PRELIMINARY STUDIES ON DEPTH OF SOIL MOISTURE EXTRACTION BY SUGARCANE USING THE NEUTRON PROBE

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Introduction

The design and operation of supplementary irrigation schemes are dependent upon an accurate estimation of the "total available moisture" in the soil. This has been defined as the amount of water held between the limits of field capacity and wilting point in the effective rooting depth of the crop. Under irrigated conditions the effective rooting depth is that depth of soil from which the crop can remove all of the available moisture before its growth is materially affected, and is determined in the field by visual inspection of the soil profile and the crop rooting habits.

Whilst this approach has permitted the establishment of a rational method for determining water duties (Thompson and Collings, 1963), it is not only subjective to an extent, but the assumption that all of the moisture used by the crop is equally available from a limited depth of soil is incorrect. In fact, moisture is removed from different strata of soil to different extents and the ideal would be to measure the total amount removed from the entire soil profile before the growth of the crop was reduced to an economically important degree.

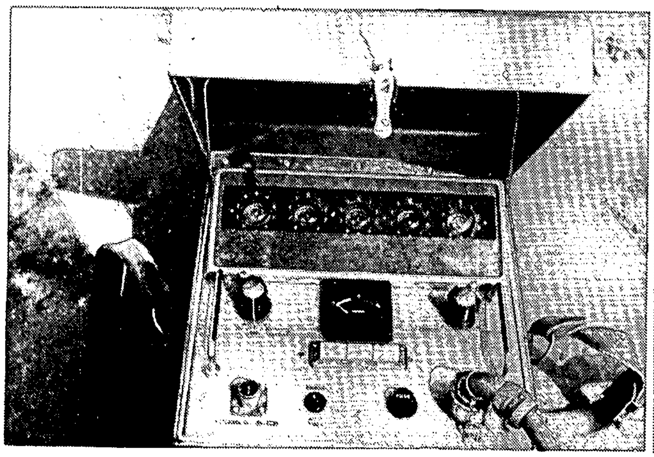
In the past it has been impractical to determine this quantity with an acceptable degree of accuracy. Gravimetric techniques for the determination of soil moisture are subject to particularly high sampling errors on the variable soils of the Natal coastal belt, and the usefulness of gypsum resistance units and tensiometers is limited due to their restricted ranges of effectiveness and their lack of quantitative reliability. This is due partly to the fact that tensions and not quantities of moisture are measured. However, the development of neutron scattering equipment has permitted the measurement of soil moisture contents *in situ* with reasonable accuracy, and actual patterns of soil moisture removal can now be determined. (Holmes 1958, Merriam 1959.)

The concept of associating measurements of moisture removal from the soil with concurrent crop growth measurements of sugarcane has been reported from Hawaii by Robinson (1963) and by Robinson and Baver (1964). A realistic economic evaluation of irrigation procedures may be possible if the effects of measured soil moisture deficits on the growth of the crop can be determined.

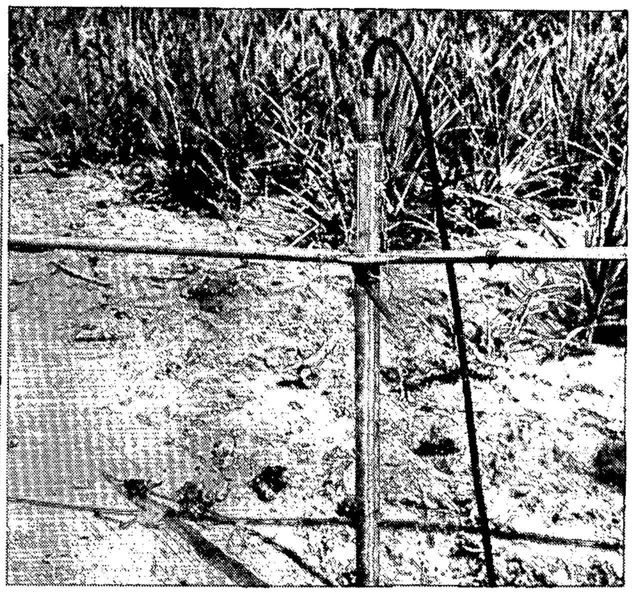
A simple procedure under any one set of climatic conditions is to estimate the potential growth of sugarcane by means of stalk height measurements in fully irrigated cane, and concurrently to measure the stalk heights of cane in soil which is allowed to dry out after having been thoroughly wetted. Neutron probe measurements of soil water throughout the profile may then be taken to indicate the amount of water used by the crop as its growth is suppressed to progressively greater extents in comparison with the potential growth rate.

