lucerne under irrigated and non-irrigated conditions. Detailed studies were made of the weekly changes in pF of the soil water, soil temperature and the amount of available water stored in the soil.

Gypsum blocks were used to measure the pF of the soil water and were installed at the depths of 6, 12, 24, 36, 48 and 60 inches before the onset of the experiments. The blocks were calibrated against pF in a pressure-membrane apparatus, and an attempt was also made to calibrate them against moisture content at different depths in the field by direct sampling. The relationship between pF and moisture content was also determined by a pressure-membrane apparatus for an undisturbed sample of soil from the six different depths.

Lucerne was established in the autumn of 1954 and was grown under both irrigated and natural rainfall conditions in the next summer for six months (November 1954 to April 1955); in the following summer (September 1955 to January 1956) the lucerne was allowed to grow without irrigation till all the available water was used. The lucerne was harvested, irrespective of age, when 25 per cent. of the plants had flowered and intermediate cuts were taken. Dry weight was used as a criterion of growth.

The main conclusions from the soil-moisture tension, soil moisture, water use and dry weight data are:

Under Irrigation

(1) Irrigation was able to maintain the pF of the soil water of

the top $2\frac{1}{2}$ feet below 3.55.

(2) The lucerne roots were not able to increase the pF of the soil water at $5\frac{1}{2}$ feet above 3.22 during the experimental period.

(3) Frequent irrigation at the surface lessens the demand for water from deeper layers.

(4) The amount of water required to bring back the whole soil profile to field capacity could not be applied every week due to low infiltration rate and quick runoff. Uneven and unequal application of water probably resulted in uneven growth and water uptake.

(5) Irrigation water never penetrated below 2 feet during the experimental period.

(6) A useful method of expressing the total available water in the whole profile has been shown.

(7) No relation between the amount of water use and dry matter production could be found.

(8) During any inter-defoliation period, the efficiency of water use increased with time to a peak value, then declined, and was found to be independent of the amount of water applied.

(9) A linear relationship between water use and mean air temperature was obtained.

(10) Prescott's relations of water use with evaporation from free water surface ($\log Wi = 0.75 \log E_W + 0.121$) and with saturation deficit ($\log Wi = 0.75 \log s.d. + 1.081$) were examined and found to be satisfactory.

(11) Water use was found to be independent of the amount of herbage present.

(12) The amount of irrigation given and the available water stored led to a constant value of Prescott's index ($Wi = KE_W^{0.75}$) regardless of the environmental conditions and age of the lucerne.

(13) Dry matter production was found to be a function of the dry weight of tops present at the beginning of the period. The rate of dry matter increase reached a maximum when dry weight of tops was between 10-15 cwt/acre and fell to zero when dry weight of tops reached to 35 cwt/acre. A possible explanation based on the concept of leaf area index is put forward.

(14) The growth of lucerne immediately after defoliation was postulated to depend on air and soil temperature and the number of shoots per crown; once the dry weight of tops reached 10 cwt/acre the rate of growth then becomes independent of seasonal conditions and the same final yield was attained in all three harvests.

Under non-irrigated Conditions

(1) The pF of the soil water of the top 2, 3, 4½ feet was increased to 4.2 within 1, 2 and 3½ months respectively.

(2) No relation between the amount of water loss and dry matter production could be found.

(3) No difference in efficiency of water use could be found compared with that of irrigated treatment because decrease in efficiency of water use was associated with decrease in dry matter production.

(4) The efficiency of water use increased with the amount of rainfall.

(5) A linear relationship was obtained between water use and the amount of available water stored plus rainfall.

(6) Prescott's index $K(Wn/E_W^{0.75})$ was found to be a function of available water stored plus rainfall. A diagram was presented which can be used to assess the amount of water required to maintain K of the lucerne growing in summer.

(7) Dry matter production is largely dependent on rain and independent of available water stored.

(8) A linear relationship was obtained between the amount of water added to the irrigated plots and the amount by which the yield of the non-irrigated plots fell below that of the irrigated plots.

Soil Temperature

Thermistors were used to measure the soil temperature and were installed at 6, 12, 24, 36, 48 and 60 inches.

The following conclusions were reached:

(1) Frequent irrigation reduced the highest temperature reached at each soil depth. The temperature differences between the two treatments decreased with increase in depth, being highest at 6 inches.

(2) Vegetative cover and irrigation were more effective in reducing the highest temperature of the 6 inch soil of the irrigated treatment than the 60 inch soil of the non-irrigated treatment.

(3) The penetration of heat in the irrigated treatment at the depths of 12, 24, 36, 48 and 60 inches was delayed by 1, 1, 1, 1, and 3 weeks

respectively as compared with the non-irrigated treatment at corresponding depths.

(4) The time of occurrence of highest temperatures in both irrigated and non-irrigated treatments at all depths was found to be a linear function of depth.

(5) The differences in time taken by the soil temperature at 12, 24, 36, 48 and 60 inches on the non-irrigated plots to exceed the air temperature was found to be a linear function of depth.

(6) The 12, 24, 36, 48 and 60 inch soil temperatures of the irrigated treatment never exceeded the air temperature during the experimental period.

(7) Rainfall tends to equalise the temperature of the whole profile.

Comparison of Penman's Potential Transpiration with actual Water Use by Irrigated Lucerne

Penman's (1952) potential transpiration (E_T) was compared with actual water use by irrigated lucerne. The conclusions are:

(1) Penman's estimate of evaporation from open water surface underestimated the actual evaporation from free water surface.

(2) Penman's potential transpiration consistently underestimated the actual water use by irrigated lucerne.

(3) The fact that the value of potential transpiration E_T' (i.e. by taking SD = 1.0) gave a better fit to water use data suggests that the value of SD calculated by Penman's (1952) formula is too low and that the theoretical treatment of SD is not yet adequate.

(4) The fact that the heat budget at plant surface gave a good measurement of water by irrigated lucerne suggests that Penman's estimate

of heat budget at plant surface is fairly good.

(5) Prescott's calculations fit the present water use data better than do Penman's, and give a more reliable estimate of water use by irrigated lucerne in Adelaide summer conditions.

Growth and Water Use in the Second Summer

In the second season, after a period of five months when both plots received heavy winter rain, the course of dry matter production was followed as the soil dried out. It was found:

(1) There was no significant difference in pF of soil water, moisture content, water use and efficiency of water use in both plots.

(2) Although the weeds were completely suppressed in the non-irrigated plots, there were no significant differences in the number of lucerne plants per unit area in the two plots.

(3) An examination of soil temperatures of both plots shows that the irrigated plot is still colder than the non-irrigated plot at all depths, except at 6 inches.

(4) Irrigated plots always gave higher yield than non-irrigated plots.

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APPENDIX A

DATE . . . .

SHEET NO. . . . . .

MONTH . . . .

PLOT . . . . .

Terminals	Depth (in.)	Blocks (old or new)	From					To					Total		Evapn. from free water surface (in.)	Theoretical loss		Remarks
			Initial Block Reading	Temp. Dial Reading	Temp. (°C)	Corrected log R	pF	Median pF for each depth	Moisture Content %	Mean Moisture % for each depth	Irrigation (in.)	Rain (in.)	Water given (in.)	Water used (in.)		Penman's estimates	Prescott's Index $1.2\ E_w^{0.75}$	
1	6																	
2	12																	
3	24																	
4	36																	
5	48																	
6	60																	
7	6																	
8	12																	
9	24																	
10	36																	
11	48																	
12	60																	
13	6																	
14	12																	
15	24																	
16	36																	
17	48																	
18	60																	

APPENDIX B 1

Values of pF at depth of 6 in.
(Irrigated Plots)

Plot	Replicate	Nov. 1954		Dec.				Jan. 1955			
		22	26	7	14	21	28	4	11	18	25
A	a	3.70	3.55	3.95	3.37	4.04	4.20	3.07	2.99	<2.90	3.22
	b	4.03	3.82	4.20	4.06	4.16	>4.20	3.09	2.91	2.99	2.94
	c	3.20	3.15	3.82	3.74	3.93	3.20	3.04	<2.90	<2.90	3.16
B	a	3.19	3.20	3.64	3.20	3.96	<2.90	3.72	2.99	3.05	2.94
	b	<2.90	3.21	3.87	3.29	4.03	<2.90	3.86	3.41	2.90	3.16
	c	<2.90	3.05	3.75	3.16	3.84	<2.90	3.14	<2.90	2.99	2.92
D	a	3.09	2.99	3.68	3.14	4.02	>4.20	3.24	3.10	2.99	3.50
	b	3.44	3.02	3.94	3.35	4.16	3.70	3.57	3.30	3.14	3.22
	c	3.72	3.52	4.10	3.39	4.04	3.79	3.74	3.10	3.19	3.06
G	a	3.61	3.77	3.90	3.38	3.95	4.08	3.10	2.99	3.00	3.06
	b	<2.90	3.28	3.81	3.01	3.91	4.03	4.06	3.10	<2.90	3.17
	c	3.96	3.96	4.03	<2.90	3.86	>4.20	3.05	2.97	2.92	3.06
H	a	3.27	3.43	4.15	3.74	4.12	<2.90	3.73	2.92	<2.90	3.79
	b	3.86	3.90	4.20	3.59	4.08	<2.90	3.61	<2.90	2.97	3.59
	c	3.40	3.46	4.00	3.43	3.92	2.99	3.10	<2.90	2.97	3.82
J	a	4.04	3.63	4.14	3.86	>4.20	<2.90	4.19	3.30	3.00	3.24
	b	3.74	3.76	4.08	3.11	4.13	<2.90	4.18	3.45	<2.90	3.46
	c	3.27	3.31	3.97	3.16	3.23	2.99	3.79	3.29	3.11	3.84

Representative Plot Values (median of 3 replicates)

A	3.70	3.55	3.95	3.74	4.04	4.20	3.07	2.91	<2.90	3.16
B	<2.90	3.20	3.75	3.20	3.96	<2.90	3.72	2.99	2.99	2.94
D	3.44	3.02	3.94	3.35	4.04	3.79	3.57	3.10	3.14	3.22
G	3.61	3.77	3.90	3.27	3.91	4.08	3.10	2.99	2.92	3.06
H	3.40	3.46	4.15	3.59	4.08	<2.90	3.61	<2.90	2.97	3.79
J	3.74	3.63	4.08	3.16	4.13	<2.90	4.18	3.30	3.00	3.46

Representative Treatment Values (median of 6 Plot medians)

3.53	3.51	3.95	3.31	4.04	3.34	3.59	2.99	2.98	3.19

pF at 6 in. (Irrigated plots) - Continued

Feb.				Mar.					Apr.			
1	8	15	22	1	8	15	22	30	5	12	19	26
2.97	3.44	3.37	3.93	2.97	2.92	3.55	2.98	2.96	<2.90	3.08	<2.90	3.11
3.01	3.01	3.05	3.60	<2.90	3.05	2.96	<2.90	2.96	<2.90	2.92	<2.90	2.95
2.99	3.25	3.24	3.66	<2.90	3.08	3.35	3.04	<2.90	<2.90	<2.90	2.95	3.24
3.01	3.53	2.98	3.83	<2.90	<2.90	<2.90	3.07	3.05	3.46	3.29	2.95	2.97
3.31	3.34	3.59	3.94	2.99	3.31	<2.90	<2.90	3.12	3.09	3.55	3.43	3.80
<2.90	<2.90	3.03	3.25	2.97	3.02	3.09	3.83	3.87	3.88	3.94	3.61	3.80
3.59	4.00	3.87	4.18	2.97	3.02	3.69	3.75	3.10	<2.90	3.44	3.07	3.14
3.35	3.88	3.64	3.29	3.11	3.18	3.92	3.04	3.17	2.99	3.21	3.07	3.14
3.46	3.25	3.57	3.25	3.03	3.08	3.69	2.91	3.10	3.02	3.08	3.16	3.12
3.10	3.05	3.00	3.65	<2.90	2.99	3.08	3.65	2.96	<2.90	3.25	3.02	3.24
2.97	3.05	3.00	3.16	<2.90	2.96	<2.90	3.01	3.02	3.02	3.59	3.12	3.55
3.69	3.44	3.21	3.62	<2.90	<2.90	2.96	<2.90	2.99	<2.90	3.31	3.16	3.34
2.97	3.36	3.19	3.60	2.97	2.96	<2.90	<2.90	2.90	<2.90	3.03	3.07	3.02
<2.90	3.61	3.29	3.72	<2.90	2.96	<2.90	3.07	2.96	<2.90	<2.90	3.01	<2.90
2.97	3.46	3.34	3.74	<2.90	<2.90	3.12	3.14	3.02	2.92	3.15	3.07	3.07
3.91	3.99	3.95	>4.20	3.13	3.15	3.22	3.07	3.56	3.30	4.00	3.82	3.99
3.27	3.42	3.61	3.87	3.08	<2.90	3.42	3.09	3.22	3.13	3.11	3.08	3.30
2.98	3.00	3.05	3.34	<2.90	2.99	3.52	3.87	2.99	3.08	3.03	3.01	3.02
2.99	3.25	3.24	3.66	<2.90	3.05	3.35	2.98	2.96	<2.90	2.92	<2.90	3.11
3.01	3.34	3.03	3.83	2.97	3.02	<2.90	3.07	3.12	3.46	3.55	3.43	3.80
3.46	3.88	3.64	3.29	3.03	3.08	3.69	3.04	3.10	2.99	3.21	3.07	3.14
3.10	3.05	3.00	3.62	<2.90	2.96	2.96	3.01	2.99	<2.90	3.31	3.12	3.34
2.97	3.46	3.29	3.72	<2.90	2.96	<2.90	3.07	2.96	<2.90	3.03	3.07	3.02
3.27	3.42	3.61	3.87	3.08	2.99	3.42	3.09	3.22	3.13	3.11	3.08	3.30
3.06	3.38	3.27	3.69	2.93	3.01	3.19	3.06	3.05	2.94	3.16	3.08	3.22

pF at 6 in. (Irrigated plots) - Continued

May					June			July	Aug.	Sept.
3	10	18	24	31	9	14	28	12	9	8
3.40	3.14	2.99	3.07	3.02	3.14	<2.90	2.92	2.93	<2.90	<2.90
<2.90	2.96	<2.90	3.02	3.01	2.92	<2.90	<2.90	2.93	<2.90	<2.90
3.42	2.92	<2.90	3.11	<2.90	3.05	2.93	3.00	3.05	<2.90	<2.90
3.55	3.06	<2.90	2.92	2.94	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90
3.86	3.03	<2.90	3.07	3.10	2.90	<2.90	2.90	2.93	<2.90	<2.90
3.88	3.56	<2.90	2.99	2.97	2.92	3.06	<2.90	2.94	<2.90	<2.90
3.39	2.96	3.05	3.06	2.94	2.92	<2.90	<2.90	2.92	<2.90	<2.90
3.12	3.12	3.10	3.15	3.07	3.19	3.03	3.05	3.22	<2.90	<2.90
3.21	3.23	3.02	3.18	3.15	3.23	3.15	3.26	3.31	<2.90	<2.90
3.55	3.12	2.99	3.02	2.97	2.99	2.94	3.03	2.92	<2.90	<2.90
3.75	2.94	3.11	3.06	3.05	2.99	3.01	3.01	2.99	<2.90	<2.90
3.52	3.16	2.94	3.02	3.06	3.05	<2.90	3.16	3.02	<2.90	<2.90
3.11	3.05	3.00	3.03	3.20	3.05	2.94	2.92	<2.90	<2.90	<2.90
3.23	<2.90	3.05	2.98	3.01	2.92	<2.90	2.90	<2.90	<2.90	<2.90
3.21	3.15	2.92	3.06	<2.90	<2.90	<2.90	3.12	<2.90	<2.90	<2.90
4.06	3.32	3.19	3.16	3.13	3.16	3.13	3.12	<2.90	<2.90	<2.90
3.58	3.26	3.09	3.10	2.96	2.95	3.01	2.92	<2.90	<2.90	<2.90
3.11	3.14	3.51	3.05	3.02	3.10	3.08	3.14	2.92	<2.90	<2.90
3.40	2.96	<2.90	3.02	3.01	3.05	<2.90	2.92	2.93	<2.90	<2.90
3.86	3.06	<2.90	2.99	2.97	2.90	<2.90	<2.90	2.93	<2.90	<2.90
3.21	3.12	3.05	3.15	3.07	3.19	3.03	3.05	3.22	<2.90	<2.90
3.55	3.12	2.99	3.02	3.05	2.99	2.94	3.03	2.99	<2.90	<2.90
3.21	3.05	3.00	3.03	3.01	2.92	<2.90	2.92	<2.90	<2.90	<2.90
3.58	3.26	3.19	3.10	3.02	3.10	3.08	3.12	<2.90	<2.90	<2.90
3.48	3.09	3.00	3.02	3.01	3.02	2.91	2.97	2.93	<2.90	<2.90

pF at 6 in. (Irrigated plots) - Continued

Oct.					Nov.			Dec.			Jan. 1956	
5	14	18	21	25	1	15	25	6	13	20	3	10
3.17	3.14	3.22	3.68	3.83	3.67	3.72	4.03	3.82	4.17	>4.20	>4.20	>4.20
2.95	3.07	3.11	3.47	3.78	3.79	3.79	3.97	3.88	4.12	>4.20	>4.20	>4.20
3.11	3.16	3.30	3.62	3.78	3.42	3.22	3.83	3.26	3.81	4.11	>4.20	>4.20
3.14	3.07	3.16	3.55	3.77	3.68	3.52	3.97	3.72	4.10	>4.20	>4.20	>4.20
<2.90	3.20	3.55	3.86	4.00	3.72	3.59	>4.20	3.46	4.19	>4.20	>4.20	>4.20
3.14	3.07	3.18	3.53	3.85	3.89	3.83	4.09	3.89	4.16	>4.20	>4.20	>4.20
3.13	3.16	3.22	3.49	3.79	3.86	3.72	4.13	3.83	>4.20	>4.20	>4.20	>4.20
3.27	3.23	3.33	3.70	3.98	3.96	3.38	4.10	3.28	>4.20	>4.20	>4.20	>4.20
3.38	3.51	3.75	3.91	3.35	3.96	3.73	4.09	3.54	4.15	4.19	>4.20	>4.20
3.09	3.19	3.64	3.86	4.03	3.95	3.90	4.18	3.69	4.18	>4.20	>4.20	>4.20
3.02	3.09	3.40	3.87	4.02	3.93	3.76	>4.20	3.52	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	4.09	3.92	4.18	>4.20	>4.20	>4.20
3.12	3.30	3.60	3.89	4.01	3.93	3.83	4.13	3.64	>4.20	>4.20	>4.20	>4.20
3.02	3.48	3.73	3.93	>4.20	3.98	3.71	4.03	3.74	4.16	>4.20	>4.20	>4.20
>2.90	3.21	3.30	3.64	3.93	3.94	3.54	3.99	3.76	4.15	>4.20	>4.20	>4.20
3.07	3.47	3.74	3.95	4.08	3.85	3.96	>4.20	3.51	>4.20	>4.20	>4.20	>4.20
3.02	3.16	3.35	3.77	4.02	3.98	3.82	4.19	3.98	>4.20	>4.20	>4.20	>4.20
<2.90	3.25	3.51	3.72	3.85	3.64	3.24	3.98	3.50	4.10	4.13	>4.20	>4.20
3.11	3.14	3.22	3.62	3.78	3.67	3.72	3.97	3.82	4.12	>4.20	>4.20	>4.20
3.14	3.07	3.18	3.55	3.85	3.72	3.59	4.09	3.72	4.16	>4.20	>4.20	>4.20
3.27	3.23	3.33	3.70	3.96	3.96	3.72	4.10	3.54	>4.20	>4.20	>4.20	>4.20
3.09	3.19	3.64	3.86	4.03	3.95	3.90	4.18	3.69	4.18	>4.20	>4.20	>4.20
3.02	3.30	3.60	3.89	4.01	3.94	3.71	4.03	3.74	4.16	>4.20	>4.20	>4.20
3.02	3.25	3.51	3.77	4.02	3,85	3.82	4.19	3.51	>4.20	>4.20	>4.20	>4.20
3.10	3.21	3.42	3.74	3.98	3.89	3.72	4.09	3.70	4.17	>4.20	>4.20	>4.20

Values of pF at depth of 12 in.
(Irrigated Plots)

Plot	Replicate	Nov. 1954		Dec.				Jan. 1955			
		22	26	7	14	21	28	4	11	18	25
A	a	3.93	3.40	4.08	4.10	>4.20	>4.20	3.29	<2.90	<2.90	3.21
	b	3.81	3.55	3.88	2.97	3.79	4.02	3.34	<2.90	2.99	3.15
	c	3.63	3.49	3.69	3.55	3.88	3.88	3.09	<2.90	<2.90	3.47
B	a	3.96	3.85	4.05	4.07	>4.20	<2.90	>4.20	2.97	<2.90	3.00
	b	3.01	3.19	3.90	3.90	4.16	<2.90	>4.20	<2.90	<2.90	3.02
	c	3.03	3.79	4.04	3.50	4.10	2.97	3.20	2.97	3.10	2.92
D	a	3.17	3.23	3.91	3.99	4.13	3.90	3.04	2.97	2.99	3.03
	b	3.49	3.41	3.86	3.80	3.66	3.15	3.47	4.06	3.93	2.92
	c	3.90	3.81	>4.20	3.26	>4.20	>4.20	3.11	3.10	3.05	2.99
G	a	3.53	3.77	4.15	4.08	>4.20	>4.20	3.76	2.97	3.00	2.99
	b	3.41	3.68	4.10	4.08	4.19	3.49	2.90	<2.90	<2.90	2.99
	c	3.30	3.52	3.97	4.00	4.16	3.76	3.03	<2.90	2.92	2.99
H	a	3.27	3.32	4.08	4.08	>4.20	2.97	3.73	2.90	<2.90	3.61
	b	3.48	3.55	4.04	4.01	>4.20	<2.90	3.80	<2.90	2.97	3.71
	c	3.65	3.70	4.03	4.05	>4.20	3.03	3.05	<2.90	2.97	3.73
J	a	3.22	3.29	4.02	3.99	>4.20	<2.90	4.02	3.09	3.00	3.06
	b	3.39	3.33	3.93	3.94	4.18	<2.90	>4.20	3.29	<2.90	3.18
	c	3.65	3.59	4.00	3.86	4.18	2.97	>4.20	3.75	3.92	>4.20

Representative Plot Values (median of 3 replicates)

A	3.81	3.49	3.88	3.55	3.88	4.02	3.29	<2.90	<2.90	3.21
B	3.03	3.79	4.04	3.90	4.16	<2.90	>4.20	2.97	<2.90	3.02
D	3.49	3.41	3.91	3.80	4.13	3.90	3.11	3.10	3.05	2.99
G	3.41	3.68	4.10	4.08	4.19	3.76	3.03	<2.90	2.92	2.99
H	3.48	3.55	4.04	4.01	>4.20	2.97	3.73	<2.90	2.97	3.71
J	3.39	3.33	4.00	3.94	4.18	<2.90	>4.20	3.29	3.00	3.18

Representative Treatment Values (median of 6 Plot medians)

3.45	3.52	4.02	3.92	4.17	3.37	3.51	2.93	2.94	3.10

pF at 12 in. (Irrigated plots) - Continued

Feb.				Mar.					Apr.			
1	8	15	22	1	8	15	22	30	5	12	19	26
3.28	3.43	3.29	3.74	<2.90	<2.90	<2.90	2.97	<2.90	<2.90	<2.90	<2.90	3.01
3.61	3.15	3.05	3.75	2.90	3.03	3.39	3.22	2.96	<2.90	3.27	3.28	3.37
3.41	<2.90	3.00	3.39	<2.90	3.20	3.25	<2.90	2.96	<2.90	3.34	3.44	3.56
3.01	3.59	3.29	3.96	<2.90	<2.90	3.05	3.04	2.90	3.02	3.03	2.95	<2.90
3.07	3.22	3.16	3.82	3.09	<2.90	<2.90	3.38	3.77	3.91	4.08	4.05	4.06
3.09	<2.90	3.03	3.90	<2.90	3.72	3.90	3.90	3.03	2.99	3.71	3.75	3.82
3.03	4.11	4.09	>4.20	3.11	3.08	2.93	3.88	3.08	<2.90	<2.90	<2.90	3.06
<2.90	3.90	3.66	3.35	2.99	2.92	3.85	3.99	2.92	2.80	3.42	2.73	2.98
3.12	3.68	3.33	3.43	3.03	3.03	3.84	3.80	3.03	2.92	3.08	3.07	3.11
3.41	3.06	3.16	3.88	<2.90	<2.90	2.96	3.01	<2.90	<2.90	3.18	3.66	3.66
3.48	3.05	3.00	3.05	<2.90	2.90	3.00	3.07	3.03	<2.90	3.11	3.34	3.42
3.45	3.10	3.03	3.77	<2.90	<2.90	2.93	<2.90	3.03	<2.90	3.58	3.46	3.51
<2.90	3.33	3.19	3.65	<2.90	<2.90	<2.90	<2.90	2.90	<2.90	3.03	<2.90	2.97
<2.90	3.15	3.19	3.68	<2.90	2.97	<2.90	<2.90	2.97	<2.90	<2.90	<2.90	3.01
3.03	3.60	3.21	3.77	<2.90	3.03	3.37	3.50	<2.90	2.92	2.97	2.97	3.03
3.89	2.99	3.05	4.03	3.09	3.03	3.03	2.98	3.08	3.02	3.33	3.47	3.68
3.90	2.99	<2.90	3.55	3.01	2.97	3.43	3.64	3.03	<2.90	3.03	3.08	2.96
3.70	3.65	>4.20	3.77	3.09	2.97	3.73	3.77	3.72	3.66	3.66	<2.90	<2.90
3.41	3.15	3.05	3.74	<2.90	3.03	3.25	2.97	2.96	<2.90	3.27	3.28	3.37
3.07	3.22	3.16	3.90	<2.90	<2.90	3.05	3.38	3.03	3.02	3.71	3.75	3.82
3.03	3.90	3.66	3.43	3.03	3.03	3.84	3.88	3.03	<2.90	3.08	<2.90	3.06
3.45	3.06	3.03	3.77	<2.90	<2.90	2.96	3.01	3.03	<2.90	3.18	3.46	3.51
<2.90	3.33	3.19	3.68	<2.90	2.97	<2.90	<2.90	<2.90	<2.90	2.97	<2.90	3.01
3.89	2.99	3.05	3.77	3.09	2.97	3.43	3.64	3.08	3.02	3.33	3.08	2.96
3.24	3.18	3.11	3.75	<2.90	2.97	3.15	3.19	3.03	<2.90	3.22	3.18	3.21

pF at 12 in. (Irrigated plots) - Continued

May					June			July	Aug.	Sept.
3	10	18	24	31	9	14	28	12	9	8
2.97	3.13	>4.20	2.99	2.94	3.12	3.01	<2.90	<2.90	<2.90	<2.90
3.54	<2.90	2.94	<2.90	<2.90	3.02	3.01	<2.90	<2.90	<2.90	<2.90
3.65	3.54	3.11	3.02	3.16	2.99	3.01	3.07	<2.90	<2.90	<2.90
3.06	3.00	2.96	2.92	3.21	3.05	3.01	3.07	<2.90	<2.90	<2.90
4.00	3.90	<2.90	2.92	3.22	3.02	<2.90	<2.90	<2.90	<2.90	<2.90
3.89	3.81	<2.90	<2.90	3.00	3.02	3.01	<2.90	<2.90	<2.90	<2.90
3.08	>4.20	<2.90	3.05	2.94	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90
3.17	3.25	2.46	2.95	2.87	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90
3.07	3.20	3.84	3.07	>4.20	3.09	3.11	<2.90	<2.90	<2.90	<2.90
3.70	3.65	<2.90	<2.90	2.94	<2.90	<2.90	3.03	<2.90	<2.90	<2.90
3.44	<2.90	3.02	2.95	3.08	2.99	2.99	3.10	2.98	<2.90	<2.90
3.64	3.33	2.93	2.92	<2.90	2.99	<2.90	<2.90	2.92	<2.90	<2.90
2.94	2.94	2.99	2.92	3.01	3.02	<2.90	2.96	<2.90	<2.90	<2.90
3.11	<2.90	<2.90	<2.90	2.96	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90
3.01	3.09	<2.90	2.92	<2.90	2.99	3.03	3.10	<2.90	<2.90	<2.90
3.80	3.54	3.09	3.06	3.13	3.02	3.03	2.99	<2.90	<2.90	<2.90
3.00	2.94	2.92	2.99	2.97	2.99	3.01	2.99	<2.90	<2.90	<2.90
<2.90	2.96	<2.90	2.92	<2.90	<2.90	<2.90	2.93	<2.90	<2.90	<2.90
3.54	3.13	2.94	2.99	2.94	3.02	3.01	<2.90	<2.90	<2.90	<2.90
3.89	3.81	<2.90	2.92	3.21	3.02	3.01	<2.90	<2.90	<2.90	<2.90
3.08	3.25	<2.90	3.05	2.94	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90
3.64	3.33	2.93	2.92	2.94	2.99	<2.90	3.03	2.92	<2.90	<2.90
3.01	2.94	<2.90	2.92	2.96	2.99	<2.90	2.96	<2.90	<2.90	<2.90
3.00	2.96	2.92	2.99	2.97	2.99	3.01	2.99	<2.90	<2.90	<2.90
3.31	3.19	2.91	2.96	2.95	2.99	2.98	2.92	<2.90	<2.90	<2.90

pF at 12 in. (Irrigated plots) - Continued

Oct.					Nov.			Dec.			Jan. 1956	
5	14	18	21	25	1	15	25	6	13	20	3	10
3.04	3.17	3.40	3.75	3.93	4.00	3.96	4.18	4.09	4.15	>4.20	>4.20	>4.20
<2.90	3.04	3.26	3.58	3.80	3.84	3.82	3.98	3.95	4.12	>4.20	>4.20	>4.20
3.01	3.14	3.46	3.74	3.91	4.01	3.95	4.09	4.02	4.15	>4.20	>4.20	>4.20
3.01	3.22	3.39	3.77	4.02	4.02	4.02	4.13	4.11	>4.20	>4.20	>4.20	>4.20
<2.90	2.94	3.06	3.29	3.81	3.96	4.01	>4.20	4.07	>4.20	>4.20	>4.20	>4.20
3.07	3.25	3.40	3.63	3.99	4.03	3.84	4.10	4.09	>4.20	>4.20	>4.20	>4.20
<2.90	3.11	3.01	3.15	3.36	3.95	4.10	>4.20	4.15	>4.20	>4.20	>4.20	>4.20
3.18	3.54	3.69	3.69	3.75	3.82	3.51	4.00	3.98	4.12	4.18	>4.20	>4.20
3.16	3.23	2.92	3.86	4.04	4.03	>4.20	4.12	4.10	>4.20	>4.20	>4.20	>4.20
3.09	3.27	3.52	3.53	3.58	3.74	3.93	4.15	4.08	>4.20	>4.20	>4.20	>4.20
2.94	3.08	3.18	3.34	3.64	3.96	4.04	4.13	4.02	4.18	>4.20	>4.20	>4.20
3.01	3.17	3.40	3.77	4.00	4.03	4.09	4.18	4.09	>4.20	>4.20	>4.20	>4.20
3.04	3.44	3.69	3.93	4.07	4.09	4.06	4.15	3.97	>4.20	>4.20	>4.20	>4.20
3.01	3.60	3.77	3.92	4.06	4.00	3.88	4.12	4.00	4.18	>4.20	>4.20	>4.20
3.01	3.36	3.67	4.00	3.77	3.85	3.93	>4.20	4.10	>4.20	>4.20	>4.20	>4.20
3.09	3.14	3.19	3.58	3.83	4.04	3.70	4.02	4.02	>4.20	>4.20	>4.20	>4.20
3.01	3.07	3.25	3.75	4.06	4.00	4.06	>4.20	4.12	>4.20	>4.20	>4.20	>4.20
2.94	3.24	3.49	3.89	4.13	4.11	4.13	>4.20	4.10	>4.20	>4.20	>4.20	>4.20

3.01	3.04	3.40	3.74	3.91	4.00	3.95	4.09	4.02	4.15	>4.20	>4.20	>4.20
3.01	3.22	3.39	3.63	3.99	4.02	4.01	4.10	4.09	>4.20	>4.20	>4.20	>4.20
3.16	3.23	3.01	3.69	3.75	3.95	4.10	4.12	4.10	>4.20	>4.20	>4.20	>4.20
3.01	3.17	3.40	3.53	3.64	3.96	4.04	4.13	4.08	>4.20	>4.20	>4.20	>4.20
3.01	3.44	3.69	3.93	4.06	4.00	3.93	4.15	4.00	>4.20	>4.20	>4.20	>4.20
3.01	3.14	3.25	3.75	4.06	4.04	4.06	>4.20	4.10	>4.20	>4.20	>4.20	>4.20
3.01	3.19	3.39	3.71	3.95	4.00	4.02	4.12	4.09	>4.20	>4.20	>4.20	>4.20

Values of pF at depth of 24 in.
(Irrigated plots)

Plot	Replicate	Nov. 1954		Dec.				Jan. 1955			
		22	26	7	14	21	28	4	11	18	25
A	a	3.76	3.70	3.99	4.01	4.13	>4.20	2.99	<2.90	<2.90	2.92
	b	2.99	<2.90	3.35	3.96	4.11	>4.20	4.20	4.12	2.99	2.99
	c	<2.90	<2.90	2.99	3.03	3.33	3.76	3.09	3.30	2.90	3.28
B	a	<2.90	2.97	<2.90	<2.90	2.99	3.32	3.15	2.97	<2.90	2.92
	b	3.12	3.52	4.69	4.06	5.45	<2.90	3.84	4.05	4.05	2.97
	c	3.92	2.97	2.59	3.89	4.08	3.05	4.07	2.97	3.10	<2.90
D	a	<2.90	2.97	2.97	3.31	4.07	>4.20	>4.20	>4.20	>4.20	4.16
	b	3.04	<2.90	3.91	3.90	4.18	4.15	4.15	4.19	4.10	3.10
	c	3.33	3.46	4.09	4.07	4.17	4.04	4.06	3.94	4.03	3.08
G	a	2.99	3.18	3.17	3.93	3.73	3.92	3.61	2.97	2.99	<2.90
	b	2.99	<2.90	3.05	3.21	3.75	3.89	>4.20	>4.20	<2.90	<2.90
	c	2.99	3.19	3.62	3.66	3.87	3.77	<2.90	<2.90	2.99	2.99
H	a	2.99	2.97	<2.90	<2.90	<2.90	3.35	3.79	3.36	3.42	3.94
	b	<2.90	<2.90	<2.90	<2.90	2.99	<2.90	2.99	<2.90	2.99	3.05
	c	<2.90	<2.90	3.05	3.81	4.00	3.92	3.87	<2.90	3.21	3.92
J	a	3.03	3.03	3.73	3.93	>4.20	<2.90	>4.20	3.24	2.99	3.10
	b	2.99	3.11	3.37	3.89	4.10	<2.90	>4.20	4.09	3.99	4.08
	c	3.03	<2.90	3.89	4.02	3.93	2.97	3.40	3.16	3.02	3.45

Representative Plot Values (median of 3 replicates)

2.99	<2.90	3.35	3.96	4.11	>4.20	3.09	3.30	2.90	2.99
3.12	2.97	<2.90	3.89	4.08	3.05	3.84	2.97	3.10	2.92
3.04	2.97	3.91	3.90	4.17	4.15	4.15	4.19	4.10	3.10
2.99	3.18	3.17	3.66	3.75	3.89	3.61	2.97	2.99	<2.90
<2.90	<2.90	<2.90	<2.90	2.99	3.35	3.79	<2.90	3.21	3.92
3.03	3.03	3.73	3.93	4.10	<2.90	>4.20	3.24	3.02	3.45

Representative Treatment Values (median of 6 Plot medians)

3.01	2.97	3.26	3.89	4.09	3.20	3.81	3.11	3.06	3.05

pF at 24 in. (Irrigated plots) - Continued

Feb.				Mar.					Apr.			
1	8	15	22	1	8	15	22	30	5	12	19	26
3.33	<2.90	3.21	3.73	<2.90	3.03	2.99	3.03	3.03	<2.90	<2.90	<2.90	<2.90
3.20	3.05	3.25	3.70	2.92	3.03	2.97	3.14	<2.90	2.96	<2.90	2.96	<2.90
3.72	3.83	3.82	3.91	3.86	3.17	2.99	3.52	2.46	<2.90	3.23	3.30	3.33
3.05	3.71	3.80	3.97	3.93	<2.90	3.11	3.14	3.28	3.70	3.79	3.70	3.65
3.31	3.87	3.93	4.03	4.00	4.00	4.00	4.06	4.00	4.00	3.96	3.96	3.97
2.99	3.03	<2.90	3.12	3.10	3.18	3.44	3.91	3.99	4.04	4.10	4.09	4.06
4.15	>4.20	>4.20	>4.20	>4.20	3.74	3.79	4.07	4.11	4.08	4.10	4.04	4.03
3.42	4.03	4.08	4.02	3.99	3.96	4.10	4.15	3.63	3.67	3.11	3.02	3.08
3.73	4.01	3.97	3.99	3.02	3.15	3.88	4.02	3.08	3.99	3.91	3.60	3.72
3.20	3.05	3.26	3.71	<2.90	<2.90	<2.90	3.05	3.27	<2.90	2.92	3.02	3.12
<2.90	3.05	3.00	3.07	<2.90	<2.90	2.97	3.01	<2.90	<2.90	3.05	3.30	3.13
3.09	3.66	3.73	3.80	<2.90	<2.90	<2.90	<2.90	2.96	<2.90	2.97	2.99	3.15
3.93	3.99	3.94	4.10	<2.90	<2.90	3.13	3.19	<2.90	<2.90	2.92	<2.90	3.02
2.99	3.15	3.60	3.85	3.31	<2.90	2.96	<2.90	<2.90	<2.90	<2.90	2.96	3.03
3.93	3.98	3.93	4.04	2.99	2.97	3.00	3.23	3.57	3.26	3.08	3.10	3.11
3.81	4.08	4.07	>4.20	4.10	3.87	3.78	2.97	3.34	3.78	4.07	4.10	4.12
4.09	4.10	4.07	4.13	4.08	4.08	4.08	4.02	4.02	4.02	3.99	3.97	3.98
2.92	3.05	<2.90	<2.90	2.99	2.99	3.03	3.74	3.01	3.03	2.92	2.99	<2.90
3.33	3.05	3.25	3.73	2.92	3.03	2.99	3.14	<2.90	<2.90	<2.90	2.96	<2.90
3.05	3.71	3.80	3.97	3.93	3.18	3.44	3.91	3.99	4.00	3.96	3.96	3.97
3.73	4.03	4.08	4.02	3.99	3.74	3.88	4.07	3.63	3.99	3.91	3.60	3.72
3.09	3.05	3.26	3.71	<2.90	<2.90	<2.90	3.01	2.97	<2.90	2.97	3.02	3.13
3.93	3.98	3.93	4.04	2.99	<2.90	3.00	3.19	<2.90	<2.90	2.92	2.96	3.03
3.81	4.08	4.07	4.13	4.08	3.87	3.78	3.74	3.34	3.78	3.99	3.97	3.98
3.53	3.84	3.86	4.00	3.46	3.11	3.22	3.46	3.15	3.33	3.38	3.31	3.42

pF at 24 in. (Irrigated plots) - Continued

May					June			July	Aug.	Sept.
3	10	18	24	31	9	14	28	12	9	8
3.05	3.13	<2.90	2.92	3.13	3.10	3.01	<2.90	<2.90	<2.90	<2.90
<2.90	<2.90	<2.90	<2.90	3.16	3.00	3.01	<2.90	2.99	<2.90	<2.90
3.36	3.35	2.45	<2.90	<2.90	2.92	2.93	<2.90	<2.90	<2.90	<2.90
3.65	3.66	3.67	3.64	3.21	3.00	2.94	3.05	<2.90	<2.90	<2.90
4.02	4.01	3.97	3.99	<2.90	2.92	<2.90	<2.90	<2.90	<2.90	<2.90
3.89	4.11	4.07	4.16	3.99	3.00	2.94	<2.90	3.05	<2.90	<2.90
4.04	3.97	4.00	3.95	3.15	3.01	<2.90	<2.90	2.99	<2.90	<2.90
3.19	3.09	2.97	3.05	2.94	3.08	<2.90	<2.90	<2.90	<2.90	<2.90
3.79	3.83	3.87	3.82	2.95	3.03	3.06	<2.90	<2.90	<2.90	<2.90
3.27	3.39	3.45	3.37	<2.90	<2.90	2.94	3.00	<2.90	<2.90	<2.90
3.72	3.74	2.94	2.97	3.05	2.99	2.94	<2.90	2.96	<2.90	<2.90
3.25	3.37	3.38	3.44	<2.90	2.93	<2.90	3.00	2.96	<2.90	<2.90
<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90
3.12	2.97	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90
3.24	3.29	<2.90	2.94	<2.90	2.99	<2.90	2.96	<2.90	<2.90	<2.90
4.15	4.09	4.10	4.06	3.97	3.00	3.01	3.00	<2.90	<2.90	<2.90
4.01	3.99	>4.20	3.99	3.34	<2.90	<2.90	2.94	2.92	<2.90	<2.90
<2.90	2.97	2.94	2.97	3.11	2.94	2.99	<2.90	<2.90	<2.90	<2.90
3.05	3.13	<2.90	<2.90	3.13	3.00	3.01	<2.90	<2.90	<2.90	<2.90
3.89	4.01	3.97	3.99	3.21	3.00	2.94	<2.90	<2.90	<2.90	<2.90
3.79	3.83	3.87	3.82	2.95	3.03	<2.90	<2.90	<2.90	<2.90	<2.90
3.27	3.39	3.38	3.37	<2.90	2.93	2.94	3.00	2.96	<2.90	<2.90
3.12	2.97	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90
4.01	3.99	4.10	3.99	3.34	2.94	2.99	2.94	<2.90	<2.90	<2.90
3.53	3.61	3.62	3.59	3.04	2.97	2.94	<2.90	<2.90	<2.90	<2.90

pF at 24 in. (Irrigated plots) - Continued

Oct.					Nov.			Dec.			Jan. 1956	
5	14	18	21	25	1	15	25	6	13	20	3	10
3.01	3.07	3.12	3.13	3.29	3.91	3.90	3.99	3.98	4.09	4.18	>4.20	>4.20
<2.90	3.07	3.07	3.07	3.11	3.35	3.89	3.96	4.00	4.13	>4.20	>4.20	>4.20
2.95	3.08	3.21	3.41	3.66	4.25	3.75	3.78	3.82	4.00	4.09	>4.20	>4.20
2.97	3.01	3.07	2.98	3.05	3.18	3.72	3.93	3.97	4.05	>4.20	>4.20	>4.20
<2.90	2.95	3.05	3.10	3.36	3.80	3.92	4.02	4.02	4.18	>4.20	>4.20	>4.20
<2.90	2.97	3.07	3.19	3.18	3.59	3.95	4.04	4.10	>4.20	>4.20	>4.20	>4.20
<2.90	2.94	<2.90	3.07	3.07	3.36	3.87	4.03	4.11	4.20	>4.20	>4.20	>4.20
3.11	3.14	3.19	3.29	3.34	3.77	3.97	4.13	4.06	>4.20	>4.20	>4.20	>4.20
3.06	3.11	3.17	3.30	3.87	4.02	4.03	4.19	4.13	>4.20	>4.20	>4.20	>4.20
3.07	3.27	3.46	3.68	3.93	3.97	4.04	4.10	4.09	>4.20	>4.20	>4.20	>4.20
3.03	3.18	3.28	3.42	3.61	4.02	4.13	4.18	4.12	>4.20	>4.20	>4.20	>4.20
3.00	3.09	3.12	3.30	3.64	3.79	3.88	3.95	3.96	4.05	>4.20	4.19	>4.20
3.03	2.95	3.05	3.17	3.67	3.83	3.90	4.01	3.99	4.07	>4.20	>4.20	>4.20
2.97	3.08	3.11	3.21	3.70	3.85	3.88	3.97	3.95	4.09	>4.20	>4.20	>4.20
<2.90	3.05	3.02	3.02	3.04	3.07	3.26	3.68	3.82	3.99	>4.20	>4.20	>4.20
3.06	3.53	3.69	3.87	4.08	4.11	4.13	>4.20	4.14	>4.20	>4.20	>4.20	>4.20
<2.90	3.11	3.24	3.50	3.89	3.96	4.04	4.18	4.10	>4.20	4.16	>4.20	>4.20
<2.90	3.27	3.38	3.64	3.82	3.87	3.91	4.03	4.05	>4.20	>4.20	>4.20	>4.20
2.95	3.07	3.12	3.13	3.29	3.91	3.89	3.96	3.98	4.09	4.18	>4.20	>4.20
<2.90	2.97	3.07	3.10	3.18	3.59	3.92	4.02	4.02	4.18	>4.20	>4.20	>4.20
3.06	3.11	3.17	3.29	3.34	3.77	3.97	4.13	4.11	>4.20	>4.20	>4.20	>4.20
3.03	3.18	3.28	3.42	3.64	3.97	4.04	4.10	4.09	>4.20	>4.20	>4.20	>4.20
2.97	3.05	3.05	3.17	3.67	3.83	3.88	3.97	3.95	4.07	>4.20	>4.20	>4.20
<2.90	3.27	3.38	3.64	3.89	3.96	4.04	4.18	4.10	>4.20	>4.20	>4.20	>4.20
2.96	3.09	3.15	3.23	3.49	3.87	3.95	4.06	4.06	4.19	>4.20	>4.20	>4.20

Values of pF at depth of 36 in.