Thus it is apparent that the neutron probe may be used to realise a new philosophy of soil moisture availability, based on crop responses. This is in contrast to the currently employed assumptions that all of the water held between field capacity and wilting point in an arbitrarily determined depth of soil is equally available to the crop and that growth is suddenly and entirely suppressed only when this supply has been exhausted.

It must be acknowledged that the direct measurement of moisture removal from the soil in the field will yield data for individual profiles only, and that the use of such data even for a single soil series may be hazardous. An apparent advantage of the existing



Scaler for neutron probe.



Neutron probe about to be lowered into position.

approach is that the soil moisture constants for any soil can be determined relatively easily from undisturbed or disturbed samples in the laboratory, and it may eventually be possible to use such data to allow for variations in patterns of soil moisture removal from soil to soil.

Materials and Methods

Three sites were chosen in established plant cane fields on different soil types. Neutron probe access tubes were emplaced in the soil in one location and reference pegs for stalk height measurements were installed in the surrounding cane. An adjacent location was irrigated with the amount of water evaporated from a Class A Pan and reference pegs were also installed on this site for the estimation of potential growth. Moisture extraction patterns were observed on the first site by measuring soil moisture weekly with the neutron probe, and height measurements were taken on the same day on all selected stalks from the top of the reference peg to the uppermost visible collar.

The theory of soil moisture determination by the neutron scattering method and the techniques generally used have been described in the literature (Marais and Smit 1962, Van Bavel, Nixon and Hauser 1963). The apparatus used in the present experiments consisted of a Viatec depth probe and scaler model HDM 2 (see Plate 1). The depth probe was made up of a stainless steel cylinder 28 in. long by 1.75 in. in diameter. This contains a 10 mc. Radium-Beryllium source of fast neutrons and a Boron trifluoride tube for measuring the thermal neutrons resulting from collisions of fast neutrons with hydrogen atoms in the soil. A discriminator for separating neutron pulses and gamma ray pulses and a pre-amplifier were also incorporated in the probe, which was connected by means of a 120 ft. cable to the scaler. The thermal neutron pulses were registered on decatron tubes in the scaler and an automatic time switch of one minute facilitated counting procedures.

A linear correlation between number of counts per minute and volumetric soil moisture percent was obtained, but separate calibrations were necessary for each soil type since factors other than soil moisture content affected the scattering of fast neutrons. Fortunately these factors which include soil bulk density, hydrogen in compounds other than water, and certain elements such as chlorine and boron, are sufficiently constant in any soil type so that differences in scaler readings from week to week should be due entirely to variations in soil moisture content.

Two-inch diameter aluminium access tubes (internal diameter 1.875 in.) sealed at one end, were cut to lengths of 6 ft. 4 in. or 10 ft., and carefully inserted into the soil after augering a hole to fit the tube exactly. The tubes protruded two inches above soil level and were covered to prevent rain or soil from entering. Measurements were taken weekly at 6 inch intervals from 9 inches down to 57 inches or 99 inches. Surface soil moisture contents were determined gravimetrically pending the construction of a separate calibration curve in each soil type for this stratum. A 10 ft. pipe with a clamp at the centre, as shown in Plate 2, was used to carry the probe from one site to another. The clamp could be released by a trigger located at one end of the pipe, and this technique allowed the operators to stand at a safe distance from the source.

The probe was regularly checked in a water standard to observe whether any instrument drift or error was occurring. For this purpose an access tube was installed in the centre of a 44 gallon drum full of water.

The three soils which were studied were a deep Clansthal sand overlying sandy clay at about 90 inches, a Windermere clay loam overlying decomposing parent material (Middle Ecca shale) at about 26 inches and a Williamson sandy loam overlying Dwyka tillite at 54 inches. The sugarcane variety was N:Co.376 on all three sites. Soil moisture contents were calculated from the mean scaler readings from six access tubes on each site. An additional access tube was placed in bare soil adjoining each plot, the purpose being to study the drainage patterns where no crop roots existed. It is reasonable to assume that drainage under bare ground can never be less than that under a crop. Thus, if over a particular period no drainage was shown under bare soil, then it could safely be assumed that no drainage occurred under the crop, and any moisture movement was due to consumptive use by the crop.