(Irrigated Plots)

Plot	Replicate	Nov. 1954		Dec.				Jan. 1955			
		22	26	7	14	21	28	4	11	18	25
A	a	2.96	<2.90	<2.90	<2.90	<2.90	<2.90	3.25	3.91	3.93	4.01
	b	<2.90	<2.90	<2.90	<2.90	<2.90	3.61	3.96	4.04	4.04	4.04
	c	2.96	3.01	<2.90	<2.90	<2.90	3.03	3.14	>4.20	4.03	3.68
B	a	<2.90	2.97	<2.90	3.10	3.71	2.97	>4.20	>4.20	>4.20	>4.20
	b	2.99	3.17	<2.90	2.97	3.70	<2.90	>4.20	>4.20	>4.20	3.04
	c	<2.90	2.97	2.97	3.16	3.92	<2.90	3.99	4.00	4.01	4.00
D	a	2.99	2.97	>2.90	3.05	3.41	3.87	3.92	3.98	3.97	4.01
	b	<2.90	2.92	3.13	<2.90	<2.90	<2.90	3.05	3.98	3.89	3.86
	c	<2.90	<2.90	<2.90	2.92	2.99	2.97	3.26	3.68	3.65	3.74
G	a	<2.90	3.02	2.97	3.10	3.26	4.08	4.17	4.04	2.97	2.97
	b	2.92	<2.90	2.97	3.64	3.60	3.61	3.10	>4.20	<2.90	<2.90
	c	2.92	2.97	<2.90	<2.90	3.93	3.26	4.13	4.12	2.97	2.97
H	a	2.99	2.97	<2.90	<2.90	3.05	3.17	3.25	<2.90	2.97	3.09
	b	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	2.97	<2.90
	c	<2.90	<2.90	<2.90	<2.90	3.05	<2.90	<2.90	<2.90	<2.90	<2.90
J	a	<2.90	2.92	2.97	<2.90	3.05	3.41	3.24	3.73	3.76	3.88
	b	<2.90	<2.90	<2.90	3.10	2.25	3.61	<2.90	<2.90	<2.90	2.97
	c	<2.90	<2.90	<2.90	2.99	2.25	3.61	3.24	3.57	3.66	3.73

Representative Plot Values (median of 3 replicates)

A	2.96	<2.90	<2.90	<2.90	<2.90	3.03	3.25	4.04	4.03	4.01
B	<2.90	2.97	<2.90	3.10	3.71	<2.90	<2.90	<2.90	<2.90	4.00
D	<2.90	2.92	<2.90	2.92	2.99	2.97	3.26	3.98	3.89	3.86
G	2.92	2.97	2.97	3.10	3.60	3.61	4.13	4.12	2.97	2.97
H	<2.90	<2.90	<2.90	<2.90	3.05	<2.90	<2.90	<2.90	2.97	<2.90
J	<2.90	<2.90	<2.90	2.99	<2.90	3.61	3.24	3.57	3.66	3.73

Representative Treatment Values (median of 6 Plot medians)

<2.90	<2.90	<2.90	2.96	3.02	3.00	3.25	3.77	3.77	3.79

pF at 36 in. (Irrigated plots) - Continued

Feb.				Mar.					Apr.			
1	8	15	22	1	8	15	22	30	5	12	19	26
4.04	4.10	4.04	4.17	4.12	4.08	4.05	4.06	3.88	3.92	3.92	3.95	3.91
4.04	4.03	4.03	4.06	3.88	4.01	4.02	4.03	4.00	3.99	4.01	3.98	4.02
3.76	3.79	3.81	3.84	3.84	3.82	3.80	3.82	3.84	3.83	3.85	3.84	3.85
4.17	4.17	4.15	4.19	4.19	4.11	3.98	3.96	3.96	3.99	4.04	4.03	4.03
3.09	3.80	3.92	4.02	3.99	<2.90	<2.90	3.06	3.21	3.88	4.08	4.05	4.03
3.97	3.99	3.99	4.00	4.00	3.98	4.02	4.01	4.00	3.97	4.00	3.97	3.96
3.98	4.09	3.68	>4.20	>4.20	4.15	4.10	4.15	4.13	4.06	4.04	4.04	3.97
3.84	3.95	3.93	3.91	3.91	3.92	3.97	3.97	4.00	3.97	3.99	3.94	3.93
3.77	3.93	3.93	3.91	3.88	3.91	3.96	3.98	4.01	4.00	3.98	3.94	4.01
3.26	3.28	3.45	3.89	3.93	3.38	3.11	3.14	3.21	3.25	3.24	3.26	3.30
3.03	3.04	3.15	3.14	2.97	<2.90	2.97	2.97	3.08	<2.90	3.10	3.17	3.12
2.90	3.25	3.55	3.76	<2.90	<2.90	2.92	<2.90	2.96	<2.90	3.08	3.05	3.22
3.27	3.48	3.58	3.73	3.30	<2.90	3.14	2.92	<2.90	<2.90	2.92	2.97	3.08
<2.90	2.98	2.99	3.23	3.32	3.44	3.50	3.51	3.51	3.51	3.50	3.53	3.05
<2.90	<2.90	<2.90	3.03	3.12	3.37	3.64	3.81	3.77	<2.90	2.92	<2.90	3.08
4.00	4.00	3.93	4.12	4.06	<2.90	3.21	3.56	3.70	3.77	3.87	3.90	3.89
3.07	3.14	3.10	3.11	3.05	2.97	3.08	3.13	3.50	<2.90	3.00	<2.90	<2.90
3.82	3.86	3.89	2.97	2.97	2.99	3.08	3.78	3.85	3.87	3.92	3.91	3.88
4.04	4.03	4.03	4.06	3.88	4.01	4.02	4.03	3.88	3.92	3.92	3.95	3.91
3.97	3.99	3.99	4.02	4.00	3.98	3.98	3.96	3.96	3.97	4.04	4.03	4.03
3.84	3.95	3.93	3.91	3.91	3.92	3.97	3.98	4.01	4.00	3.99	3.94	3.97
3.03	3.25	3.45	3.76	2.97	<2.90	2.97	2.97	3.08	<2.90	3.10	3.17	3.22
<2.90	2.98	2.99	3.23	3.30	3.37	3.50	3.51	3.51	<2.90	2.92	2.97	3.08
3.82	3.86	3.89	3.11	3.05	2.97	3.08	3.56	3.70	3.77	3.87	3.90	3.88
3.83	3.92	3.91	3.83	3.59	3.65	3.73	3.77	3.79	3.84	3.90	3.92	3.89

pF at 36 in. (Irrigated plots) - Continued

May					June			July	Aug.	Sept.
3	10	18	24	31	9	14	28	12	9	8
3.91	3.89	3.91	3.89	3.88	3.86	3.84	<2.90	<2.90	<2.90	<2.90
4.02	3.98	4.03	3.99	3.68	3.00	2.97	<2.90	3.00	<2.90	<2.90
3.86	3.86	3.84	3.84	3.85	<2.90	3.06	2.99	3.01	<2.90	<2.90
4.04	4.03	4.03	3.98	3.85	3.06	3.03	3.01	<2.90	<2.90	<2.90
4.11	4.09	4.03	4.03	3.23	3.03	2.97	3.01	<2.90	<2.90	<2.90
4.03	3.98	3.97	3.96	3.92	3.97	3.93	3.83	3.46	<2.90	<2.90
3.98	3.96	3.98	3.93	<2.90	3.01	2.94	2.94	<2.90	<2.90	<2.90
3.94	3.87	3.95	3.96	3.94	3.22	3.13	<2.90	3.02	<2.90	<2.90
3.97	3.97	3.93	3.92	3.91	3.23	3.16	<2.90	<2.90	<2.90	<2.90
3.35	3.41	3.47	3.52	3.13	<2.90	2.94	3.01	<2.90	<2.90	<2.90
3.21	3.29	3.32	3.35	2.94	2.96	<2.90	<2.90	<2.90	<2.90	<2.90
3.30	3.43	3.11	3.56	3.01	2.94	<2.90	<2.90	2.94	<2.90	<2.90
3.13	3.16	2.97	<2.90	<2.90	2.92	<2.90	<2.90	<2.90	<2.90	<2.90
3.53	3.54	3.52	3.57	3.14	2.92	<2.90	<2.90	<2.90	<2.90	<2.90
<2.90	3.16	2.94	2.94	<2.90	<2.90	<2.90	<2.90	2.94	<2.90	<2.90
3.93	3.93	3.92	3.91	3.83	<2.90	<2.90	<2.90	2.94	<2.90	<2.90
2.96	3.02	2.94	2.99	<2.90	2.94	<2.90	2.94	2.94	<2.90	<2.90
3.90	3.92	3.88	3.90	3.87	3.78	3.59	<2.90	<2.90	<2.90	<2.90

3.91	3.89	3.91	3.89	3.85	3.00	3.06	<2.90	3.00	<2.90	<2.90
4.04	4.03	4.03	3.98	3.85	3.06	3.03	3.01	<2.90	<2.90	<2.90
3.97	3.96	3.95	3.93	3.91	3.22	3.13	<2.90	<2.90	<2.90	<2.90
3.30	3.41	3.32	3.52	3.01	2.94	<2.90	<2.90	<2.90	<2.90	<2.90
3.13	3.16	2.97	2.94	<2.90	2.92	<2.90	<2.90	<2.90	<2.90	<2.90
3.90	3.92	3.88	3.90	3.83	2.94	<2.90	<2.90	2.94	<2.90	<2.90

3.90	3.90	3.90	3.90	3.84	2.97	2.96	<2.90	<2.90	<2.90	<2.90

pF at 36 in. (Irrigated plots) - Continued

Oct.					Nov.			Dec.			Jan. 1956	
5	14	18	21	25	1	15	25	6	13	20	3	10
3.08	<2.90	3.01	<2.90	3.02	3.39	3.85	3.94	3.94	4.11	>4.20	<4.20	<4.20
<2.90	<2.90	2.94	<2.90	3.01	3.11	3.61	3.77	3.79	3.98	4.19	>4.20	>4.20
2.25	<2.90	3.06	3.12	3.34	3.78	3.87	3.98	3.97	4.07	4.17	>4.20	>4.20
<2.90	2.95	3.01	2.97	3.14	3.33	3.85	4.03	4.03	4.18	4.19	>4.20	>4.20
<2.90	2.97	3.06	3.08	3.12	3.29	3.87	3.81	4.04	4.15	4.19	>4.20	>4.20
<2.90	3.21	3.25	3.29	3.43	3.93	3.98	4.20	4.07	4.13	4.16	4.11	>4.20
<2.90	3.01	3.01	3.06	3.12	3.33	3.97	4.03	4.09	4.16	>4.20	>4.20	>4.20
<2.90	2.99	<2.90	3.10	2.95	3.18	3.52	3.90	3.91	4.02	4.11	4.14	>4.20
2.94	3.00	3.11	3.18	3.34	3.91	4.00	4.07	4.09	4.15	>4.20	>4.20	>4.20
3.16	3.14	3.11	3.12	3.12	3.16	3.30	3.73	3.90	4.01	>4.20	>4.20	>4.20
3.03	3.07	2.90	3.18	3.28	3.54	3.70	3.74	3.76	3.81	>4.20	3.90	>4.20
2.96	2.95	2.94	3.01	3.09	3.30	3.68	3.86	3.87	4.03	>4.20	4.18	>4.20
2.94	3.14	3.16	3.20	3.54	3.88	3.98	4.09	4.08	>4.20	>4.20	>4.20	>4.20
3.04	<2.90	2.94	2.94	3.07	3.25	3.64	3.87	3.88	4.02	>4.20	>4.20	>4.20
<2.90	<2.90	<2.90	2.94	2.98	2.95	3.12	3.72	3.72	3.92	>4.20	4.13	>4.20
<2.90	3.21	3.36	3.64	3.91	3.95	3.96	4.02	4.03	4.16	>4.20	>4.20	>4.20
<2.90	3.01	3.06	3.11	3.46	3.82	3.94	4.10	3.99	4.15	>4.20	>4.20	>4.20
<2.90	2.97	3.11	3.58	3.80	3.85	3.92	3.97	3.98	4.01	4.12	>4.20	>4.20
<2.90	<2.90	3.01	<2.90	3.02	3.39	3.85	3.94	3.94	4.07	4.19	>4.20	>4.20
<2.90	2.97	3.06	3.08	3.14	3.33	3.87	4.03	4.04	4.15	4.19	>4.20	>4.20
<2.90	3.00	3.01	3.10	3.12	3.33	3.97	4.03	4.09	4.15	>4.20	>4.20	>4.20
3.03	3.07	2.94	3.12	3.12	3.30	3.68	3.74	3.87	4.01	>4.20	4.18	>4.20
2.94	<2.90	2.94	2.94	3.07	3.25	3.64	3.87	3.88	4.02	>4.20	>4.20	>4.20
<2.90	3.01	3.11	3.58	3.80	3.85	3.94	4.02	3.99	4.15	>4.20	>4.20	>4.20
<2.90	2.99	3.01	3.09	3.12	3.33	3.86	3.98	3.96	4.11	>4.20	>4.20	>4.20

Values of pF at depth of 48 in.
(Irrigated Plots)

Plot	Replicate	Nov. 1954		Dec.				Jan. 1955			
		22	26	7	14	21	28	4	11	18	25
A	a	3.02	<2.90	<2.90	<2.90	3.26	3.78	3.77	3.82	3.76	3.80
	b	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	3.18	3.82	3.80	3.85
	c	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	2.97	2.88	<2.90	<2.90
B	a	<2.90	2.97	<2.90	<2.90	3.02	<2.90	<2.90	2.97	2.99	2.97
	b	<2.90	<2.90	<2.90	<2.90	4.00	3.59	4.01	4.03	4.00	3.99
	c	<2.90	2.97	2.97	2.97	<2.90	<2.90	<2.90	<2.90	2.99	3.04
D	a	2.92	2.97	<2.90	2.97	2.92	<2.90	2.99	3.29	3.37	3.46
	b	2.99	<2.90	<2.90	<2.90	2.99	2.97	2.97	2.97	<2.90	<2.90
	c	<2.90	<2.90	<2.90	<2.90	<2.90	2.97	<2.90	2.97	<2.90	2.97
G	a	2.99	3.02	3.08	3.32	3.82	3.48	3.18	3.06	2.97	2.97
	b	2.92	2.97	<2.90	<2.90	3.46	2.97	3.96	4.02	3.99	3.05
	c	2.92	<2.90	<2.90	<2.90	<2.90	<2.90	3.77	3.76	<2.90	2.97
H	a	2.99	<2.90	<2.90	2.92	<2.90	<2.90	<2.90	<2.90	2.97	3.22
	b	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90
	c	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90
J	a	2.99	2.92	2.97	<2.90	3.05	2.97	3.03	3.51	3.40	3.38
	b	<2.90	<2.90	<2.90	2.97	<2.90	<2.90	<2.90	<2.90	<2.90	2.97
	c	<2.90	<2.90	<2.90	<2.90	<2.90	3.41	<2.90	2.97	3.01	2.97
		Representative Plot Values (median of 3 replicates)									
A		<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	3.18	3.82	2.76	3.80
B		<2.90	2.97	<2.90	<2.90	3.02	<2.90	<2.90	2.97	2.99	3.04
D		2.92	<2.90	<2.90	<2.90	2.92	2.97	2.97	2.97	<2.90	2.97
G		2.92	2.97	<2.90	<2.90	3.46	2.97	3.77	3.76	2.97	2.97
H		<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90
J		<2.90	<2.90	<2.90	<2.90	<2.90	2.97	<2.90	2.97	3.01	2.97
		Representative Treatment Values (median of 6 Plot medians)									
		<2.90	<2.90	<2.90	<2.90	2.90	2.93	2.93	2.97	2.98	2.97

pF at 48 in. (Irrigated plots) - Continued

Feb.				Mar.					Apr.			
1	8	15	22	1	8	15	22	30	5	12	19	26
3.82	3.84	3.85	3.90	3.88	3.89	3.88	3.86	3.85	3.85	3.83	3.83	3.82
3.83	3.86	4.09	3.87	3.87	3.91	3.90	3.89	3.88	3.87	3.86	3.83	3.84
<2.90	3.01	3.09	3.38	3.45	3.52	3.56	3.65	3.65	3.64	3.68	3.68	3.70
<2.90	3.17	3.70	3.99	3.90	3.91	3.83	3.91	3.90	3.93	3.94	3.92	3.93
3.96	3.95	3.95	4.01	3.97	4.00	4.08	4.06	4.02	4.02	4.01	4.03	4.03
3.03	2.99	3.12	3.24	3.34	3.48	3.58	3.80	3.88	3.96	4.03	4.04	4.05
3.48	3.77	3.85	4.05	4.01	4.06	>4.20	4.02	4.03	4.00	4.01	4.00	4.00
2.97	3.55	4.02	3.86	3.80	3.85	3.95	4.08	4.06	4.09	4.07	4.05	4.05
3.18	3.69	3.77	3.79	3.77	3.77	>4.20	3.86	3.86	3.88	3.88	3.88	3.87
3.03	3.12	3.19	3.30	<2.90	2.99	<2.90	<2.90	3.09	3.07	3.08	3.18	3.34
3.92	3.88	3.88	3.89	3.82	<2.90	<2.90	2.97	2.90	<2.90	3.03	3.14	3.34
3.03	3.41	3.60	3.68	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	2.97	3.03	2.97
3.37	3.63	3.61	3.72	3.69	3.64	3.16	3.67	3.69	3.64	3.39	3.48	3.54
<2.90	2.99	3.20	3.76	3.70	3.67	3.69	3.69	3.69	3.70	3.72	3.70	3.69
<2.90	<2.90	3.30	3.75	3.74	3.74	3.77	3.80	3.79	3.81	3.81	3.80	3.79
3.25	4.07	3.91	4.03	3.96	3.96	3.96	3.93	3.94	3.94	3.99	3.98	4.01
<2.90	3.05	3.20	3.39	3.54	3.58	3.63	3.68	3.72	3.74	3.75	3.77	3.76
3.06	2.91	<2.90	<2.90	2.99	<2.90	<2.90	<2.90	3.09	<2.90	2.92	<2.90	<2.90
3.82	3.84	3.85	3.87	3.87	3.89	3.88	3.86	3.85	3.85	3.83	3.83	3.82
3.03	3.17	3.70	3.99	3.90	3.91	3.83	3.91	3.90	3.96	4.01	4.03	4.03
3.18	3.69	3.85	3.86	3.80	3.85	<2.90	4.02	4.03	4.00	4.01	4.00	4.00
3.03	3.41	3.60	3.68	<2.90	<2.90	<2.90	<2.90	2.90	<2.90	3.03	3.14	3.34
<2.90	2.99	3.30	3.75	3.70	3.67	3.69	3.69	3.69	3.70	3.72	3.70	3.69
3.06	3.05	3.20	3.39	3.54	3.58	3.63	3.68	3.72	3.74	3.75	3.77	3.76
3.04	3.29	3.65	3.80	3.75	3.76	3.66	3.78	3.78	3.79	3.79	3.80	3.79

pF at 48 in. (Irrigated plots) - Continued

May					June			July	Aug.	Sept.
3	10	18	24	31	9	14	28	12	9	8
3.83	3.83	3.82	3.82	3.62	3.83	3.82	<2.90	3.01	<2.90	<2.90
3.83	3.83	3.82	3.83	3.78	3.33	3.06	3.01	<2.90	<2.90	<2.90
3.70	3.74	3.74	3.70	3.66	3.62	3.47	<2.90	<2.90	<2.90	<2.90
3.92	3.93	3.92	3.90	3.92	3.50	3.22	<2.90	2.94	<2.90	<2.90
4.02	4.05	4.04	4.05	4.12	4.00	4.00	<2.90	<2.90	<2.90	<2.90
4.11	4.04	4.08	4.07	3.99	4.06	4.03	<2.90	2.94	<2.90	<2.90
4.02	4.02	4.08	4.05	4.04	4.03	4.00	4.04	3.95	<2.90	<2.90
4.08	4.02	3.98	4.06	4.05	4.00	4.04	3.29	<2.90	<2.90	<2.90
3.90	3.87	3.90	3.90	3.89	3.89	3.83	3.81	3.69	<2.90	<2.90
3.42	3.49	3.32	3.54	2.95	3.02	2.95	<2.90	2.94	<2.90	<2.90
3.56	3.64	3.68	3.66	3.51	2.96	<2.90	2.94	<2.90	<2.90	<2.90
2.97	3.07	3.02	3.16	2.91	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90
3.57	3.58	3.09	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90
3.69	3.68	3.67	3.68	3.72	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90
3.81	3.80	3.81	3.81	3.78	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90
4.01	4.03	4.06	4.06	4.05	4.07	4.03	4.04	<2.90	<2.90	<2.90
3.77	3.82	3.80	3.80	3.80	3.82	3.81	3.55	2.94	<2.90	<2.90
<2.90	<2.90	2.97	2.96	<2.90	2.96	2.99	<2.90	2.94	<2.90	<2.90

3.83	3.83	3.82	3.82	3.66	3.62	3.47	<2.90	<2.90	<2.90	<2.90
4.02	4.04	4.04	4.05	3.99	4.00	4.00	<2.90	2.94	<2.90	<2.90
4.02	4.02	3.98	4.05	4.04	4.00	4.00	3.81	3.69	<2.90	<2.90
3.56	3.49	3.32	3.54	2.95	2.96	<2.90	<2.90	<2.90	<2.90	<2.90
3.69	3.68	3.67	3.68	3.72	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90
3.77	3.82	3.80	3.80	3.80	3.82	3.81	3.55	2.94	<2.90	<2.90

3.80	3.82	3.81	3.81	3.76	3.72	3.64	<2.90	2.92	<2.90	<2.90

pF at 48 in. (Non-irrigated plots) - Continued

Oct.					Nov.			Dec.			Jan. 1956	
5	14	18	21	25	1	15	25	6	13	20	3	10
<2.90	<2.90	<2.90	2.96	3.15	3.78	3.95	4.10	4.10	4.18	>4.20	>4.20	>4.20
3.07	3.04	<2.90	<2.90	<2.90	3.25	3.93	4.04	3.98	4.20	>4.20	>4.20	>4.20
2.99	2.96	<2.90	3.18	3.30	3.37	3.98	4.08	4.13	4.18	>4.20	>4.20	>4.20
<2.90	<2.90	3.02	3.21	3.72	3.85	3.98	4.09	4.09	4.12	>4.20	>4.20	>4.20
<2.90	<2.90	<2.90	<2.90	<2.90	3.12	3.92	4.07	4.07	4.17	>4.20	>4.20	>4.20
<2.90	<2.90	2.96	<2.90	<2.90	<2.90	3.15	3.79	3.90	4.20	4.18	>4.20	>4.20
<2.90	<2.90	<2.90	3.06	<2.90	<2.90	<2.90	3.65	4.07	4.14	>4.20	4.19	>4.20
<2.90	3.02	2.96	2.96	2.99	3.07	3.72	3.98	4.01	4.10	>4.20	>4.20	>4.20
<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	3.17	4.04	4.10	>4.20	>4.20	>4.20	>4.20
<2.90	3.07	2.96	2.98	3.05	3.38	4.04	>4.20	4.13	>4.20	>4.20	>4.20	>4.20
<2.90	3.17	3.22	3.24	3.33	3.49	3.72	3.87	3.93	4.04	4.18	>4.20	>4.20
<2.90	3.19	3.22	3.24	3.33	3.65	4.04	4.20	4.10	>4.20	>4.20	>4.20	>4.20
<2.90	2.98	3.05	3.09	3.06	3.09	3.77	4.11	4.04	4.20	>4.20	>4.20	>4.20
<2.90	3.11	3.15	3.16	3.22	3.49	3.97	4.13	4.09	>4.20	>4.20	>4.20	>4.20
<2.90	3.02	3.07	3.02	3.08	3.14	3.78	3.99	3.97	4.10	>4.20	>4.20	>4.20
<2.90	<2.90	<2.90	<2.90	2.96	3.07	3.83	4.03	4.02	4.09	>4.20	>4.20	>4.20
<2.90	3.05	3.04	3.05	<2.90	2.96	2.97	3.12	3.68	3.99	>4.20	>4.20	>4.20
<2.90	3.05	<2.90	<2.90	3.02	3.02	3.68	4.06	4.09	4.18	>4.20	>4.20	>4.20
2.99	2.96	<2.90	2.96	3.15	3.37	3.95	4.08	4.10	4.18	>4.20	>4.20	>4.20
<2.90	<2.90	2.96	<2.90	<2.90	3.12	3.92	4.07	4.07	4.12	>4.20	>4.20	>4.20
<2.90	<2.90	<2.90	2.96	<2.90	<2.90	3.17	3.98	4.07	4.14	>4.20	>4.20	>4.20
<2.90	3.17	3.22	3.24	3.33	3.49	4.04	4.20	4.10	>4.20	>4.20	>4.20	>4.20
<2.90	3.02	3.07	3.09	3.08	3.14	3.78	4.11	4.04	4.20	>4.20	>4.20	>4.20
<2.90	3.05	<2.90	<2.90	2.96	3.02	3.68	4.03	4.02	4.09	>4.20	>4.20	>4.20
<2.90	2.99	2.93	2.96	3.02	3.13	3.85	4.08	4.07	4.16	>4.20	>4.20	>4.20

Values of pF at depth of 60 in.
(Irrigated Plots)

Plot	Replicate	Nov. 1954		Dec.				Jan. 1955			
		22	26	7	14	21	28	4	11	18	25
A	a	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	2.97
	b	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	2.97	<2.90	2.97
	c	<2.90	3.01	<2.90	<2.90	2.92	<2.90	2.97	<2.90	2.99	<2.90
B	a	<2.90	2.97	<2.90	<2.90	<2.90	<2.90	<2.90	3.44	3.43	3.31
	b	<2.90	2.97	<2.90	<2.90	2.92	<2.90	2.92	3.70	3.57	3.46
	c	<2.90	3.02	2.97	2.97	<2.90	<2.90	<2.90	>4.20	2.99	<2.90
D	a	3.37	3.33	3.30	2.97	3.36	3.33	2.99	3.31	3.45	3.54
	b	<2.90	2.92	<2.90	<2.90	<2.90	<2.90	2.97	<2.90	<2.90	<2.90
	c	<2.90	<2.90	<2.90	<2.90	<2.90	2.97	<2.90	<2.90	<2.90	<2.90
G	a	2.99	3.00	<2.90	<2.90	<2.90	<2.90	3.18	3.85	3.75	3.72
	b	2.92	<2.90	<2.90	<2.90	<2.90	<2.90	3.96	3.19	3.03	2.92
	c	2.92	2.97	<2.90	<2.90	<2.90	2.97	3.77	3.53	3.41	2.97
H	a	2.99	2.97	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	2.97	<2.90
	b	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	2.97	<2.90
	c	<2.90	<2.90	2.97	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90
J	a	<2.90	<2.90	2.97	<2.90	<2.90	2.97	3.03	<2.90	<2.90	<2.90
	b	<2.90	<2.90	<2.90	<2.90	<2.90	2.97	<2.90	3.03	3.09	2.97
	c	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	3.01	3.42

Representative Plot Values (median of 3 replicates)

A	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	2.97
B	<2.90	2.97	<2.90	<2.90	<2.90	<2.90	<2.90	3.70	3.43	3.31
D	<2.90	2.92	<2.90	<2.90	<2.90	2.97	2.97	<2.90	<2.90	<2.90
G	2.92	2.97	<2.90	<2.90	<2.90	<2.90	3.77	3.53	3.41	2.97
H	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	2.97	<2.90
J	<2.90	<2.90	<2.90	<2.90	<2.90	2.97	<2.90	<2.90	3.01	2.97

Representative Treatment Values (median of 6 Plot medians)

<2.90	290	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	2.99	2.97

pF at 60 in. (Irrigated plots) - Continued

Feb.				Mar.					Apr.			
1	8	15	22	1	8	15	22	30	5	12	19	26
3.09	3.22	3.72	3.35	3.31	3.37	3.43	3.50	3.52	3.49	3.48	3.48	3.49
<2.90	<2.90	3.03	3.09	3.15	3.14	3.39	3.48	3.55	3.61	3.66	3.69	3.70
<2.90	2.00	3.03	2.97	2.00	3.49	2.97	<2.90	3.13	3.09	3.11	3.18	3.27
3.39	3.41	3.38	3.47	3.44	3.47	3.99	3.62	3.70	3.80	3.47	3.82	3.77
3.37	3.50	3.69	3.91	3.78	3.74	3.73	3.74	3.75	3.85	3.93	3.93	3.92
3.01	<2.90	3.03	3.03	3.09	3.14	3.26	3.59	3.75	3.74	3.99	3.79	3.80
3.54	3.65	3.67	3.75	3.79	3.79	>4.20	3.79	3.79	3.80	3.80	3.80	3.81
3.14	3.63	3.64	3.69	3.64	3.64	3.78	3.88	3.82	3.83	3.84	3.80	3.81
<2.90	2.97	2.97	2.90	2.97	2.92	<2.90	3.03	3.15	3.27	3.44	3.54	3.56
3.64	3.64	3.58	3.62	3.67	3.65	3.65	3.68	3.66	3.67	3.75	3.77	3.77
<2.90	2.97	<2.90	<2.90	<2.90	<2.90	2.96	<2.90	2.90	<2.90	3.02	2.97	2.96
3.03	<2.90	<2.90	3.02	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	2.92	3.03	3.08
<2.90	<2.90	2.97	<2.90	<2.90	2.97	3.14	<2.90	<2.90	<2.90	<2.90	3.01	3.02
<2.90	2.97	3.01	3.11	3.05	3.11	3.13	3.14	3.09	3.17	3.21	3.14	3.22
<2.90	<2.90	<2.90	<2.90	2.90	<2.90	3.14	2.97	<2.90	2.92	<2.90	<2.90	3.00
<2.90	<2.90	2.97	3.29	3.37	3.47	3.61	3.70	3.73	3.74	3.77	3.77	3.77
3.01	2.97	3.03	2.90	3.06	<2.90	<2.90	<2.90	3.03	3.01	<2.90	2.97	<2.90
3.11	3.58	3.48	3.37	3.13	<2.90	3.09	<2.90	3.03	2.92	3.03	4.03	3.16
<2.90	<2.90	3.03	3.09	3.15	3.37	3.39	3.48	3.52	3.49	3.48	3.48	3.49
3.37	3.41	3.38	3.47	3.44	3.47	3.73	3.62	3.75	3.80	3.93	3.82	3.80
3.14	3.63	3.64	3.69	3.64	3.64	3.78	3.79	3.79	3.80	3.80	3.80	3.81
3.03	2.97	<2.90	3.02	<2.90	<2.90	2.96	<2.90	2.90	<2.90	3.02	3.03	3.08
<2.90	<2.90	2.97	<2.90	2.90	2.97	3.14	2.97	<2.90	2.92	<2.90	3.01	3.02
3.01	2.97	3.03	3.29	3.13	<2.90	3.09	<2.90	3.03	3.01	3.03	3.77	3.16
3.02	2.97	3.03	3.19	3.14	3.17	3.26	3.23	3.27	3.25	3.25	3.63	3.33

pF at 60 in. (Irrigated plots) - Continued

May					June			July	Aug.	Sept.
3	10	18	24	31	9	14	28	12	9	8
3.48	3.48	3.53	3.53	3.52	3.54	3.54	3.55	3.53	<2.90	<2.90
3.73	3.74	3.76	3.77	3.77	3.79	3.79	<2.90	3.01	<2.90	<2.90
3.26	3.39	3.42	3.41	3.46	3.44	3.46	3.14	<2.90	<2.90	<2.90
3.78	3.79	3.78	3.77	3.80	3.79	3.79	3.74	3.64	<2.90	<2.90
3.95	3.90	3.90	3.92	3.88	3.90	3.88	<2.90	<2.90	<2.90	<2.90
3.84	3.83	3.85	3.85	3.89	3.86	3.86	3.82	3.79	<2.90	<2.90
3.82	3.99	3.82	3.82	3.86	3.65	3.55	3.16	3.28	<2.90	<2.90
3.80	3.80	3.82	3.82	3.83	3.82	3.80	3.79	3.90	<2.90	<2.90
3.58	>4.20	3.64	3.62	3.65	3.67	3.64	3.66	3.67	<2.90	<2.90
3.77	3.77	3.78	3.78	3.79	3.65	3.50	<2.90	2.94	<2.90	<2.90
2.97	3.08	3.16	3.27	3.29	2.95	<2.90	<2.90	<2.90	<2.90	<2.90
3.29	3.42	3.47	3.47	3.40	2.96	<2.90	2.95	<2.90	<2.90	<2.90
<2.90	<2.90	3.06	<2.90	3.05	<2.90	<2.90	<2.90	2.94	<2.90	<2.90
3.15	3.67	3.21	3.25	3.24	3.22	3.21	3.23	3.01	<2.90	<2.90
3.00	<2.90	2.92	3.02	2.95	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90
3.76	3.77	3.80	3.80	3.80	3.79	3.79	3.80	<2.90	<2.90	<2.90
2.80	<2.90	3.01	2.99	2.95	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90
3.18	3.29	3.36	3.42	3.43	3.47	3.49	<2.90	<2.90	<2.90	<2.90
3.48	3.48	3.53	3.53	3.52	3.54	3.54	3.14	3.01	<2.90	<2.90
3.84	3.83	3.85	3.85	3.88	3.86	3.86	3.74	3.64	<2.90	<2.90
3.80	3.99	3.82	3.82	3.83	3.67	3.64	3.66	3.67	<2.90	<2.90
3.29	3.42	3.47	3.47	3.40	2.96	<2.90	<2.90	<2.90	<2.90	<2.90
3.00	<2.90	3.06	3.02	3.05	<2.90	<2.90	<2.90	2.94	<2.90	<2.90
3.18	3.29	3.36	3.42	3.43	3.47	3.49	<2.90	<2.90	<2.90	<2.90
3.33	3.45	3.50	3.50	3.48	3.51	3.51	3.03	2.97	<2.90	<2.90

pF at 60 in. (Irrigated plots) - Continued

Oct.					Nov.			Dec.			Jan. 1956	
5	14	18	21	25	1	15	25	6	13	20	3	10
<2.90	<2.90	2.95	<2.90	<2.90	2.94	3.38	3.61	3.60	3.73	3.86	3.97	>4.20
<2.90	2.98	2.95	<2.90	<2.90	2.94	3.47	3.68	3.68	3.90	4.12	4.13	>4.20
<2.90	<2.90	<2.90	<2.90	<2.90	3.05	3.34	3.60	3.61	3.80	3.97	4.04	>4.20
<2.90	<2.90	2.95	3.05	3.37	3.68	3.77	3.88	3.79	3.93	4.06	4.18	>4.20
<2.90	<2.90	<2.90	<2.90	2.98	3.46	3.78	3.77	3.91	4.10	4.17	>4.20	>4.20
<2.90	3.82	3.82	3.83	3.85	3.89	3.88	3.95	3.97	4.10	>4.20	>4.20	>4.20
3.29	3.29	3.31	3.34	3.38	3.50	3.49	3.55	3.77	3.87	4.04	4.19	>4.20
2.44	2.99	3.08	3.12	3.18	3.32	3.55	3.83	3.86	3.96	4.05	4.09	>4.20
3.45	3.48	3.51	3.55	3.60	3.70	3.78	3.81	3.90	4.02	4.15	>4.20	>4.20
3.04	3.07	3.11	<2.90	2.98	2.94	3.05	3.27	3.77	3.95	4.11	>4.20	>4.20
<2.90	3.07	<2.90	<2.90	<2.90	3.19	3.58	3.77	3.74	3.93	4.11	>4.20	>4.20
3.01	<2.90	<2.90	<2.90	2.95	3.30	3.74	3.91	3.83	4.05	4.15	4.18	>4.20
<2.90	2.97	3.01	<2.90	2.94	<2.90	3.16	3.47	3.53	3.74	4.17	4.11	>4.20
<2.90	<2.90	3.07	<2.90	<2.90	<2.90	3.05	3.13	3.29	3.49	>4.20	4.04	>4.20
<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	3.02	3.13	4.20	3.86	>4.20
<2.90	3.04	3.07	3.14	3.39	3.79	3.89	3.95	3.96	4.14	4.15	>4.20	>4.20
<2.90	2.95	<2.90	2.92	2.95	3.32	3.78	3.95	3.90	4.06	4.17	>4.20	>4.20
<2.90	2.95	<2.90	2.95	2.95	3.24	3.79	3.99	3.91	4.03	4.15	>4.20	>4.20
<2.90	<2.90	2.95	<2.90	<2.90	2.94	3.38	3.61	3.61	3.80	3.97	4.04	>4.20
<2.90	<2.90	2.95	3.05	3.37	3.68	3.78	3.88	3.91	4.10	4.17	>4.20	>4.20
3.29	3.29	3.31	3.34	3.38	3.50	3.55	3.81	3.86	3.96	4.05	4.19	>4.20
3.01	3.07	<2.90	<2.90	2.95	3.19	3.58	3.77	3.77	3.95	4.11	<2.90	>4.20
<2.90	<2.90	3.01	<2.90	<2.90	<2.90	3.05	3.13	3.29	3.49	4.20	4.04	>4.20
<2.90	2.95	<2.90	2.95	2.95	3.32	3.79	3.95	3.91	4.06	4.15	>4.20	>4.20
<2.90	2.92	2.95	2.92	2.95	3.25	3.56	3.79	3.81	3.95	4.13	4.20	>4.20

APPENDIX B_2

Values of pF at depth of 6 in.
(Non-Irrigated Plots)

Plot	Replicate	Nov. 1954		Dec.				Jan. 1955			
		22	26	7	14	21	28	4	11	18	25
C	a	<2.90	3.00	3.96	4.02	4.20	>4.20	>4.20	>4.20	>4.20	3.86
	b	<2.90	3.36	3.89	4.02	4.15	>4.20	>4.20	>4.20	3.88	3.95
	c	3.10	3.00	3.95	4.01	>4.20	>4.20	>4.20	3.64	3.29	3.81
E	a	2.99	3.13	4.18	4.20	>4.20	>4.20	3.91	>4.20	3.03	3.96
	b	3.45	3.53	4.10	4.15	4.18	>4.20	>4.20	>4.20	3.09	4.06
	c	3.03	3.59	4.18	4.20	>4.20	>4.20	>4.20	3.13	>4.20	>4.20
F	a	3.42	3.17	3.96	4.00	4.05	4.15	>4.20	>4.20	3.03	3.47
	b	<2.90	3.07	4.03	4.09	4.19	>4.20	>4.20	>4.20	3.03	3.79
	c	3.49	3.69	4.18	4.15	4.15	>4.20	3.59	4.10	3.09	4.20
I	a	3.05	3.06	3.77	3.90	>4.20	>4.20	>4.20	>4.20	3.09	3.81
	b	3.50	3.50	4.18	4.18	>4.20	>4.20	>4.20	>4.20	3.09	3.85
	c	3.10	3.06	3.70	3.90	>4.20	>4.20	>4.20	>4.20	3.19	4.05
K	a	3.27	3.52	4.06	4.10	4.13	>4.20	4.08	>4.20	3.09	4.15
	b	4.10	3.96	>4.20	4.20	3.91	4.00	>4.20	4.05	>4.20	>4.20
	c	3.51	3.38	4.20	3.89	4.13	>4.20	4.11	4.10	2.97	4.04
L	a	3.92	3.73	4.18	4.20	>4.20	>4.20	>4.20	>4.20	<2.90	4.08
	b	3.94	3.71	4.20	>4.20	4.15	4.15	>4.20	>4.20	<2.90	3.75
	c	3.72	3.48	3.94	4.00	4.02	4.10	>4.20	>4.20	3.25	3.79

Representative Plot Values (median of 3 replicates)

Plot	22	26	7	14	21	28	4	11	18	25
C	<2.90	3.00	3.95	4.02	4.20	>4.20	>4.20	>4.20	3.88	3.86
E	3.03	3.53	4.18	4.20	>4.20	>4.20	>4.20	>4.20	3.09	4.06
F	3.42	3.17	4.03	4.09	4.15	>4.20	>4.20	>4.20	3.03	3.79
I	3.10	3.06	3.77	3.90	>4.20	>4.20	>4.20	>4.20	3.09	3.85
K	3.51	3.52	4.20	4.10	4.13	>4.20	4.11	4.10	3.09	4.15
L	3.92	3.71	4.18	4.20	4.15	4.15	>4.20	>4.20	<2.90	4.08

Representative Treatment Values (median of 6 Plot medians)