Results

1. Moisture Extraction and Drainage from a Sand

Weekly readings were started in April, 1964, on a Clansthal sand, but only the data from limited periods could be used for the calculation of moisture extraction patterns. It is not possible to discriminate between drainage from one stratum to another and water removal by the crop, so that only drainage-free periods can be studied with confidence. Drainage at depth continued at measurable rates for an appreciably longer time than was expected in a coarse sand. Figure 1 shows the moisture contents, at weekly intervals, of a Clansthal sand by 6 inch depth increments down to 7 ft. 6 in. over a period of five weeks from 19th October, 1964. During the month prior to this date only 0.93 in. of rain was recorded and consequently the soil profile was initially dry, particularly in the 1 ft.-4 ft. zone. During the succeeding two weeks 5.57 in. of rain fell, and percolation reached a maximum at the 45 in. depth by the 2nd November. During the following two weeks, when only 0.57 in. of rain fell, percolation continued and the soil moisture content at 51 in. reached a maximum on 9th November and at 60 in. on 16th November. Meanwhile the extraction of moisture by the crop from the top four feet of soil was apparent during this two week period. A further 2.63 in. of rain fell during the week 16th-23rd November, and by the 23rd this had penetrated to about 39 in., immediately below which depth the soil was drier than it was on the 16th. However, further drainage from the original heavy rain evidently occurred between 60 and 72 in. during this period. Still further drainage from the 72 to 81 in. depths occurred during succeeding weeks from 23rd November to 8th December, but this data has been omitted from Figure 1, for the sake of clarity. The data show that significant amounts of drainage took place up to five weeks after