22	26	7	14	21	28	4	11	18	25
3.26	3.35	4.11	4.10	4.18	>4.20	>4.20	>4.20	3.09	3.96

pF at 6 in. (Non-irrigated plots) - Continued

Feb.				Mar.					Apr.			
1	8	15	22	1	8	15	22	30	5	12	19	26
>4.20	>4.20	3.75	4.15	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.82	3.91
>4.20	>4.20	3.61	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.33	3.79
4.19	>4.20	3.50	4.08	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	4.08
>4.20	>4.20	3.74	4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.66	3.87
>4.20	>4.20	3.58	4.16	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.53	3.83
>4.20	>4.20	3.60	3.96	4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.74	3.90
3.92	>4.20	3.47	3.88	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.30	3.72
4.13	>4.20	3.94	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.72	3.97
>4.20	>4.20	3.91	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.70	4.06
4.18	>4.20	3.79	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.89	3.99
>4.20	>4.20	3.74	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.68	3.92
>4.20	>4.20	3.81	4.12	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	4.10
>4.20	>4.20	3.92	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.80	3.91
>4.20	>4.20	3.65	3.88	4.15	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.75	3.88
>4.20	>4.20	3.68	4.12	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.64	3.84
>4.20	>4.20	3.33	4.15	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.65	4.01
4.07	>4.20	3.63	4.08	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.69	3.92
4.04	>4.20	3.64	3.91	4.19	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.64	3.85
>4.20	>4.20	3.61	4.15	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.82	3.91
>4.20	>4.20	3.60	4.10	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.66	3.87
4.13	>4.20	3.91	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.70	3.97
>4.20	>4.20	3.79	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.89	3.99
>4.20	>4.20	3.68	4.12	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.75	3.88
4.07	>4.20	3.63	4.08	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.65	3.92
>4.20	>4.20	3.66	4.14	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.73	3.90

pF at 6 in. (Non-irrigated plots) - Continued

May					June			July	Aug.	Sept.
3	10	18	24	31	9	14	28	12	9	8
4.09	3.82	2.92	3.14	2.94	2.92	<2.90	<2.90	<2.90	<2.90	<2.90
4.08	3.42	3.09	3.08	3.03	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90
>4.20	4.05	3.43	3.09	3.00	<2.90	3.05	<2.90	<2.90	<2.90	<2.90
4.09	3.43	3.02	3.11	3.20	<2.90	3.05	<2.90	<2.90	<2.90	<2.90
4.09	3.30	3.09	3.16	3.18	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90
4.08	3.77	3.14	2.94	3.15	<2.90	3.05	<2.90	<2.90	<2.90	<2.90
3.89	3.27	3.03	3.11	<2.90	2.98	3.05	<2.90	2.92	<2.90	<2.90
3.89	3.62	3.05	3.14	3.03	2.91	<2.90	<2.90	<2.90	<2.90	<2.90
>4.20	3.56	3.19	3.22	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90
4.13	3.81	3.09	3.22	3.66	3.12	3.05	3.12	<2.90	<2.90	<2.90
4.18	3.56	3.14	3.20	3.08	3.06	3.11	3.06	<2.90	<2.90	<2.90
4.20	4.05	3.43	3.30	3.17	3.16	3.20	3.10	<2.90	<2.90	<2.90
4.09	3.60	3.17	3.18	3.09	3.09	3.11	3.09	2.92	<2.90	<2.90
3.96	3.78	3.14	3.19	3.12	3.13	>4.20	3.09	<2.90	<2.90	<2.90
4.04	3.33	3.14	4.02	3.19	3.09	3.05	3.05	<2.90	<2.90	<2.90
4.19	3.54	3.18	3.16	2.97	3.01	2.94	<2.90	<2.90	<2.90	<2.90
4.08	3.46	3.14	3.03	3.05	3.06	2.94	2.92	2.92	<2.90	<2.90
4.02	3.59	3.18	3.23	3.14	3.04	3.03	2.95	<2.90	<2.90	<2.90

4.09	3.82	3.09	3.09	3.00	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90
4.09	3.43	3.09	3.11	3.18	<2.90	3.05	<2.90	<2.90	<2.90	<2.90
3.89	3.56	3.05	3.14	<2.90	2.91	<2.90	<2.90	<2.90	<2.90	<2.90
4.18	3.56	3.14	3.22	3.17	3.12	3.11	3.10	<2.90	<2.90	<2.90
4.04	3.60	3.14	3.19	3.12	3.09	3.11	3.09	<2.90	<2.90	<2.90
4.08	3.54	3.18	3.16	3.05	3.04	2.94	2.92	<2.90	<2.90	<2.90

4.08	3.56	3.12	3.15	3.09	2.98	3.00	2.91	<2.90	<2.90	<2.90

pF at 6 in. (Non-irrigated plots) - Continued

Oct.					Nov.			Dec.			Jan. 1956	
5	14	18	21	25	1	15	25	6	13	20	3	10
3.16	3.27	3.47	3.87	4.00	4.08	3.97	>4.20	4.18	>4.20	>4.20	>4.20	>4.20
3.02	3.11	3.38	3.80	3.98	3.98	3.67	4.11	3.69	>4.20	>4.20	>4.20	>4.20
3.09	3.45	3.76	4.00	4.12	4.13	4.08	4.14	4.18	>4.20	>4.20	>4.20	>4.20
3.04	3.32	3.65	3.85	4.05	4.00	3.77	>4.20	3.64	>4.20	>4.20	>4.20	>4.20
3.14	3.04	3.11	3.26	3.64	3.71	3.68	4.10	3.50	4.18	>4.20	>4.20	>4.20
3.12	<2.90	2.99	3.42	3.75	3.21	3.02	4.06	3.29	>4.20	>4.20	>4.20	>4.20
3.04	3.14	3.52	3.91	4.08	4.02	3.65	4.15	3.92	>4.20	>4.20	>4.20	>4.20
3.11	3.14	3.47	3.84	3.97	3.96	3.66	4.16	3.87	4.13	>4.20	>4.20	>4.20
3.21	3.33	3.63	3.95	4.04	3.88	3.89	4.13	3.89	4.11	>4.20	>4.20	>4.20
3.04	3.25	3.58	3.92	4.16	4.08	3.75	>4.20	3.79	>4.20	>4.20	>4.20	>4.20
3.09	3.16	3.24	3.42	3.69	3.64	3.24	4.12	3.46	>4.20	>4.20	>4.20	>4.20
<2.90	3.26	3.59	3.87	4.08	4.11	3.98	>4.20	4.18	>4.20	>4.20	>4.20	>4.10
3.12	3.69	3.91	4.08	>4.20	4.07	3.87	>4.20	3.91	>4.20	>4.20	>4.20	>4.20
3.09	3.27	3.37	3.67	3.89	3.86	3.80	4.17	4.06	>4.20	>4.20	>4.20	>4.20
3.14	3.75	3.95	4.14	>4.20	4.09	3.95	>4.20	4.07	>4.20	>4.20	>4.20	>4.20
3.16	3.25	3.72	4.05	>4.20	3.89	3.60	>4.20	3.61	>4.20	>4.20	>4.20	>4.20
3.06	3.22	3.53	3.61	3.73	3.59	3.50	4.10	3.83	>4.20	>4.20	>4.20	>4.20
3.09	3.21	3.55	3.90	4.11	3.82	3.90	>4.20	3.73	>4.20	>4.20	>4.20	>4.20
3.09	3.27	3.47	3.87	4.00	4.08	3.97	4.14	4.18	>4.20	>4.20	>4.20	>4.20
3.12	3.04	3.11	3.42	3.75	3.71	3.68	4.10	3.50	>4.20	>4.20	>4.20	>4.20
3.11	3.14	3.52	3.91	4.04	3.96	3.66	4.15	3.89	4.13	>4.20	>4.20	>4.20
3.04	3.25	3.58	3.87	4.08	4.08	3.75	>4.20	3.79	>4.20	>4.20	>4.20	>4.20
3.12	3.69	3.91	4.08	>4.20	4.07	3.87	>4.20	4.06	>4.20	>4.20	>4.20	>4.20
3.09	3.22	3.55	3.90	4.11	3.82	3.60	>4.20	3.73	>4.20	>4.20	>4.20	>4.20
3.10	3.23	3.53	3.88	4.06	4.01	3.71	4.17	3.84	4.17	>4.20	>4.20	>4.20

Values of pF at depth of 12 in.
(Non-Irrigated Plots)

Plot	Replicate	Nov. 1954		Dec.				Jan. 1955			
		22	26	7	14	21	28	4	11	18	25
C	a	<2.90	<2.90	3.80	3.90	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
	b	3.53	2.92	4.08	4.12	4.18	>4.20	>4.20	>4.20	3.03	3.11
	c	2.96	<2.90	3.30	3.65	4.18	>4.20	>4.20	>4.20	3.03	3.16
E	a	3.78	3.77	4.05	4.09	4.15	4.18	>4.20	>4.20	3.03	3.80
	b	3.29	3.53	4.13	4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.97
	c	3.70	3.73	4.18	4.20	>4.20	>4.20	>4.20	3.13	>4.20	>4.20
F	a	3.26	3.29	4.05	4.12	>4.20	>4.20	3.01	3.68	3.99	4.08
	b	3.88	3.69	>4.20	>4.20	>4.20	>4.20	3.17	4.08	3.91	3.90
	c	3.53	3.67	<2.90	<2.90	>4.20	>4.20	>4.20	>4.20	3.08	3.89
I	a	3.69	3.66	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
	b	3.47	3.15	3.89	4.00	4.13	4.16	>4.10	>4.20	3.62	3.64
	c	3.94	3.80	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
K	a	3.51	3.53	4.10	4.18	>4.20	>4.20	3.89	>4.20	>4.20	3.95
	b	3.57	3.51	4.10	4.17	4.09	4.18	>4.20	>4.20	>4.20	>4.20
	c	3.83	3.83	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
L	a	3.79	3.87	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	2.97	3.81
	b	3.99	4.03	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
	c	3.87	3.96	>4.20	>4.20	<2.90	3.60	>4.20	>4.20	3.08	4.03

Representative Plot Values (median of 3 replicates)

C	2.96	<2.90	3.80	3.90	4.18	>4.20	>4.20	>4.20	3.03	3.16
E	3.70	3.73	4.13	4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.97
F	3.53	3.67	4.05	4.12	>4.20	>4.20	3.17	4.08	3.91	3.90
I	3.69	3.66	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
K	3.57	3.53	4.10	4.18	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
L	3.87	3.96	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.08	4.03
	3.63	3.67	4.12	4.19	>4.20	>4.20	>4.20	>4.20	4.06	4.00

pF at 12 in. (Non-irrigated plots) - Continued

Feb.				Mar.					Apr.			
1	8	15	22	1	8	15	22	30	5	12	19	26
>4.20	>4.20	4.05	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	3.17	>4.10	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	3.17	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	3.68	4.11	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	3.52	3.95	4.19	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	4.19	4.17
>4.20	>4.20	4.09	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	3.85	4.11	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
4.18	>4.20	3.54	3.90	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	4.08	3.92
>4.20	>4.20	3.61	4.07	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
4.01	>4.20	3.57	3.96	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	4.02	3.79	4.02	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	4.15	3.94
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
4.08	>4.20	3.58	3.96	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	4.12	3.94
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	3.77	4.03	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	3.17	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	3.68	4.11	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	3.61	4.11	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	3.77	4.03	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	3.73	4.16	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20

pF at 12 in. (Non-irrigated plots) - Continued

May					June			July	Aug.	Sept.
3	10	18	24	31	9	14	28	12	9	8
>4.20	>4.20	<2.90	<2.90	2.92	<2.90	3.09	<2.90	2.91	<2.90	<2.90
>4.20	>4.20	3.05	2.97	2.90	3.05	3.03	<2.90	<2.90	<2.90	<2.90
>4.20	>4.20	3.01	3.07	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90
>4.20	>4.20	3.11	3.07	<2.90	2.92	2.94	<2.90	2.94	<2.90	<2.90
>4.20	3.99	2.94	3.02	3.20	2.92	2.92	2.93	<2.90	<2.90	<2.90
>4.20	>4.20	4.09	3.26	3.23	3.07	3.05	3.25	<2.90	<2.90	<2.90
3.79	4.02	2.93	2.95	3.04	3.05	3.05	<2.90	<2.90	<2.90	<2.90
3.96	3.70	2.94	2.96	<2.90	3.07	3.05	<2.90	3.09	<2.90	<2.90
>4.20	>4.20	3.14	3.00	2.94	3.05	<2.90	<2.90	2.92	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	3.31	3.15	2.94	3.12	2.99	<2.90	<2.90
>4.20	>4.20	<2.90	2.99	3.19	3.13	3.05	3.15	2.93	<2.90	<2.90
>4.20	>4.20	>4.20	3.47	3.15	3.16	3.16	3.07	<2.90	<2.90	<2.90
4.00	3.91	3.06	2.92	<2.90	2.92	2.94	2.93	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	3.69	3.05	2.99	<2.90	3.05	2.93	<2.90	<2.90
>4.20	>4.20	>4.20	3.80	2.96	3.10	3.05	3.06	<2.90	<2.90	<2.90
4.04	3.79	2.93	2.92	<2.90	2.99	2.94	<2.90	2.96	<2.90	<2.90
>4.20	>4.20	3.09	3.10	3.11	3.12	3.00	3.04	3.03	<2.90	<2.90
>4.20	>4.20	3.07	3.13	2.94	2.99	3.00	2.93	<2.90	<2.90	<2.90
>4.20	>4.20	3.01	2.97	2.90	<2.90	3.03	<2.90	<2.90	<2.90	<2.90
>4.20	>4.20	3.11	3.02	3.20	2.92	2.94	2.93	<2.90	<2.90	<2.90
3.96	4.02	2.94	2.96	2.94	3.05	3.05	<2.90	2.92	<2.90	<2.90
>4.20	>4.20	>4.20	3.47	3.19	3.15	3.05	3.12	2.93	<2.90	<2.90
>4.20	>4.20	>4.20	3.69	2.96	2.99	2.94	3.05	<2.90	<2.90	<2.90
>4.20	>4.20	3.07	3.10	2.94	2.99	3.00	2.93	2.96	<2.90	<2.90
>4.20	>4.20	3.09	3.06	2.95	2.99	3.02	2.93	2.91	<2.90	<2.90

pF at 12 in. (Non-irrigated plots) - Continued

Oct.					Nov.			Dec.			Jan. 1956	
5	14	18	21	25	1	15	25	6	13	20	3	10
3.22	3.44	3.63	3.84	4.08	3.99	4.06	4.16	4.05	>4.20	>4.20	>4.20	>4.20
3.04	3.17	3.29	3.52	3.90	4.06	4.09	4.08	4.09	>4.20	>4.20	>4.20	>4.20
<2.90	2.99	2.96	3.12	3.15	3.19	3.25	3.51	3.96	4.15	>4.20	>4.20	>4.20
<2.90	3.24	3.46	3.80	3.99	4.06	4.09	>4.20	4.18	>4.20	>4.20	>4.20	>4.20
3.17	3.05	3.07	3.20	3.57	3.91	3.91	4.10	4.13	>4.20	>4.20	>4.20	>4.20
3.07	2.96	3.07	3.33	3.90	4.02	4.06	4.17	4.17	>4.20	>4.20	>4.20	>4.20
3.02	3.07	3.16	3.33	3.52	4.01	4.00	4.06	4.07	4.18	>4.20	>4.20	>4.20
3.17	3.22	3.42	3.81	4.03	4.00	4.06	4.20	>4.20	>4.20	>4.20	>4.20	>4.20
3.17	3.02	3.32	3.74	3.96	4.10	3.98	>4.20	4.12	>4.20	>4.20	>4.20	>4.20
3.02	3.24	3.38	3.59	3.95	4.09	4.18	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
3.12	3.19	3.26	3.60	3.85	3.96	3.96	>4.20	4.10	>4.20	>4.20	>4.20	>4.20
3.02	3.22	3.24	3.48	3.81	3.96	3.98	4.12	4.18	>4.20	>4.20	>4.20	>4.20
3.07	3.50	3.80	4.03	>4.20	4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
3.02	3.26	3.29	3.51	3.73	3.86	3.89	4.15	4.15	>4.20	>4.20	>4.20	>4.20
<2.90	3.15	3.29	3.49	3.83	3.98	4.07	>4.20	4.15	>4.20	>4.20	>4.20	>4.20
3.16	3.33	3.64	3.91	4.09	4.17	4.06	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
3.67	3.78	3.94	4.15	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
3.27	3.68	3.88	4.07	>4.20	3.83	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20

3.04	3.17	3.29	3.52	3.90	3.99	4.06	4.08	4.05	>4.20	>4.20	>4.20	>4.20
3.07	3.05	3.07	3.33	3.90	4.02	4.06	4.17	4.17	>4.20	>4.20	>4.20	>4.20
3.17	3.07	3.32	3.74	3.96	4.10	4.00	4.20	4.12	>4.20	>4.20	>4.20	>4.20
3.02	3.22	3.26	3.59	3.85	3.96	3.98	>4.20	4.18	>4.20	>4.20	>4.20	>4.20
3.02	3.26	3.29	3.51	3.83	3.98	4.07	>4.20	4.15	>4.20	>4.20	>4.20	>4.20
3.27	3.68	3.88	4.15	>4.20	4.17	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20

3.06	3.20	3.29	3.56	3.90	4.05	4.06	4.20	4.16	>4.20	>4.20	>4.20	>4.20

Values of pF at depth of 24 in.
(Non-Irrigated Plots)

Plot	Replicate	Nov. 1954		Dec.				Jan. 1955			
		22	26	7	14	21	28	4	11	18	25
C	a	<2.90	<2.90	3.54	3.60	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
	b	2.96	2.98	3.03	3.50	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
	c	2.96	<2.90	3.87	4.12	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
E	a	2.96	2.98	3.03	3.98	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
	b	<2.90	3.04	3.21	3.55	3.97	>4.20	>4.20	>4.20	>4.20	>4.20
	c	<2.90	3.01	<2.90	3.12	4.05	4.15	>4.20	3.94	>4.20	>4.20
F	a	<2.90	<2.90	2.97	3.32	3.73	3.80	>4.20	>4.20	>4.20	>4.20
	b	2.96	2.98	<2.90	2.92	3.02	3.72	>4.20	>4.20	>4.20	>4.20
	c	2.96	2.98	<2.90	<2.90	2.93	3.09	3.48	3.80	3.92	4.02
I	a	2.96	3.01	3.09	3.62	4.03	>4.20	>4.20	>4.20	>4.20	>4.20
	b	2.96	3.04	3.79	4.15	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
	c	2.96	3.04	3.31	4.15	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
K	a	3.51	3.04	3.11	3.47	3.48	3.72	4.03	>4.20	>4.20	>4.20
	b	3.08	3.14	3.52	3.69	3.90	>4.20	>4.20	>4.20	>4.20	>4.20
	c	3.08	3.04	3.32	3.58	3.62	3.72	3.74	3.88	4.08	4.15
L	a	2.96	3.28	4.11	4.16	4.18	>4.20	>4.20	>4.20	>4.20	>4.20
	b	<2.90	3.14	3.92	4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
	c	2.96	2.98	<2.90	3.02	3.15	3.62	3.78	4.00	4.10	4.06

Representative Plot values (median of 3 replicates)

C	2.96	<2.90	3.54	3.60	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
E	<2.90	3.01	3.03	3.55	4.05	>4.20	>4.20	>4.20	>4.20	>4.20
F	2.96	2.98	<2.90	2.92	3.02	3.72	>4.20	>4.20	>4.20	>4.20
I	2.96	3.04	3.31	4.15	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
K	3.08	3.04	3.32	3.58	3.62	3.72	4.03	>4.20	>4.20	>4.20
L	2.96	3.14	3.92	4.16	4.18	>4.20	>4.20	>4.20	>4.20	>4.20

Representative Treatment Values (median of 6 Plot medians)

2.96	3.03	3.32	3.59	4.12	>4.20	>4.20	>4.20	>4.20	>4.20

pF at 24 in. (Non-irrigated plots) - Continued

Feb.				Mar.					Apr.			
1	8	15	22	1	8	15	22	30	5	12	19	26
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
4.08	4.18	4.10	4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	4.05	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	4.08	4.17	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20

pF at 24 in. (Non-irrigated plots) - Continued

May					June			July	Aug.	Sept.
3	10	18	24	31	9	14	28	12	9	8
>4.20	>4.20	4.10	>4.20	>4.20	3.05	3.06	3.06	3.05	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	<2.90	3.03	<2.90	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	4.18	3.09	3.07	<2.90	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	3.21	3.00	<2.90	2.97	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	3.23	3.00	2.94	2.97	3.01	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	4.08	3.06	3.01	3.06	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	<2.90	3.00	2.94	<2.90	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	2.99	3.05	3.01	<2.90	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	3.05	<2.90	<2.90	3.05	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	2.94	2.94	3.05	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	4.07	3.03	3.01	3.08	2.94	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	2.94	<2.90	2.94	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	3.02	2.97	<2.90	3.06	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	3.03	3.05	<2.90	3.06	2.94	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	2.99	2.97	2.94	3.06	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	3.77	2.95	2.94	3.00	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	3.03	<2.90	2.94	3.00	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	3.52	<2.90	<2.90	2.94	<2.90	<2.90	<2.90

>4.20	>4.20	>4.20	>4.20	>4.20	3.05	3.06	<2.90	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	3.23	3.00	2.94	2.97	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	2.99	3.05	2.94	<2.90	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	2.94	2.94	3.05	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	3.02	2.97	<2.90	3.06	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	3.52	<2.90	2.94	3.00	<2.90	<2.90	<2.90

>4.20	>4.20	>4.20	>4.20	3.38	2.99	2.94	2.99	<2.90	<2.90	<2.90

pF at 24 in. (Non-irrigated plots) - Continued

Oct.					Nov.			Dec.			Jan. 1956	
5	14	18	21	25	1	15	25	6	13	20	3	10
2.95	2.98	3.13	3.20	3.60	3.87	4.15	4.17	>4.20	>4.20	>4.20	>4.20	>4.20
3.12	3.12	3.01	3.12	3.12	3.60	4.00	4.07	4.15	>4.20	>4.20	>4.20	>4.20
<2.90	2.96	3.07	3.16	3.37	4.15	4.09	4.13	4.18	>4.20	>4.20	>4.20	>4.20
<2.90	2.96	2.96	<2.90	2.96	3.23	3.91	4.12	4.18	>4.20	>4.20	>4.20	>4.20
<2.90	2.96	3.02	3.15	3.07	3.31	3.94	4.10	4.09	>4.20	>4.20	>4.20	>4.20
<2.90	<2.90	2.96	<2.90	2.96	3.07	3.51	3.91	3.97	>4.20	>4.20	>4.20	>4.20
<2.90	2.96	3.15	3.15	3.39	3.98	4.04	4.11	4.10	>4.20	>4.20	>4.20	>4.20
<2.90	2.96	3.07	3.09	3.24	3.69	3.94	4.08	4.04	4.13	>4.20	>4.20	>4.20
<2.90	3.05	3.23	3.34	3.64	3.93	4.02	>4.20	4.13	>4.20	>4.20	>4.20	>4.20
<2.90	3.53	3.72	3.91	4.09	4.18	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
<2.90	2.99	3.52	3.56	3.65	3.71	3.81	3.89	3.97	4.08	>4.20	>4.20	>4.20
3.02	3.58	3.74	3.97	4.10	4.10	4.15	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
<2.90	3.44	3.73	4.06	>4.20	4.15	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
<2.90	3.23	3.25	3.35	3.51	3.88	4.09	4.18	>4.20	>4.20	>4.20	>4.20	>4.20
<2.90	3.62	3.80	4.06	>4.20	4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
2.96	3.09	3.22	3.34	3.90	4.08	4.13	>4.20	4.16	>4.20	>4.20	>4.20	>4.20
3.09	3.42	3.71	3.69	3.72	3.82	3.93	4.13	4.18	>4.20	>4.20	>4.20	>4.20
3.12	3.37	3.60	3.89	4.13	4.15	4.19	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
2.95	2.98	3.07	3.16	3.37	3.87	4.09	4.13	4.18	>4.20	>4.20	>4.20	>4.20
<2.90	2.96	2.96	<2.90	2.96	3.23	3.91	4.10	4.09	>4.20	>4.20	>4.20	>4.20
<2.90	2.96	3.15	3.15	3.39	3.93	4.02	4.11	4.10	>4.20	>4.20	>4.20	>4.20
<2.90	3.53	3.72	3.91	4.09	4.10	4.15	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
<2.90	3.44	3.73	4.06	>4.20	4.15	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
3.09	3.37	3.60	3.69	3.90	4.08	4.13	>4.20	4.18	>4.20	>4.20	>4.20	>4.20
<2.90	3.18	3.38	3.43	3.65	4.01	4.11	4.17	4.18	>4.20	>4.20	>4.20	>4.20

Values of pF at depth of 36 in.