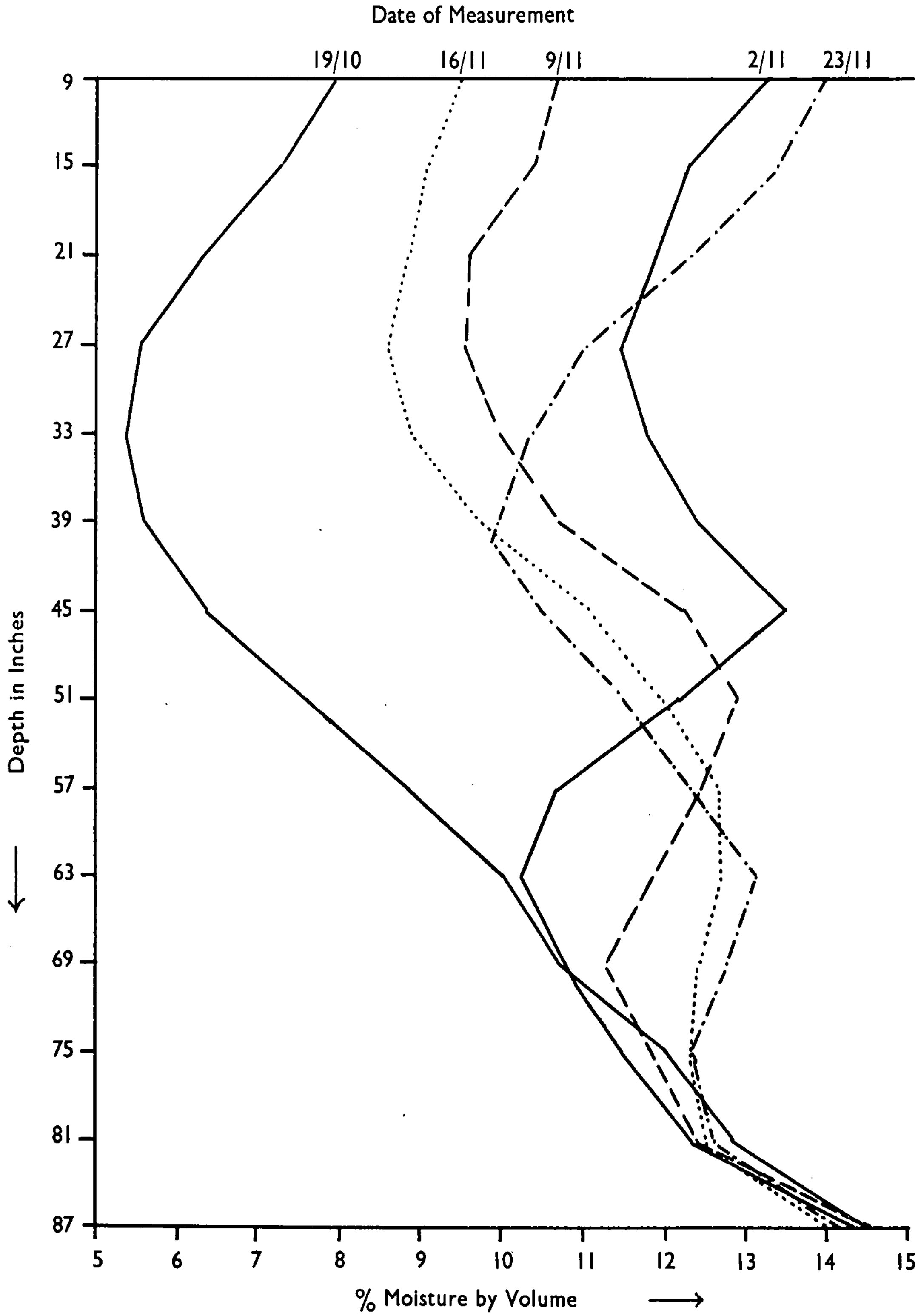


FIG. 1. DRAINAGE PATTERNS IN A CLANSTHAL SAND

the heavy rainfall of 3.75 in. on 28th October. No drainage below 87 in. took place during this period of observation, but moisture extraction patterns could not be calculated because of drainage between measured depths.

An example of moisture extraction patterns from a Clansthal sand during a dry period is shown in Figure 2 for six weeks from 5th May, 1964, by 6 in. increments down to 5 ft. The absence of appreciable drainage was indicated by the progressive drying out of the soil at all depths in successive weeks.

2. The Effect of Soil Moisture Content on Depth of Moisture Extraction from a Sand

The sugarcane crop is known to remove readily available moisture from the surface strata of soil before exploiting progressively deeper depths. Figure 3 shows these trends expressed on a quantitative basis for the same total period as shown in Figure 2. The increasing proportions of moisture extracted from lower depths as the soil profile dried out from 5th May to 15th June is clearly shown. It became clear at this early stage that significant quantities of moisture were being removed from the 4-5 ft. zone, and longer access tubes were therefore installed to permit probe readings to be made to a depth of 8 ft. 6 in. However, the deepest foot of soil was a sandy clay which would have required separate calibrations of the probe, and useful readings were only obtained to a depth of 7 ft.

After the installation of the longer tubes, in August, 1964, it was clear that soil moisture had become severely depleted between 1 ft. and 4 ft. (see Figure 1 data for 19/10/64). It is therefore not surprising to find over the ensuing four weeks during September-October that 36 per cent of the water used by the crop came from the 4-7 ft. depth, and only 19 per cent from the 1-4 ft. depth as shown in Figure 4. The large proportion of water extracted from the top foot of soil was due to light rains which wetted only the surface stratum of the profile. The actual growth rate was reduced to 55 per cent of the potential rate over this same period. In order to confirm that the greater apparent extraction from deeper depths was not due to drainage, the total soil moisture changes over a nine-week period from 25/8/64 to 26/10/64 for one foot strata from 3 ft. down to 7 ft. are shown in Table 1 for the crop site and an adjacent bare site.

Small amounts of rain caused fluctuations to occur in the 1-3 ft. depths and their data have therefore been omitted. It is unfortunate that under local climatic