(Non-Irrigated Plots)

Plot	Replicate	Nov. 1954		Dec.				Jan. 1955			
		22	26	7	14	21	28	4	11	18	25
C	a	<2.90	<2.90	<2.90	<2.90	4.03	4.04	4.06	>4.20	>4.20	>4.20
	b	2.96	2.97	2.97	3.18	3.99	4.10	>4.20	>4.20	>4.20	>4.20
	c	<2.90	<2.90	<2.90	<2.90	<2.90	2.98	>4.20	>4.20	>4.20	>4.20
E	a	2.96	3.01	3.03	3.10	3.19	3.19	4.09	>4.20	>4.20	>4.20
	b	<2.90	<2.90	<2.90	3.00	3.89	>4.20	>4.20	>4.20	>4.20	>4.20
	c	<2.90	<2.90	<2.90	<2.90	4.08	>4.20	>4.20	3.70	>4.20	>4.20
F	a	<2.90	3.01	2.97	2.99	3.01	3.52	4.08	4.09	4.10	4.18
	b	3.03	<2.90	<2.90	<2.90	2.92	2.93	3.07	3.73	4.04	4.13
	c	<2.90	<2.90	<2.90	<2.90	3.04	3.57	4.05	4.15	>4.20	4.18
I	a	2.96	2.97	2.97	3.01	3.01	3.15	3.26	3.60	3.74	3.98
	b	2.96	3.03	3.03	3.12	3.09	3.42	3.69	4.19	>4.20	4.20
	c	2.96	3.03	<2.90	2.92	3.14	3.73	4.08	4.13	4.13	4.19
K	a	<2.90	2.97	2.97	3.00	3.04	3.14	3.22	3.91	4.18	>4.20
	b	3.00	3.09	2.97	3.05	<2.90	2.98	3.01	2.94	3.09	3.28
	c	2.96	3.03	2.97	3.19	3.37	3.59	4.18	>4.20	>4.20	>4.20
L	a	<2.90	<2.90	<2.90	<2.90	<2.90	2.93	3.93	4.05	4.08	4.06
	b	<2.90	<2.90	<2.90	<2.90	<2.90	2.98	4.10	>4.20	>4.20	>4.20
	c	2.96	2.97	2.90	2.92	2.98	3.51	4.00	4.15	>4.20	3.83

Representative Plot values (median of 3 replicates)

C	<2.90	<2.90	<2.90	<2.90	3.99	4.04	>4.20	>4.20	>4.20	>4.20
E	<2.90	<2.90	<2.90	3.00	3.89	>4.20	>4.20	>4.20	>4.20	>4.20
F	<2.90	<2.90	<2.90	<2.90	3.01	3.52	4.05	4.09	4.10	4.18
I	2.96	3.03	2.97	3.01	3.09	3.42	3.69	4.13	4.13	4.19
K	2.96	3.03	2.97	3.05	3.04	3.14	3.22	3.91	4.18	>4.20
L	<2.90	<2.90	<2.90	<2.90	<2.90	2.98	4.00	4.15	>4.20	4.06

Representative Treatment Values (median of 6 Plot medians)

<2.90	<2.90	<2.90	2.95	3.07	3.47	4.03	4.14	4.19	4.20

pF at 36 in. (Non-irrigated plots) - Continued

Feb.				Mar.					Apr.			
1	8	15	22	1	8	15	22	30	5	12	19	26
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
4.09	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
3.51	3.82	3.90	3.94	4.08	4.15	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
4.15	>4.20	4.16	4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
4.08	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
4.15	>4.20	4.16	4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20

pF at 36 in. (Non-irrigated plots) - Continued

May					June			July	Aug.	Sept.
3	10	18	24	31	9	14	28	12	9	8
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	<2.90	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	3.01	3.04	<2.90	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	4.13	3.98	<2.90	3.03	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	4.09	3.30	3.29	<2.90	3.00	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	3.24	3.04	3.04	<2.90	<2.90	<2.90	<2.90
>4.20	>4.20	4.13	>4.20	4.12	>4.20	>4.20	3.05	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	<2.90	2.95	2.98	2.95	3.00	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.07	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	4.17	<2.90	3.02	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.03	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	3.07	3.01	3.07	3.01	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	4.19	3.91	2.94	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	3.04	3.01	3.06	<2.90	<2.90	<2.90
>4.20	4.11	>4.20	>4.20	4.15	>4.20	>4.20	3.06	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	<2.90	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	<2.90	2.95	3.01	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	4.11	3.01	3.02	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	<2.90	2.92	<2.90	2.92	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	4.13	3.98	<2.90	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	4.09	3.30	3.29	<2.90	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	4.17	2.95	3.00	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	4.19	3.91	3.03	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.06	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	<2.90	2.95	3.01	2.92	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	4.16	3.95	2.98	<2.90	<2.90	<2.90

pF at 36 in. (Non-irrigated plots) - Continued

Oct.					Nov.			Dec.			Jan. 1956	
5	14	18	21	25	1	15	25	6	13	20	3	10
<2.90	2.96	3.12	3.32	3.76	3.97	4.03	4.05	4.01	4.11	>4.20	>4.20	>4.20
3.13	3.09	3.11	3.16	3.37	3.87	3.97	4.03	4.11	4.10	>4.20	>4.20	>4.20
<2.90	2.96	3.07	3.11	3.01	3.23	3.64	3.88	3.88	4.10	>4.20	>4.20	>4.20
<2.90	3.09	3.12	3.12	3.20	3.47	3.94	4.09	4.18	>4.20	>4.20	>4.20	>4.20
<2.90	<2.90	3.07	3.14	2.94	3.12	3.93	4.09	4.10	4.18	>4.20	>4.20	>4.20
<2.90	2.98	3.02	3.07	3.40	3.98	4.03	>4.20	4.13	>4.20	>4.20	>4.20	>4.20
<2.90	2.93	3.09	3.12	3.31	3.81	3.87	4.01	3.94	4.10	4.20	>4.20	>4.20
3.02	3.19	3.17	3.17	3.15	3.99	3.50	4.05	4.16	4.09	>4.20	>4.20	>4.20
<2.90	<2.90	2.96	<2.90	2.94	3.25	3.94	4.06	4.13	4.19	>4.20	>4.20	>4.20
<2.90	3.29	3.45	3.68	3.93	4.10	4.17	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
<2.90	3.22	3.28	3.38	3.56	3.86	3.99	4.08	4.10	4.18	>4.20	>4.20	>4.20
2.98	3.24	3.36	3.47	3.66	3.93	4.03	4.16	>4.20	>4.20	>4.20	>4.20	>4.20
<2.90	3.11	4.01	3.09	3.51	4.02	4.18	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
<2.90	3.04	2.96	3.01	3.05	3.19	3.69	4.01	4.03	4.18	>4.20	>4.20	>4.20
<2.90	3.09	3.12	3.14	3.26	3.68	3.93	4.07	4.11	>4.20	>4.20	>4.20	>4.20
<2.90	<2.90	2.98	3.14	3.76	4.02	4.05	4.19	4.18	>4.20	>4.20	>4.20	>4.20
3.06	3.09	3.12	3.16	3.29	3.77	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
2.95	2.98	3.17	3.23	3.77	4.05	4.12	>4.20	4.18	>4.20	>4.20	>4.20	>4.20
<2.90	2.96	3.11	3.16	3.37	3.87	3.97	4.03	4.01	4.10	>4.20	>4.20	>4.20
<2.90	2.98	3.07	3.12	3.20	3.47	3.94	4.09	4.13	>4.20	>4.20	>4.20	>4.20
<2.90	2.95	3.09	3.12	3.15	3.88	3.87	4.05	4.13	4.10	>4.20	>4.20	>4.20
<2.90	3.24	3.36	3.47	3.66	3.93	4.03	4.16	>4.20	>4.20	>4.20	>4.20	>4.20
<2.90	3.09	3.12	3.09	3.26	3.68	3.93	4.07	4.11	>4.20	>4.20	>4.20	>4.20
2.95	2.98	3.12	3.16	3.76	4.02	4.12	>4.20	4.18	>4.20	>4.20	>4.20	>4.20
<2.90	2.98	3.12	3.14	3.32	3.88	3.96	4.08	4.13	>4.20	>4.20	>4.20	>4.20

Values of pF at depth of 48 in.
(Non-Irrigated Plots)

Plot	Replicate	Nov. 1954		Dec.				Jan. 1955			
		22	26	7	14	21	28	4	11	18	25
C	a	<2.90	<2.90	<2.90	<2.90	<2.90	3.51	>4.20	>4.20	>4.20	>4.20
	b	2.96	2.96	2.97	2.95	2.97	2.90	2.99	3.85	3.93	4.02
	c	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	3.05	3.22	3.75	3.99
E	a	<2.90	<2.90	<2.90	2.93	2.97	3.00	<2.90	4.09	4.07	4.05
	b	<2.90	<2.90	2.90	2.98	3.11	3.52	4.13	>4.20	>4.20	>4.20
	c	<2.90	<2.90	<2.90	2.90	2.97	3.10	3.91	2.94	4.19	4.20
F	a	<2.90	<2.90	<2.90	<2.90	<2.90	2.98	>4.20	>4.20	>4.20	>4.20
	b	<2.90	<2.90	<2.90	<2.90	<2.90	2.91	3.11	3.68	3.70	3.74
	c	<2.90	<2.90	<2.90	<2.90	2.92	2.92	<2.90	3.90	3.91	4.04
I	a	2.96	2.96	2.97	2.98	<2.90	3.39	3.21	4.03	4.01	4.03
	b	2.96	2.96	2.97	3.00	3.03	3.45	<2.90	3.61	3.72	3.95
	c	2.96	2.96	<2.90	2.95	2.97	3.17	3.78	4.03	4.00	4.07
K	a	2.96	3.03	2.97	2.97	2.97	3.00	3.08	3.05	3.15	3.84
	b	2.96	3.03	2.97	2.97	<2.90	3.51	3.88	3.94	3.98	4.04
	c	2.96	2.96	2.97	2.97	2.97	3.10	3.05	3.17	3.17	3.21
L	a	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	3.79	3.91	3.91	3.95
	b	<2.90	<2.90	<2.90	<2.90	<2.90	2.91	3.78	3.94	3.97	3.99
	c	2.96	<2.90	<2.90	<2.90	<2.90	2.90	<2.90	<2.90	3.08	3.00

Representative Plot Values (median of 3 replicates)

C	<2.90	<2.90	<2.90	<2.90	<2.90	2.90	3.05	3.85	3.75	4.02
E	<2.90	<2.90	<2.90	2.93	2.97	3.10	3.91	4.09	4.19	4.20
F	<2.90	<2.90	<2.90	<2.90	<2.90	2.92	3.11	3.90	3.91	4.04
I	2.96	2.96	2.97	2.98	2.97	3.39	3.21	4.03	4.00	4.03
K	2.96	3.03	2.97	2.97	2.97	3.10	3.08	3.17	3.17	3.84
L	<2.90	<2.90	<2.90	<2.90	<2.90	2.90	3.78	3.91	3.91	3.95

Representative Treatment Values (median of 6 Plot medians)

<2.90	<2.90	<2.90	2.91	2.93	3.02	3.16	3.91	3.91	4.03

pF at 48 in. (Non-irrigated plots) - Continued

Feb.				Mar.					Apr.			
1	8	15	22	1	8	15	22	30	5	12	19	26
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	4.18	>4.20	>4.20	>4.20	>4.20	>4.20
4.19	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
4.13	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
4.10	>4.20	4.18	4.18	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	4.11	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
3.80	4.00	4.01	4.06	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
4.05	4.13	4.08	4.11	4.15	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
4.03	4.10	4.11	4.12	>4.20	4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
4.07	4.14	4.09	4.12	4.15	4.17	4.17	>4.20	4.18	>4.20	>4.20	>4.20	>4.20
4.18	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
4.07	>4.20	4.12	4.20	4.18	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
4.03	4.15	4.12	4.18	>4.20	4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
3.33	3.60	3.60	3.72	3.85	3.92	3.95	3.99	>4.20	4.08	>4.20	4.13	>4.20
3.91	3.96	3.93	3.99	4.02	4.06	4.09	4.09	4.14	4.19	>4.20	>4.20	>4.20
3.93	4.04	4.05	4.07	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
3.01	3.06	3.11	3.90	4.04	4.02	>4.20	4.05	4.05	4.07	4.07	4.06	4.05
4.19	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
4.05	4.13	4.08	4.11	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
4.07	4.14	4.11	4.12	>4.20	4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
4.03	4.15	4.12	4.18	4.18	4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
3.91	3.96	3.93	3.99	4.04	4.06	>4.20	4.09	4.14	4.19	>4.20	>4.20	>4.20
4.06	4.15	4.12	4.15	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20

pF at 48 in. (Non-irrigated plots) - Continued

May					June			July	Aug.	Sept.
3	10	18	24	31	9	14	28	12	9	8
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	<2.90	3.06	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	<2.90	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.02	2.94	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	4.13	4.20	>4.20	4.18	4.05	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	4.08	>4.20	>4.20	<2.90	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	3.28	>4.20	>4.20	<2.90	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	4.19	<2.90	3.01	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	4.19	3.07	2.94	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	<2.90	3.01	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.02	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	3.85	>4.20	>4.20	3.07	3.01	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	2.98	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.07	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	2.92	<2.90	3.01	2.94	<2.90	<2.90
4.16	>4.20	4.18	4.15	4.10	4.15	4.14	<2.90	2.92	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.36	2.94	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.01	<2.90	<2.90	<2.90
4.10	4.00	4.09	4.07	4.09	4.10	4.06	<2.90	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	2.94	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	4.08	>4.20	>4.20	<2.90	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	4.19	<2.90	3.01	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.02	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	4.15	4.14	3.01	2.92	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.01	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	2.95	2.91	<2.90	<2.90

pF at 48 in. (Irrigated plots) - Continued

Oct.					Nov.			Dec.			Jan. 1956	
5	14	18	21	25	1	15	25	6	13	20	3	10
3.03	2.96	2.96	<2.90	<2.90	<2.90	3.22	3.72	3.83	3.97	4.13	>4.20	>4.20
<2.90	3.07	2.96	2.99	<2.90	<2.90	3.23	3.58	3.73	3.84	4.04	4.15	>4.20
<2.90	<2.90	2.96	<2.90	<2.90	<2.90	3.35	3.66	3.64	3.86	3.99	4.16	>4.20
<2.90	<2.90	2.96	<2.90	<2.90	<2.90	3.20	3.68	3.77	3.96	4.15	4.12	>4.20
<2.90	<2.90	<2.90	<2.90	3.11	3.67	3.89	4.05	4.05	4.15	>4.20	>4.20	>4.20
<2.90	<2.90	<2.90	<2.90	3.15	3.17	3.30	3.75	3.90	4.03	>4.20	>4.20	>4.20
<2.90	2.96	2.96	3.04	3.05	3.25	3.53	3.94	4.03	4.14	>4.20	>4.20	>4.20
<2.90	3.07	2.96	3.02	3.16	3.55	3.85	4.08	3.95	4.13	>4.20	>4.20	>4.20
2.94	3.05	3.05	3.07	3.21	3.33	3.80	3.95	4.00	4.07	4.17	>4.20	>4.20
3.01	3.22	3.19	3.35	3.72	3.87	3.94	4.05	4.06	4.12	>4.20	>4.20	>4.20
<2.90	3.12	<2.90	3.06	3.05	3.23	3.83	4.04	3.97	4.15	>4.20	>4.20	>4.20
3.00	<2.90	3.06	<2.90	2.96	3.16	3.39	3.73	3.82	3.99	>4.20	>4.20	>4.20
<2.90	2.98	<2.90	<2.90	3.03	3.47	3.72	3.86	3.85	3.98	>4.20	>4.20	>4.20
<2.90	3.05	2.96	3.05	3.06	3.09	3.09	3.13	3.20	3.25	>4.20	4.01	>4.20
<2.90	2.96	<2.90	2.96	2.96	2.96	3.06	3.13	3.08	3.24	>4.20	4.08	>4.20
2.97	3.50	3.56	3.72	3.94	4.04	4.08	>4.20	4.15	>4.20	>4.20	>4.20	>4.20
<2.90	3.08	3.12	3.24	3.25	3.22	3.59	3.78	3.86	3.94	4.05	>4.20	>4.20
<2.90	2.96	3.02	3.02	3.18	3.55	3.79	3.95	3.94	4.09	>4.20	>4.20	>4.20
<2.90	2.96	2.96	<2.90	<2.90	<2.90	3.23	3.66	3.73	3.86	4.04	4.16	>4.20
<2.90	<2.90	<2.90	<2.90	3.11	3.17	3.30	3.75	3.90	4.03	>4.20	>4.20	>4.20
<2.90	3.05	2.96	3.04	3.16	3.33	3.80	3.95	4.00	4.13	>4.20	>4.20	>4.20
3.00	3.12	3.06	3.06	3.05	3.23	3.83	4.04	3.97	4.12	>4.20	>4.20	>4.20
<2.90	2.98	<2.90	2.96	3.03	3.09	3.09	3.13	3.20	3.25	>4.20	4.03	>4.20
<2.90	3.08	3.12	3.24	3.25	3.55	3.79	3.95	3.94	4.09	>4.20	>4.20	>4.20
<2.90	3.01	2.96	3.00	3.08	3.20	3.55	3.85	3.92	4.06	>4.20	>4.20	>4.20

Values of pF at depth of 60 in.
(Non-Irrigated Plots)

Plot	Replicate	Nov. 1954		Dec.				Jan. 1955			
		22	26	7	14	21	28	4	11	18	25
C	a	<2.90	<2.90	<2.90	<2.90	<2.90	2.92	<2.90	3.71	3.72	3.69
	b	2.96	2.96	2.97	3.01	3.01	3.15	2.99	3.33	3.28	3.20
	c	<2.90	<2.90	<2.90	<2.90	<2.90	2.93	<2.90	2.92	2.99	2.99
E	a	<2.90	<2.90	<2.90	2.91	3.03	4.12	<2.90	2.99	2.99	<2.90
	b	<2.90	<2.90	<2.90	<2.90	<2.90	2.91	<2.90	3.02	3.30	3.49
	c	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	3.60	3.76
F	a	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	3.61	3.86	3.88	4.00
	b	<2.90	<2.90	<2.90	<2.90	<2.90	3.12	2.99	<2.90	<2.90	3.86
	c	4.00	3.97	4.02	3.15	4.00	3.62	3.93	4.10	>4.20	>4.20
I	a	2.96	2.96	2.97	3.15	<2.90	<2.90	2.99	2.99	3.10	2.99
	b	2.96	2.96	3.03	3.29	3.09	3.12	<2.90	3.05	3.05	3.36
	c	2.96	2.96	<2.90	2.90	2.97	2.97	<2.90	2.99	<2.90	3.17
K	a	2.96	<2.90	2.97	2.92	2.97	3.10	3.07	3.91	3.97	4.06
	b	2.96	3.03	2.97	3.04	<2.90	2.92	<2.90	2.99	2.92	2.99
	c	2.96	2.96	2.97	3.12	<2.90	3.15	3.94	4.05	4.05	4.06
L	a	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	2.99	<2.90	3.05
	b	<2.90	<2.90	<2.90	<2.90	<2.90	3.15	3.47	3.92	3.93	4.01
	c	<2.90	<2.90	<2.90	<2.90	<2.90	3.13	3.29	4.13	4.13	4.09

Representative Plot Values (median of 3 replicates)