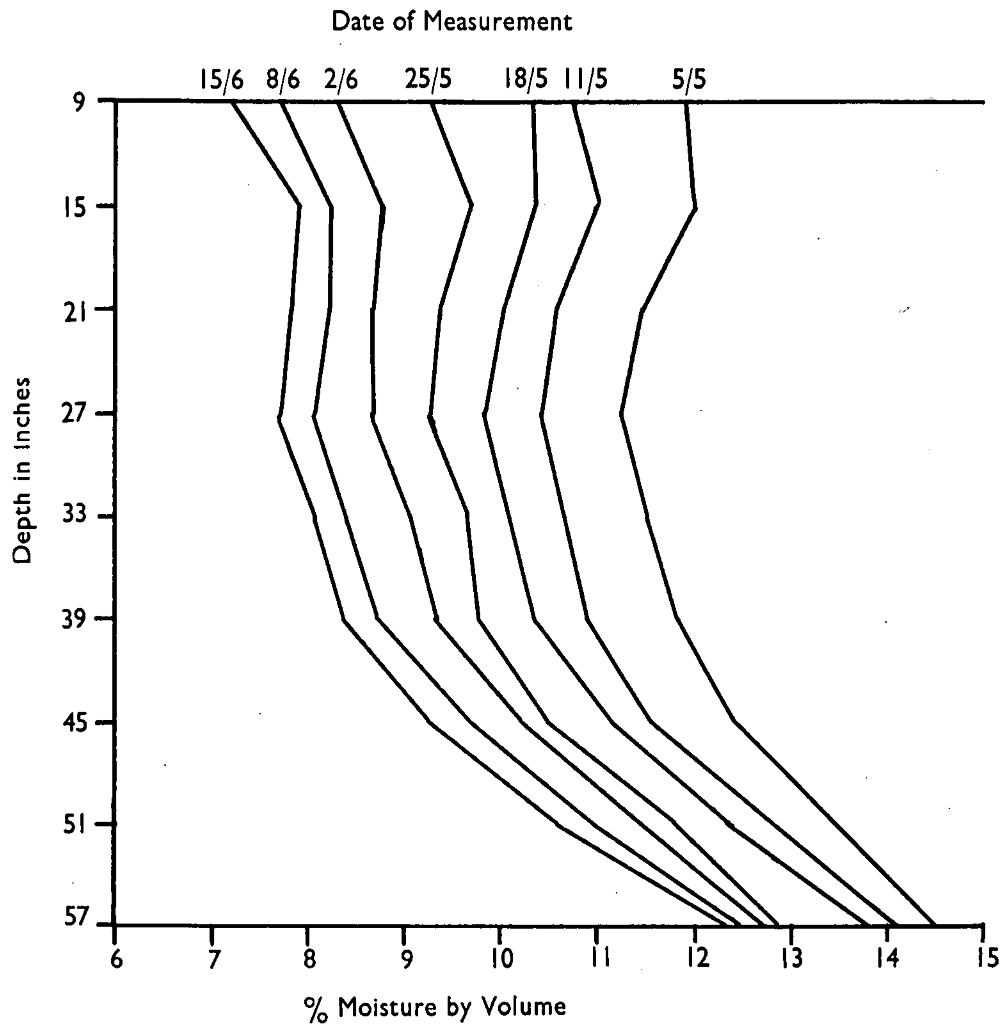


FIG. 2. MOISTURE EXTRACTION IN A CLANSTHAL SAND

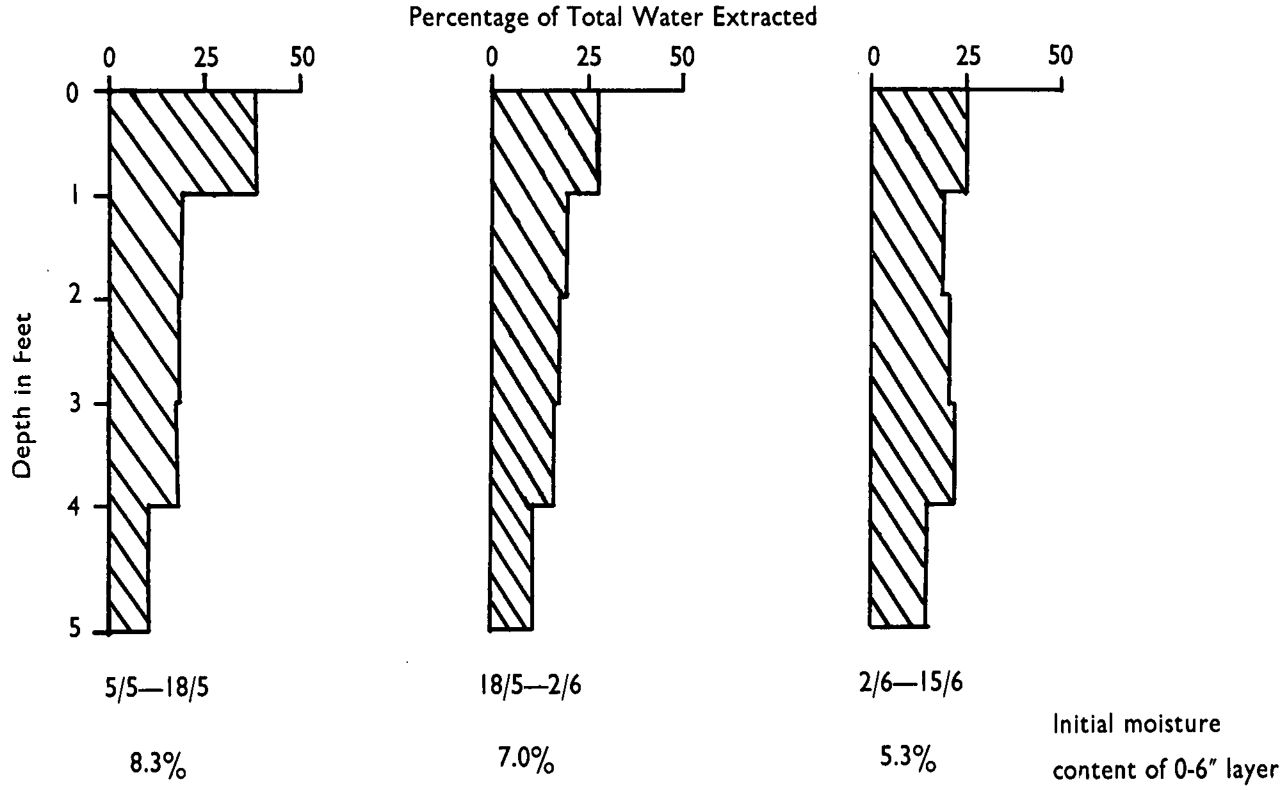


FIG. 3. MOISTURE EXTRACTION TO 5 FT. ON A DRYING CURVE

conditions it is difficult to follow moisture extraction entirely on a drying cycle because of intermittent rains.

TABLE 1

Moisture Extraction under cane and bare soil, 25/8–26/10/64

Soil Depth (ft.)	Moisture Extraction Percent	
	Cane	Bare Soil
3–4 . . .	1.81	0.05
4–5 . . .	2.47	0.51
5–6 . . .	3.51	0.38
6–7 . . .	3.11	-0.06
	10.90	0.88

These results clearly show that there was no drainage below 7 ft. on the bare site over this period. The extraction of moisture by sugarcane at depth showed a similar pattern to that illustrated in Figure 4.

3. The Effect of Soil Type on Depth of Extraction

Figure 5 shows the remarkable differences which occurred between the moisture extraction patterns to a depth of 5 ft. in a Clansthal sand and in Windermere and Williamson loams. Both the latter two soils have compacted layers below 18 in. and overlying decomposing rock. In contrast the Clansthal is a uniform sand down to 7½ ft. Under moist conditions, 85-90 per cent of the total moisture extracted came from the top foot of the Windermere and Williamson loams, while 75 per cent of the moisture extracted from the Clansthal sand was from the top two feet. Under drier conditions, where the topsoil had lost about half of its available moisture, 75 per cent of the moisture extracted from the Windermere and Williamson soils was from the top two feet whereas in the Clansthal soil this proportion was extracted from about 3½ ft. Growth measurement data were not available for the cane on the Williamson loam, but the ratio of actual to potential growth rate dropped from 83 to 74 per cent on the Windermere site and from 85 to 66 per cent on the Clansthal site as the moisture contents of the top soils became depleted.

Discussion

More results over a wider range of soil types will be required before firm conclusions can be drawn on which to base irrigation recommendations. However, a number of interesting points have been demonstrated. While 75-90 per cent of the crop moisture requirements were extracted from the top 2 ft. in both the Williamson and Windermere soils, moisture extraction patterns in the Clansthal sand varied considerably, depending on the antecedent soil moisture conditions both in the surface soil and at depths. After a complete saturation of the profile initially, 75 per cent of the total moisture removed was extracted from the top 2 ft., but ensuing dry weather conditions caused later extraction to be fairly uniform down to 4 ft. As drying proceeded down the profile, during periods of little or no rain, the 1-4 ft. zone became increasingly desiccated, and under these conditions, significantly greater quantities of water were removed from the 4-7 ft. zone than from the 1-4 ft. zone. Actual growth rates under these conditions were about half

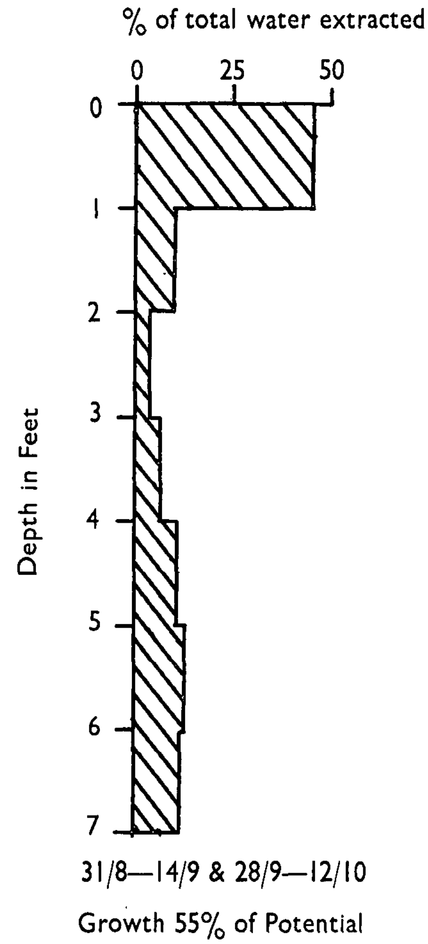


FIG. 4. MOISTURE EXTRACTION TO A DEPTH OF 7 FT. AFTER A DRY PERIOD

of the potential rates. The possibility of appreciable quantities of moisture being extracted from depths below 7 ft. cannot be discounted, especially in view of the fact that root exposures have shown well developed root systems to 12 ft. on a Clansthal sand (S.A.S.A. 1965).

However, the sandy clay layer at 7½ ft. depth in the experiment under discussion effectively stopped the majority of further visible root penetration.

It is interesting to note how slowly drainage occurred at depth in the Clansthal sand. Although the profile texture was fairly uniform (90-95 per cent sand) down to 7 ft. and drainage was complete in the top 3½ ft. within five days, it took a further four weeks to pass through the next 3½ ft. This was possibly caused by the relatively impermeable and compacted sandy clay layer at 7½ ft.

Only two factors affecting depth of moisture extraction, viz. soil type and antecedent moisture conditions, have been discussed in this paper. Work is continuing in an attempt to elucidate the effects of other factors such as evaporative demand, cane variety and the age of the crop. Three additional soil series are also being investigated.

Summary

The depth to which soil moisture was extracted by sugarcane was shown to be markedly affected by antecedent soil moisture conditions and by soil type. When the soil was wet, 85 to 90 per cent of the moisture extracted from a Windermere clay loam and a Williamson sandy loam was from the surface foot, while on a Clansthal sand, 75 per cent was extracted from the top 2 ft. of soil. Under drier conditions 75 per cent was extracted from the top 2 ft. of the Windermere and Williamson loams while the crop explored 4 ft. to extract 85 per cent of its moisture requirements from the Clansthal sand. When the 1-4 ft. layer of the Clansthal sand dried out, twice as much moisture was extracted from the 4-7 ft. depth as from 1-4 ft. depth, but by this stage growth had been reduced to about half of the potential rate. Drainage patterns were followed through successively deeper strata in a sand and slow drainage at depth was considered to be related to a sandy clay layer at a depth of 7½ ft.