C	<2.90	<2.90	<2.90	<2.90	<2.90	2.92	<2.90	3.33	3.28	3.20
E	<2.90	<2.90	<2.90	<2.90	<2.90	2.91	<2.90	2.99	3.30	3.49
F	<2.90	<2.90	<2.90	<2.90	<2.90	3.12	3.61	3.86	3.80	4.00
I	2.96	2.96	2.97	3.15	2.97	2.97	<2.90	2.99	3.05	3.17
K	2.96	2.96	2.97	3.04	<2.90	3.10	3.07	3.91	3.97	4.06
L	<2.90	<2.90	<2.90	<2.90	<2.90	3.13	3.29	3.92	3.93	4.01
	<2.90	<2.90	<2.90	<2.90	<2.90	3.04	2.98	3.60	3.55	3.75

pF at 60 in. (Non-irrigated plots) - Continued

Feb.				Mar.					Apr.			
1	8	15	22	1	8	15	22	30	5	12	19	26
3.66	3.79	3.71	3.78	3.84	3.94	3.91	4.00	4.00	4.02	4.03	4.05	4.06
3.28	3.47	3.46	3.64	3.93	4.05	3.99	4.06	4.13	4.13	4.15	4.10	4.13
3.16	3.92	3.96	4.01	4.13	4.13	>4.20	4.17	4.17	>4.20	4.20	4.20	>4.20
<2.90	<2.90	3.13	3.37	3.81	3.88	>4.20	3.87	3.92	3.94	4.01	3.99	4.07
3.64	3.76	3.80	3.84	3.90	4.04	>4.20	4.18	>4.20	>4.20	>4.20	>4.20	>4.20
3.77	3.89	3.84	3.92	3.99	4.01	4.00	4.04	4.04	4.06	4.10	4.08	4.15
4.00	4.14	4.11	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
4.00	4.00	4.02	4.14	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
>4.20	>4.20	4.16	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
<2.90	3.68	3.69	3.79	3.90	4.20	3.91	3.96	3.98	3.99	4.01	3.93	3.99
3.54	3.72	3.73	4.04	3.88	3.95	4.00	4.03	4.04	4.06	4.10	4.11	4.13
3.51	3.79	3.77	4.03	3.85	3.87	3.86	3.86	3.89	3.89	3.91	3.93	3.94
4.06	4.11	4.11	4.15	4.14	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
3.05	3.73	3.72	3.86	3.94	4.20	3.91	3.99	4.02	4.04	4.07	4.06	4.07
4.00	4.04	3.99	4.06	4.08	4.08	>4.20	4.06	4.06	4.07	4.10	4.08	4.15
3.51	3.92	3.86	3.96	4.03	4.06	4.11	4.11	4.18	4.18	4.20	>4.20	>4.20
3.98	4.05	3.99	4.03	4.08	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
4.04	4.15	4.08	4.08	4.11	4.18	>4.20	4.18	>4.20	4.20	>4.20	>4.20	>4.20
3.28	3.79	3.71	3.78	3.93	4.05	3.99	4.06	4.13	4.13	4.15	4.10	4.13
3.64	3.76	3.80	3.84	3.90	4.01	>4.20	4.04	4.04	4.06	4.10	4.08	4.15
4.00	4.14	4.11	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
3.51	3.72	3.73	4.03	3.88	3.95	3.91	3.96	3.98	3.99	4.01	3.93	3.99
4.00	4.04	3.99	4.06	4.08	4.20	>4.20	4.06	4.06	4.07	4.10	4.08	4.15
3.98	4.05	3.99	4.03	4.08	4.18	>4.20	4.18	>4.20	4.20	>4.20	>4.20	>4.20
3.81	3.92	3.90	4.03	4.01	4.12	>4.20	4.06	4.10	4.10	4.13	4.09	4.15

pF at 60 in. (Non-irrigated plots) - Continued

May					June			July	Aug.	Sept.
3	10	18	24	31	9	14	28	12	9	8
4.09	>4.20	4.08	4.05	4.19	4.07	4.05	4.03	4.00	<2.90	<2.90
4.15	4.20	4.18	4.15	4.20	4.10	4.10	4.08	3.65	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	4.16	>4.20	4.17	>4.20	3.84	<2.90	<2.90
4.10	4.04	4.18	4.14	4.03	4.10	>4.20	4.04	3.96	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	4.06	4.20	4.14	4.09	3.29	<2.90	<2.90
4.11	4.20	4.15	4.13	4.02	4.20	4.14	<2.90	2.99	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.93	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	4.19	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	4.15	4.14	3.91	3.98	<2.90	<2.90
4.02	4.05	>4.20	4.03	4.03	4.06	4.03	<2.90	<2.90	<2.90	<2.90
4.10	4.12	>4.20	4.13	4.09	4.10	4.12	2.96	3.01	<2.90	<2.90
3.97	3.96	3.98	3.99	>4.20	>4.20	>4.20	3.04	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	<2.90	3.72	<2.90	<2.90
4.08	>4.20	4.09	4.10	4.06	4.10	4.08	2.95	<2.90	<2.90	<2.90
4.09	4.08	4.09	4.10	4.13	4.08	4.10	<2.90	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.29	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	4.15	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	2.95	<2.90	<2.90	<2.90
4.15	>4.20	4.18	4.15	4.19	4.10	4.10	4.08	3.84	<2.90	<2.90
4.11	4.20	4.18	4.14	4.03	4.20	4.14	4.04	3.29	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.98	<2.90	<2.90
4.02	4.05	>4.20	4.03	4.09	4.10	4.12	2.96	<2.90	<2.90	<2.90
4.09	>4.20	4.09	4.10	4.13	4.10	4.10	<2.90	<2.90	<2.90	<2.90
>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20	3.29	<2.90	<2.90	<2.90
4.14	>4.20	4.19	4.15	4.16	4.15	4.13	3.67	3.09	<2.90	<2.90

pF at 60 in. (Non-irrigated plots) - Continued

Oct.					Nov.			Dec.			Jan. 1856	
5	14	18	21	25	1	15	25	6	13	20	3	10
<2.90	<2.90	<2.90	<2.90	<2.90	3.11	3.66	3.81	3.78	4.03	4.09	4.18	>4.20
<2.90	3.06	<2.90	<2.90	<2.90	2.94	3.09	3.44	3.69	3.93	4.12	>4.20	>4.20
<2.90	<2.90	<2.90	<2.90	<2.90	3.12	3.06	3.27	3.68	3.87	4.07	>4.20	>4.20
<2.90	2.92	<2.90	<2.90	<2.90	3.07	2.95	3.06	3.41	4.06	4.15	4.15	>4.20
<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	3.27	3.83	4.15	4.08	>4.20
<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	3.23	3.84	3.88	4.13	4.12	4.12	>4.20
<2.90	<2.90	<2.90	<2.90	<2.90	2.94	3.67	3.95	3.89	4.03	4.15	>4.20	>4.20
<2.90	<2.90	2.96	<2.90	2.90	3.05	3.71	3.95	3.93	3.98	4.19	4.18	>4.20
<2.90	>4.20	<2.90	4.08	>4.20	4.13	4.12	4.11	4.12	>4.20	>4.20	>4.20	>4.20
<2.90	3.95	3.95	3.97	4.11	>4.20	4.18	>4.20	>4.20	>4.20	>4.20	>4.20	>4.20
<2.90	3.03	3.10	3.07	3.09	3.23	3.82	4.00	3.98	4.11	4.17	>4.20	>4.20
<2.90	3.16	3.10	3.12	3.27	3.83	4.03	4.12	4.08	4.18	>4.20	>4.20	>4.20
<2.90	3.02	3.05	3.05	3.02	3.22	3.99	>4.20	4.15	>4.20	>4.20	>4.20	>4.20
<2.90	3.05	3.08	3.07	3.07	3.06	3.14	3.68	3.83	4.06	>4.20	>4.20	>4.20
<2.90	3.03	3.06	3.07	3.07	3.11	3.50	3.96	3.96	4.09	>4.20	>4.20	>4.20
<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	2.92	2.92	<2.90	2.92	3.24	>4.20	>4.20
3.01	3.06	3.05	<2.90	<2.90	2.94	3.03	3.61	3.38	4.11	>4.20	>4.20	>4.20
<2.90	2.92	<2.90	<2.90	<2.90	2.94	2.99	3.23	3.50	3.80	4.03	>4.20	>4.20
<2.90	<2.90	<2.90	<2.90	<2.90	3.11	3.09	3.44	3.69	3.93	4.09	>4.20	>4.20
<2.90	<2.90	<2.90	<2.90	<2.90	<2.90	2.95	3.06	3.41	4.06	4.15	4.12	>4.20
<2.90	<2.90	<2.90	<2.90	2.90	3.05	3.71	3.95	3.93	4.03	4.19	>4.20	>4.20
<2.90	3.16	3.10	3.12	3.27	3.83	4.03	4.12	4.08	4.18	>4.20	>4.20	>4.20
<2.90	3.03	3.06	3.07	3.07	3.11	3.50	3.96	3.96	4.09	>4.20	>4.20	>4.20
<2.90	2.92	<2.90	<2.90	<2.90	2.94	2.99	3.23	3.50	3.80	4.03	>4.20	>4.20
<2.90	2.91	<2.90	<2.90	<2.90	3.08	3.20	3.70	3.81	4.05	4.17	>4.20	>4.20

APPENDIX C

TABLE 1

Average Moisture Content, Date and Amount of Water Applied (Irrigation + Rain)
(Irrigated Plot)

Plot B

Date of Recording	Average Moisture Content of Soil* 3 replicates						Irrigation †		Rain †	
	0"-9"	9"-18"	18"-30"	30"-42"	42"-54"	54"-66"	Date	Amount (in.)	Date	Amount (in.)
	%	%	%	%	%	%				
Nov. 22, 1954	13.4	14.0	26.9	25.7	25.7	21.5	Nov. 22,1954	0.50		
26	12.3	10.3	22.9	22.2	24.4	21.5				
									Dec. 3,1954	0.270
Dec. 7	8.8	8.3	22.6	22.7	24.4	21.5			7	0.005
									9	0.180
									11	1.070
14	11.9	9.2	21.9	22.0	24.4	21.5				
21	7.8	7.6	21.2	19.1	24.4	20.3	Dec. 21	2.10		
							23	1.32		
28	14.0	14.8	23.1	22.9	23.4	20.3				
									Jan. 3,1955	0.050
Jan. 4, 1955	9.9	9.1	21.3	17.9	22.8	21.5	Jan. 4,1955	0.80		
							6	0.66		
11	12.7	14.6	22.5	17.9	21.1	15.4	11	0.70		
							13	0.74		
18	13.6	14.4	22.9	17.9	19.4	16.7				
							20	1.00		
							22	0.57		
25	13.4	14.3	23.8	19.4	19.3	17.0	25	0.50		
							27	0.45		
									30	0.020
									31	0.015
Feb. 1	14.4	13.7	23.0	19.4	19.6	16.9	Feb. 1	1.11	Feb. 1	0.035
							3	1.00		
8	12.8	12.6	21.7	18.4	19.6	16.8				
									9	1.565
15	12.1	12.9	21.8	18.3	18.7	16.6			15	0.570
22	9.3	8.8	21.2	18.1	18.2	16.3	22	0.96		
							24	0.70		

(Continued -

TABLE 1 (Cont'd)

Date of Recording	Average Moisture Content of Soil* 3 replicates						Irrigation †		Rain †	
	0"-9"	9"-18"	18"-30"	30"-42"	42"-54"	54"-66"	Date	Amount (in.)	Date	Amount (in.)
	%	%	%	%	%	%				
Mar. 1, 1955	13.7	14.5	21.3	18.2	18.4	16.3	Mar. 1	1.52		
							3	1.10		
									Mar. 5	0.050
8	13.3	14.6	22.3	19.8	18.0	16.3				
							10	0.40		
15	13.6	12.8	21.7	20.0	17.9	15.7	15	0.40		
							17	0.60		
									21	0.005
22	14.4	11.4	21.2	19.6	17.6	15.6	22	0.39	22	0.100
							29	0.55		
30	11.2	12.8	21.0	19.4	17.6	15.4				
									Apr. 1	0.015
									2	0.010
Apr. 5	10.4	12.3	20.6	18.6	17.6	15.3	Apr. 5	1.03		
									6	0.010
12	9.1	10.5	20.5	18.2	17.4	15.3			12	0.140
									13	0.550
									14	0.330
									15	0.140
									18	0.090
19	11.3	10.7	20.6	18.3	17.4	15.2				

* Expressed as percentages of oven-dry soil.

† Appropriate allowance being made for runoff.

TABLE 2

Average Moisture Content, Date and Amount of Water Applied (Irrigation + Rain)

(Non-irrigated Plot)

Plot C

Date of Recording	Average Moisture Content of Soil* 3 replicates 0"-9" %	9"-18" %	18"-30" %	30"-42" %	42"-54" %	54"-66" %	Irrigation † Date	Irrigation † Amount (in.)	Rain † Date	Rain † Amount (in.)
Nov. 22, 1954	13.6	16.8	23.7	26.9	24.4	21.5	Nov. 22, 1954	0.50		
26	12.6	16.8	23.8	26.5	24.4	21.5				
									Dec. 3, 1954	0.270
Dec. 7	7.9	9.7	21.8	26.6	24.3	21.5			7	0.005
									9	0.180
									11	1.070
14	7.4	8.7	21.0	25.0	24.3	21.0				
21	6.7	7.5	19.9	21.9	24.1	20.0				
28	6.6	7.5	19.9	20.2	21.8	19.0				
									Jan. 3, 1955	0.050
Jan. 4, 1955	6.6	7.4	19.9	17.8	19.4	18.0				
11	7.5	7.4	19.9	17.7	18.3	16.7				
							Jan. 14, 1955 15 16	1.50		
18	8.7	9.6	19.9	17.7	17.5	16.7				
25	8.2	11.2	19.9	17.7	17.2	16.8				
									Jan. 30	0.020
									31	0.015
Feb. 1	6.6	7.4	19.9	17.7	16.9	16.5			Feb. 1	0.035
8	6.6	7.4	19.9	17.7	16.9	15.5				
									9	1.565
15	9.3	11.3	19.9	17.7	16.9	15.5			15	0.570
22	6.9	7.4	19.9	17.7	16.9	15.3				
Mar. 1	6.6	7.4	19.9	17.7	16.9	14.9				
									Mar. 5	0.050
8	6.6	7.4	19.9	17.7	16.9	14.7				
15	6.6	7.4	19.9	17.7	16.9	14.8				
									21	0.005
22	6.6	7.4	19.9	17.7	16.9	14.6			22	0.100
30	6.6	7.4	19.9	17.7	16.9	14.6				
									Apr. 1	0.015
									2	0.010
Apr. 5	6.6	7.4	19.9	17.7	16.9	14.6			6	0.010
12	6.6	7.4	19.9	17.7	16.9	14.5			12	0.140
									13	0.550
									14	0.330
									15	0.140
									18	0.090
Apr. 19	8.7	7.4	19.9	17.7	16.9	14.6				

* Expressed as percentages of oven-dry soil.

† Appropriate allowance being made for runoff.

APPENDIX D

The period 1954, Nov. 23 to 26 (inclusive) will be referred to as period 1
" 27 to Dec. 7 " " " " 2
" 8 to 14 " " " " 3
" 15 to 21 " " " " 4
" 22 to 28 " " " " 5
" Dec. 29 to Jan. 4, 1955 " " " " 6
" Jan. 5 to 11 " " " " 7
" 12 to 18 " " " " 8
" 19 to 25 " " " " 9
" Jan. 26 to Feb. 1 " " " " 10
" Feb. 2 to 8 " " " " 11
" 9 to 15 " " " " 12
" 16 to 22 " " " " 13
" Feb. 23 to Mar. 1 " " " " 14
" Mar. 2 to 8 " " " " 15
" 9 to 15 " " " " 16
" 16 to 22 " " " " 17
" 23 to 30 " " " " 18
" Mar. 31 to Apr. 5 " " " " 19
" Apr. 6 to 12 " " " " 20
" 13 to 19 " " " " 21

Table 1

Summary of Climatic Conditions

Period	Mean Daily Values of Air Temperature (°F)			Mean Solar Radiation (equiv. mm/day)	Mean Evaporation from free water surface (in./day)	Mean Saturation Deficit (in. Hg)	Mean Duration of Sunshine (Hrs/day)	Mean Wind Speed (miles-day)
	Mean T_a	Max.	Min.	R_C	E_W		n	U_2
1	71.61	82.18	61.03	11.70	0.257	0.427	11.30	92.48
2	68.24	78.69	57.79	10.52	0.244	0.290	9.36	84.50
3	69.35	79.67	59.03	9.13	0.209	0.348	7.13	102.64
4	68.80	79.66	57.94	11.61	0.261	0.385	10.80	94.89
5	72.78	82.77	62.79	10.96	0.314	0.427	9.84	101.39
6	75.49	87.77	63.20	8.95	0.323	0.516	6.80	123.31
7	66.25	76.60	55.89	11.89	0.257	0.311	11.30	86.42
8	77.82	89.70	65.94	10.13	0.310	0.645	8.74	85.83
9	74.52	86.63	62.41	11.67	0.340	0.529	11.26	114.67
10	75.18	82.06	68.29	9.87	0.304	0.405	8.71	125.99
11	77.62	89.27	65.96	10.15	0.325	0.574	9.39	113.69
12	77.82	84.46	71.17	7.33	0.139	0.263	5.24	68.66
13	70.24	79.66	60.81	10.37	0.249	0.371	10.44	85.31
14	68.46	78.61	58.31	10.03	0.262	0.337	10.44	108.56
15	65.47	73.97	56.97	8.02	0.206	0.269	7.76	91.27
16	65.93	75.29	56.57	8.45	0.197	0.310	9.04	87.52
17	72.82	80.70	64.93	6.57	0.185	0.411	6.23	105.75
18	68.28	76.34	60.21	6.25	0.150	0.282	6.25	82.76
19	63.58	71.88	55.28	5.50	0.176	0.282	5.32	108.07
20	69.96	78.77	61.13	6.03	0.153	0.374	6.89	85.51
21	60.20	66.94	53.46	5.36	0.133	0.204	6.10	85.92

Table 2

Relation between Water Use, Mean Air Temperature and Total Available Water

Period	Water Use (in./day) Z	Mean Air Temperature (°F) X	Total Available Water (in.) Y
1	0.365	71.61	7.32
2	0.110	68.24	6.44
3	0.161	69.35	6.32
4	0.197	68.80	5.20
5	0.234	72.78	6.71
6	0.239	72.49	4.84
7	0.232	66.25	6.41
8	0.271	77.82	5.69
9	0.163	74.52	5.58
10	0.243	75.18	4.65
11	0.257	77.62	5.55
12	0.257	77.82	4.67
13	0.171	70.24	3.54
14	0.200	68.46	3.97
15	0.143	65.47	5.82
16	0.143	65.93	4.65
17	0.143	72.82	4.46
18	0.163	68.28	3.84
19	0.150	63.58	3.68
20	0.157	69.96	4.66
21	0.100	60.20	4.36

Analysis of Variance

Variation	d.f.	S.S.	M.S.	V.R.	
Due to Z	20	0.08113			
Regression on X and Y	2	0.04072	0.02036	9.07	XXX
Regression on X alone	1	0.03192	0.03192	14.22	XXX
Additional for Additional of Y to regression on X alone	1	0.00880	0.00880	3.92	X
Residual about regression on X and Y	18	0.04041	0.002245		
		S.E.	± 0.047		

Table 3

Relation between Water Use, Irrigation + Rain, and Amount of Available Water Stored in the Soil

(Non-Irrigated Plots)

Period	Water Use (in./day) Z	Irrigation + Rain (in./day) X_1	Available Water Stored in the soil (in.) X_2
1	0.275	0.125	6.10
2	0.134	0.026	5.49
3	0.256	0.179	4.30
4	0.097	0.000	3.70
5	0.110	0.000	3.09
6	0.114	0.007	2.32
7	0.064	0.000	1.57
8	0.134	0.214	1.12
9	0.099	0.000	1.68
10	0.080	0.010	0.99
11	0.033	0.000	0.50
12	0.143	0.224	0.27
13	0.161	0.081	0.84
14	0.024	0.000	0.28
15	0.010	0.007	0.11
16	0.006	0.000	0.10
17	0.016	0.016	0.05
18	0.000	0.000	0.05
19	0.010	0.004	0.05
20	0.019	0.021	0.02
21	0.099	0.154	0.05

Analysis of Variance

Variation	d.f.	S.S.	M.S.	V.R.	
Due to Z	20	0.121542			
Regression on X_1 and X_2	2	0.106815	0.053408	65.29	XXX
Regression on X_1 alone	1	0.051794	0.051794	63.32	XXX
Additional for Additional of X_2 to regression on X_1 alone	1	0.055021	0.055021	67.26	XXX
Residual about regression on X_1 and X_2	18	0.014717	0.000818		

Table 4

Amount of Available Water Stored in the Soil, Irrigation + Rain and the Total Available Water for Each Period

(Irrigated Plots)

Period	Available Water Stored in the Soil at the beginning of the period (in.) Ws	Irrigation + Rain during period (in.) I + R	Total Available Water during period (in.) Wa	Wa (in./day)	30.4 x Wa (in./month)
1	6.82	0.50	7.32	1.83	55.63
2	6.02	0.42	6.44	0.59	17.94
3	5.07	1.25	6.32	0.90	27.36
4	5.20	0.00	5.20	0.74	22.50
5	4.08	2.63	6.71	0.96	29.18
6	4.79	0.05	4.84	0.69	21.00
7	3.89	2.52	6.41	0.92	28.00
8	4.09	1.60	5.69	0.81	24.62
9	4.48	1.10	5.58	0.80	24.32
10	3.65	1.00	4.65	0.66	20.06
11	3.79	1.76	5.55	0.79	24.02
12	3.13	1.54	4.67	0.67	20.37
13	2.94	0.60	3.54	0.51	15.50
14	2.07	1.90	3.97	0.57	17.33
15	3.62	2.20	5.82	0.83	25.32
16	3.85	0.80	4.65	0.66	20.06
17	3.26	1.20	4.46	0.64	19.46
18	3.19	0.65	3.84	0.48	14.60
19	3.38	0.33	3.71	0.62	18.85
20	3.56	1.11	4.67	0.67	20.37
21	3.10	1.08	4.18	0.60	18.24

Table 5

Relation between Water Use and Evaporation from a Free Water Surface

(Irrigated Plots)

Period	Water Use (in./day) Wi	Evaporation from a Free Water Surface (in./day) E_W	Index $Wi/E_W^{0.75}$
1	0.365	0.257	2.37
2	0.110	0.244	0.74
3	0.161	0.209	1.22
4	0.197	0.261	1.30
5	0.234	0.314	1.31
6	0.239	0.323	1.31
7	0.232	0.257	1.51
8	0.271	0.310	1.53
9	0.163	0.340	0.86
10	0.243	0.304	1.46
11	0.257	0.325	1.40
12	0.257	0.139	2.65
13	0.171	0.249	1.14
14	0.200	0.262	1.28
15	0.143	0.206	1.10
16	0.143	0.197	1.14
17	0.143	0.185	1.19
18	0.163	0.150	1.59
19	0.150	0.176	1.30
20	0.157	0.153	1.51
21	0.100	0.133	1.07

Table 6

Relation between Water Use, and Evaporation from a Free Water Surface

(Non-Irrigated Plots)

Period	Water Use (in./day) Wn	Evaporation from a Free Water Surface. (in./day) E_W	Index $W_n/E_W^{0.75}$ K
1	0.275	0.257	1.79
2	0.134	0.244	0.91
3	0.254	0.209	1.93
4	0.097	0.261	0.62
5	0.110	0.314	0.62
6	0.114	0.323	0.63
7	0.064	0.257	0.42
8	0.134	0.310	0.76
9	0.099	0.340	0.52
10	0.080	0.304	0.46
11	0.033	0.325	0.18
12	0.143	0.139	1.48
13	0.161	0.249	1.07
14	0.024	0.262	0.15
15	0.010	0.206	0.08
16	0.006	0.197	0.05
17	0.016	0.185	0.13
18	0.000	0.150	0.00
19	0.010	0.176	0.09
20	0.019	0.153	0.18
21	0.099	0.133	1.07

Table 7

Relation between Water Use, Evaporation from a Free Water Surface, Irrigation + Rain and Amount of Available Water Stored in the Soil

(Non-Irrigated Plots)

Period	Index $Wn/E_W^{0.75}$ Z	Irrigation + Rain (in./day) X	Available Water Stored in the Soil (in.) Y
1	1.79	0.125	6.10
2	0.91	0.026	5.49
3	1.93	0.179	4.30
4	0.62	0.000	3.70
5	0.62	0.000	3.09
6	0.63	0.007	2.32
7	0.42	0.000	1.57
8	0.76	0.214	1.12
9	0.52	0.000	1.68
10	0.46	0.010	0.99
11	0.18	0.000	0.50
12	1.48	0.224	0.27
13	1.07	0.081	0.84
14	0.15	0.000	0.28
15	0.08	0.007	0.11
16	0.05	0.000	0.10
17	0.13	0.016	0.05
18	0.00	0.000	0.05
19	0.09	0.004	0.05
20	0.18	0.021	0.02
21	1.07	0.154	0.05

Analysis of Variance

Variation	d.f.	S.S.	M.S.	V.R.	
Due to Z	20	7.518			
Regression on X and Y	2	5.918	2.959	33.3	XXX
Regression on X alone	1	4.778	4.778	53.8	XXX
Additional for additional of Y to regression on X alone	1	1.140	1.140	12.8	XXX
Residual about regression on X and Y	18	1.600	0.0889		

APPENDIX E

Table 1

Calculations for Calculation of Potential Transpiration by Penman's Formula
(Waite Institute)

Period (inclusive)	T_a (°F)	Wet Bulb (°F)	Dry Bulb (°F)	T_d (°F)	e_a (in. Hg)	e_d (in. Hg)	Δ (in. Hg/°F)	σT_a^4 (mm/day)	n (Hrs/day)	N (Hrs/day)	U_2 (miles/	R_A	R_C	R_B	S (when L_s=0.16)	D	H_T	E_a	E_T
												(Equiv. mm/day)					(mm/day)		
1954, Nov. 23 to Dec. 14	68.7	58.3	69.8	48.0	0.707	0.336	0.024	14.70	8.99	14.34	92.75	17.35	10.22	2.90	0.67	0.756	5.28	4.70	3.93
15 to 28	70.8	60.4	72.9	49.7	0.760	0.358	0.026	14.95	10.21	14.51	96.00	17.73	11.17	3.17	0.67	0.747	5.76	5.21	4.98
29 to Jan. 11 1955	70.7	60.2	71.6	50.4	0.757	0.368	0.026	14.93	9.11	14.43	105.60	17.68	10.45	2.84	0.66	0.772	5.52	5.38	4.28
12 to 25	75.2	60.5	75.6	47.1	0.881	0.325	0.029	15.44	9.94	14.18	97.44	17.28	10.87	3.40	0.67	0.710	5.30	7.29	4.50
26 to Feb. 8	77.7	64.1	78.2	53.2	0.957	0.408	0.032	15.74	9.91	13.81	116.88	16.58	10.58	3.17	0.63	0.700	5.29	8.14	4.56
9 to 22	73.7	65.7	72.9	60.7	0.838	0.535	0.028	15.28	7.10	13.36	77.04	15.67	8.42	2.01	0.70	0.742	4.72	3.42	3.48
23 to Mar. 8	67.5	58.3	67.0	51.9	0.678	0.389	0.023	14.57	9.00	12.84	96.72	14.25	8.96	2.89	0.66	0.731	4.28	3.78	3.08
9 to 30	69.2	59.7	68.3	52.5	0.719	0.397	0.025	14.77	7.14	12.18	93.60	12.44	7.04	2.54	0.66	0.665	3.10	4.11	2.46
31 to Apr. 19	65.2	56.4	65.5	47.8	0.626	0.334	0.022	14.31	6.16	11.44	92.40	10.48	5.67	2.49	0.66	0.632	2.05	3.68	1.77

Table 2

Comparisons of Penman's estimates of evaporation from open water surface (E_O) and potential transpiration (E_T) with evaporation from free water surface (E_W) and water use (Wi).

(9 Periods)

Period (inclusive)	H_O	H_T	E_O	E_T	E_a	E_W	Wi	Wi/H_O	Wi/H_T	E_T/E_O	E_T/E_W	E_T/Wi	E_O/E_W	Wi/E_O	Wi/E_W	Wi/E_a
	mm/day															
1954, Nov. 23 to Dec. 14	6.81	5.28	6.16	3.93	4.70	6.10	4.39	0.64	0.83	0.64	0.64	0.90	1.01	0.71	0.72	0.93
15 to 28	7.44	5.76	6.79	4.98	5.21	7.11	5.49	0.74	0.95	0.73	0.70	0.91	0.95	0.81	0.77	1.05
29 to Jan. 11.1955	7.09	5.52	6.59	4.28	5.38	7.37	5.99	0.84	1.09	0.65	0.58	0.71	0.89	0.91	0.81	1.11
12 to 25	6.93	5.30	7.03	4.50	7.29	8.13	5.72	0.83	1.08	0.64	0.55	0.79	0.86	0.81	0.70	0.78
26 to Feb. 8	6.88	5.29	7.19	4.56	8.14	8.13	6.15	0.89	1.16	0.63	0.56	0.74	0.88	0.86	0.76	0.76
9 to 22	5.99	4.72	5.28	3.48	3.42	5.08	5.77	0.96	1.22	0.66	0.69	0.60	1.04	1.09	1.14	1.69
23 to Mar. 8	5.62	4.28	5.02	3.08	3.72	5.84	3.73	0.66	0.87	0.61	0.53	0.83	0.86	0.74	0.64	0.99
9 to 30	4.15	3.10	4.14	2.46	4.11	4.57	3.94	0.95	1.27	0.59	0.54	0.62	0.91	0.95	0.86	0.96
31 to April 19	2.90	2.05	3.16	1.77	3.68	4.06	3.73	1.29	1.82	0.56	0.44	0.47	0.78	1.18	0.92	1.01
Mean	5.98	4.59	5.71	3.67	5.08	6.27	4.99	0.87	1.14	0.63	0.58	0.73	0.91	0.90	0.81	1.03

Table 3

Calculations for Calculation of Potential Transpiration by Penman's Formula

(Waite Institute)

Period*	Wet Bulb (°F)	Dry Bulb (°F)	T_d (°F)	e_a (in. Hg)	e_d (in. Hg)	Δ (in. Hg)	σT_a^4 mm/day)	N Hrs/day)	R_A	R_B	S (when $L_g = 0.76$)	D	H_T	E_a	E_T
									(equi. mm/day)				(mm/day)		
1	55.4	69.1	40.9	0.683	0.256	0.026	15.03	14.18	17.15	4.07	0.67	0.696	5.29	5.41	4.00
2	59.0	69.6	53.0	0.695	0.405	0.024	14.65	14.34	17.44	2.73	0.68	0.808	5.69	3.47	4.00
3	59.7	69.9	51.0	0.724	0.376	0.025	14.79	14.46	17.70	2.27	0.66	0.771	5.03	4.72	3.84
4	58.4	70.8	47.0	0.709	0.324	0.024	14.71	14.51	17.80	3.42	0.67	0.755	5.87	4.96	4.29
5	61.9	74.4	51.7	0.813	0.386	0.027	15.17	14.51	17.80	3.00	0.66	0.748	5.77	5.75	4.47
6	62.6	77.1	50.8	0.890	0.374	0.030	15.48	14.46	17.75	2.29	0.64	0.753	4.87	7.95	4.43
7	57.7	67.9	48.3	0.651	0.340	0.023	14.45	14.37	17.64	3.44	0.68	0.774	6.07	3.77	4.18
8	61.3	78.3	46.3	0.960	0.315	0.032	15.74	14.24	17.41	3.13	0.68	0.708	4.97	7.79	4.47
9	60.9	76.1	47.6	0.861	0.332	0.029	15.36	14.08	17.11	3.76	0.65	0.724	5.58	7.75	4.74
10	64.6	74.4	57.4	0.881	0.476	0.029	15.44	13.89	16.76	2.53	0.64	0.698	5.37	6.34	4.23
11	63.4	78.6	51.3	0.954	0.380	0.032	15.72	13.66	16.34	3.16	0.65	0.707	4.96	8.35	4.49
12	71.4	76.7	68.3	0.960	0.697	0.032	15.74	13.45	15.89	1.29	0.72	0.777	4.57	2.78	3.45
13	60.1	71.0	50.8	0.744	0.373	0.025	14.87	13.20	15.32	3.42	0.70	0.702	4.88	4.47	3.64
14	58.4	67.7	50.3	0.702	0.365	0.024	14.69	12.95	14.64	3.47	0.65	0.717	4.55	4.75	3.42
15	57.3	65.2	50.1	0.633	0.364	0.022	14.35	12.70	13.83	2.67	0.67	0.704	3.75	3.38	2.66
16	55.8	64.3	47.6	0.642	0.332	0.022	14.39	12.45	13.13	3.23	0.67	0.682	3.51	3.79	2.60
17	61.5	72.2	52.8	0.813	0.402	0.027	15.17	12.20	12.49	2.31	0.66	0.634	2.95	5.69	2.70
18	59.9	67.4	53.7	0.697	0.415	0.024	14.67	11.92	11.73	2.25	0.68	0.678	2.75	3.33	2.16
19	54.7	63.6	45.8	0.592	0.310	0.021	14.16	11.63	11.07	2.22	0.65	0.634	2.22	3.96	1.90
20	59.3	69.8	50.2	0.739	0.365	0.025	14.85	11.43	10.47	2.73	0.67	0.617	2.09	4.51	1.98
21	54.1	61.5	46.8	0.525	0.321	0.019	13.79	11.19	9.86	2.47	0.67	0.625	1.82	2.46	1.38

* For period see Appendix D.

Table 4

Comparisons of Penman's estimates of evaporation from open water surface (E_O) and potential transpiration (E_T) with evaporation from free water surface (E_W) and water use (Wi).

(21 Periods).

Period*	H_O	H_T	E_O	E_T	E_a	E_W	Wi	Wi/H_O	Wi/H_T	E_T/E_O	E_T/E_W	E_T/Wi	E_O/E_W	Wi/E_O	Wi/E_W	Wi/E_a
	mm/day															
1	7.05	5.29	6.57	4.00	5.41	6.53	9.27	1.31	1.75	0.61	0.61	0.43	1.01	1.41	1.42	1.71
2	7.26	5.69	6.09	4.00	3.47	6.20	2.79	0.38	0.49	0.66	0.65	1.43	0.98	0.46	0.45	0.80
3	6.40	5.03	5.90	3.84	4.72	5.30	4.09	0.64	0.81	0.65	0.72	0.94	1.11	0.69	0.77	0.87
4	7.55	5.87	6.75	4.29	4.96	6.63	5.00	0.66	0.85	0.64	0.65	0.86	1.02	0.74	0.75	1.01
5	7.41	5.77	6.94	4.47	5.75	8.00	5.94	0.80	1.03	0.64	0.56	0.75	0.87	0.86	0.74	1.03
6	6.21	4.87	6.66	4.43	7.95	8.20	6.07	0.98	1.25	0.67	0.54	0.73	0.81	0.91	0.74	0.76
7	7.86	6.07	6.56	4.18	3.77	6.53	5.89	0.75	0.97	0.64	0.64	0.71	1.00	0.90	0.90	1.56
8	6.49	4.97	6.81	4.47	7.79	7.87	6.88	1.06	1.38	0.66	0.57	0.65	0.87	1.01	0.87	0.88
9	7.33	5.58	7.44	4.74	7.75	8.64	4.14	0.56	0.74	0.64	0.55	1.14	0.86	0.56	0.48	0.53
10	6.85	5.37	6.71	4.23	6.34	7.72	6.17	0.90	1.15	0.63	0.55	0.69	0.87	0.92	0.80	0.97
11	6.48	4.96	6.95	4.49	8.35	8.26	6.53	1.01	1.32	0.65	0.54	0.69	0.84	0.94	0.79	0.78
12	5.67	4.57	4.95	3.45	2.78	3.53	6.53	1.15	1.15	0.70	0.98	0.53	1.40	1.32	1.85	2.35
13	6.43	4.88	5.85	3.64	4.47	6.32	4.34	0.67	0.89	0.62	0.58	0.84	0.93	0.74	0.69	0.97
14	6.06	4.55	5.66	3.42	4.75	6.65	5.08	0.84	1.12	0.60	0.51	0.67	0.85	0.90	0.76	1.07
15	4.95	3.75	4.54	2.66	3.38	5.23	3.63	0.73	0.97	0.59	0.51	0.73	0.87	0.80	0.69	1.07
16	4.80	3.51	4.47	2.60	3.79	5.00	3.63	0.76	1.03	0.58	0.52	0.72	0.89	0.81	0.73	0.96
17	3.93	2.95	4.43	2.70	5.69	4.70	3.63	0.92	1.23	0.61	0.57	0.74	0.94	0.82	0.77	0.64
18	3.69	2.75	3.58	2.16	3.33	3.81	4.14	1.12	1.51	0.60	0.57	0.52	0.94	1.16	1.09	1.24
19	3.01	2.22	3.33	1.90	3.96	4.47	3.81	1.27	1.72	0.57	0.43	0.50	0.74	1.14	0.85	0.96
20	3.00	2.09	3.45	1.98	4.51	3.89	3.99	1.33	1.91	0.57	0.51	0.50	0.89	1.16	1.02	0.88
21	2.62	1.82	2.56	1.38	2.46	3.38	2.54	0.97	1.40	0.54	0.41	0.54	0.76	0.99	0.75	1.03
Mean	5.76	4.41	5.53	3.48	5.02	6.04	4.96	0.90	1.17	0.62	0.58	0.73	0.93	0.92	0.85	1.05

* For period see Appendix D.

Table 5

Comparisons between Penman's E_T and potential transpiration taking BD as 1.0 (E'_T)

(9 periods)

Period (inclusive)	E'_T	E_0	E_T	Wi	E'_T/E_0	E'_T/Wi
		mm/day				
1954. Nov. 23 to Dec. 14	5.10	6.16	3.93	4.39	0.83	1.16
15 to 28	5.60	6.79	4.98	5.49	0.82	1.02
29 to Jan.11 1955	5.48	6.59	4.28	5.99	0.83	0.91
12 to 25	5.84	7.03	4.50	5.72	0.83	1.02
26 to Feb. 8	6.00	7.19	4.56	6.15	0.83	0.98
9 to 22	4.36	5.28	3.48	5.77	0.83	0.76
23 to Mar. 8	4.13	5.02	3.08	3.73	0.82	1.11
9 to 30	3.40	4.14	2.46	3.94	0.82	0.86
31 to Apr.19	2.58	3.16	1.77	3.73	0.82	0.69
Mean	4.72	5.71	3.67	4.99	0.83	0.95

Table 6

Comparisons between Penman's E_T^{v} and potential transpiration taking SD as 1.0 ($E_T^{!}$)

(21 periods)

Period*	$E_T^{!}$	E_O	E_T	Wi	$E_T^{!}/E_O$	$E_T^{!}/Wi$
		mm/day				
1	5.32	6.57	4.00	9.27	0.81	0.57
2	5.01	6.09	4.00	2.79	0.82	1.80
3	4.94	5.90	3.84	4.09	0.84	1.21
4	5.58	6.75	4.29	5.00	0.83	1.12
5	5.77	6.94	4.47	5.94	0.83	0.97
6	5.67	6.66	4.43	6.07	0.85	0.93
7	5.35	6.56	4.18	5.89	0.82	0.91
8	5.67	6.81	4.47	6.88	0.83	0.82
9	6.16	7.44	4.74	4.14	0.83	1.49
10	5.63	6.71	4.23	6.17	0.84	0.91
11	5.80	6.95	4.49	6.53	0.83	0.89
12	4.12	4.95	3.45	6.53	0.83	0.63
13	4.76	5.85	3.64	4.34	0.81	1.10
14	4.61	5.66	3.42	5.08	0.81	0.91
15	3.63	4.54	2.66	3.63	0.80	1.00
16	3.60	4.47	2.60	3.63	0.81	0.99
17	3.72	4.43	2.70	3.63	0.84	1.02
18	2.93	3.58	2.16	4.14	0.82	0.71
19	2.81	3.33	1.90	3.81	0.84	0.74
20	2.81	3.45	1.98	3.99	0.81	0.70
21	2.05	2.56	1.38	2.54	0.80	0.81
Mean	4.57	5.53	3.48	4.96	0.82	0.96

* For period see Appendix D.

APPENDIX F

SYMBOLS USED

AD = Apparent Density (Volume weight)
D = Depth of soil in inches
P = Water content % on dry weight basis
$P_{2.0}$ = " " " " " " " at pF 2.0
$P_{4.2}$ = " " " " " " " at pF 4.2
P_0 = " " " " " " " at observed pF
P_6 = " " " " " " " difference between $P_{2.0}$ and $P_{4.2}$ for 0.-9" depth.
P_{12} = " " " " " " " " " 9-18" "
P_{24} = " " " " " " " " " 18-30" "
P_{36} = " " " " " " " " " 30-42" "
P_{48} = " " " " " " " " " 42-54" "
P_{60} = " " " " " " " " " 54-66" "
P_6^1 = " " " " " " " difference between P_0 and $P_{4.2}$ for 0-9" depth
P_{12}^1 = " " " " " " " " " 9-18" "
P_{24}^1 = " " " " " " " " " 18-30" "
P_{36}^1 = " " " " " " " " " 30-42" "
P_{48}^1 = " " " " " " " " " 42-54" "
P_{60}^1 = " " " " " " " " " 54-66" "
e = Efficiency of Water Use
e_t = Efficiency of Water Use at any time t
e_0 = Efficiency of Water Use at cutting 0
e_{0-1} = Efficiency of Water Use from cutting 0 to cutting 1
e_{1-2} = " " " " " 1 " 2
e_{2-3} = " " " " " 2 " 3
e_{3-4} = " " " " " 3 " 4
Y = Yield of dry matter (cwt/acre)
Y_0 = Cumulative yield of dry matter (cwt/acre) using W_0 amount of water (in./acre) at cutting 0 in time t_0 (days)
Y_1 = " " " " W_1 " " " " 0 to cutting 1 in time t_1 (days)
Y_2 = " " " " W_2 " " " " 0 " 2 " t_2 "
Y_3 = " " " " W_3 " " " " 0 " 3 " t_3 "
Y_4 = " " " " W_4 " " " " 0 " 4 " t_4 "

SYMBOLS USED (Cont'd)

W_0 = Cumulative amount of Water Use (in./acre) yielding Y_0 amount of dry matter (cwt/acre) at cutting 0 in time t_0 (days)

W_1 = " " " " " Y_1 " " from cutting 0 to cutting 1 in time t_1 (days)

W_2 = " " " " " Y_2 " " " " 0 " " 2 " " t_2 "

W_3 = " " " " " Y_3 " " " " 0 " " 3 " " t_3 "

W_4 = " " " " " Y_4 " " " " 0 " " 4 " " t_4 "

W = Amount of Water Use (in/acre) in general

Wi = " " " in irrigated plots

Wn = " " " in non-irrigated plots

Ws = " of available water stored in the soil (in.) from 0-66" depth in the irrigated plots

Ws - n = " " " " " " " in the non-irrigated plots

Wst_0 = " " " " " " " at time t_0

Wst_1 = " " " " " " " " " t_1

Wt = Amount of water taken from the soil (in.) over the time interval from $t_0 - t_1$

= ($Wst_0 - Wst_1$)

Wa = Total available water stored (in.) in the irrigated plots

= Ws + I + R

DMP = Dry matter production

DWT = Dry weight of tops

dt = Deficit in rate of growth (cwt/acre/day)

R = Rainfall (in.)

I = Irrigation given to irrigated plots

In = " " non-irrigated plots

r = Runoff

R_C = Incoming short wave radiation (equiv. mm/day)

= $R_A (0.25 + 0.54\ {}^{n}/N)$ . . . after Penman 1952.

R_A = Theoretical maximum incoming solar radiation (equiv. mm/day) that would reach the earth in the absence of an atmosphere.

n = Actual duration of bright sunshine (hrs/day)

N = Maximum possible duration of bright sunshine (hrs/day)

E_W = Evaporation from free water surface (in.)

s.d. = Saturation deficit (in. Hg.)

Ta = Mean air temperature (°F) - $\left(\frac{\text{Max.} + \text{Min.}}{2}\right)$