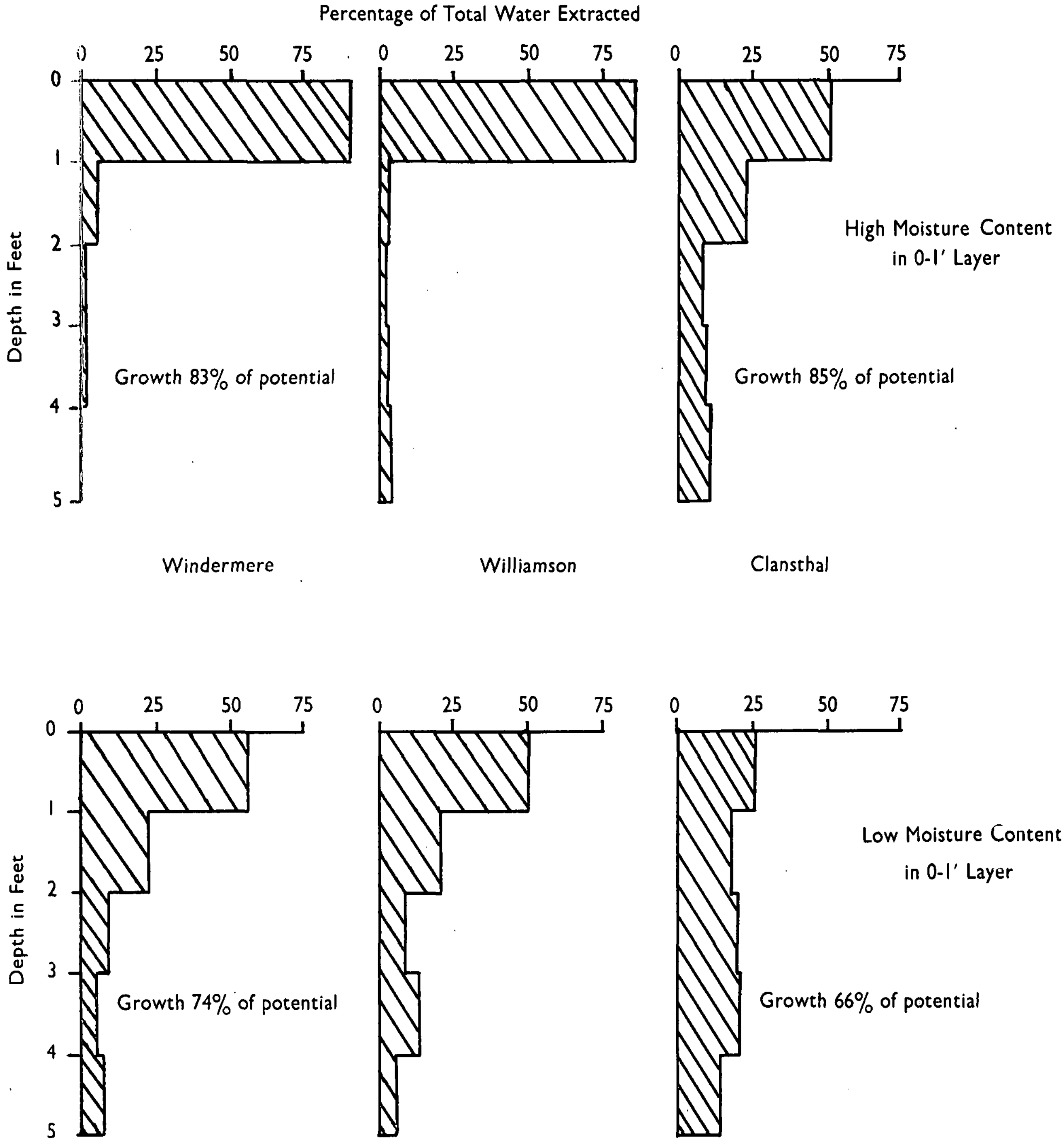


FIG. 5. MOISTURE EXTRACTION IN THREE SOILS

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Mr. R. A. Wood: Do the authors think the neutron probe will be useful on stratified soils such as we have?

Its value is obvious in uniform soils where there is deep rooting but what about in other soils?

Mr. Thompson: At present, to determine total available moisture in soils we take undisturbed cores and bring them into the laboratory, where a field capacity test is done and a wilting point obtained. Then a personal judgement is made in the field regarding the effective rooting depth. We make a simple calculation and say that so much moisture is going to be available to the crop before it gets into trouble.

We will not immediately be able to use the probe in each phase of all the different types of soil. We would like to get a certain amount of data for, shall we say, the Waldene series to compare with the figures obtained by the usual process, to get a basis for comparison. By eliminating the subjective evaluation of effective rooting depth with the probe, we should then have far more confidence in the recommendations that we can make after measuring actual moisture removal from the soils in the field, even though a fair degree of variability from phase to phase is inevitable.

Mr. Gosnell: It is on non-uniform soils that the neutron probe is of greatest advantage. The only other quantitative soil moisture measurement that we can use is gravimetric — we cannot at present use gypsum blocks or tensiometers for quantitative purposes.

Mr. Gilfillan: In an earlier paper Mr. Gosnell asked Mr. Hill if he thought it was safe to measure field capacity after 72 hours.

In Figure 1, after rain, the advancing head of water down a profile in a Clansthal sand only moves five or six inches in seven days. Surely, therefore, wilt and field capacity should only be measured after a much longer period?

Mr. Gosnell: The advancing head at lower depths is very slow. In the top 45 inches drainage was complete within three days after rain. The drainage from 45 down to 90 inches took six weeks so I agree with you that field capacity for lower depths is rather tricky.

Mr. von der Meden: I am now inclined to support Mr. Gosnell that the water present at 72 hours is still truly available so that to measure field capacity after this period, whether drainage is complete or not, would surely give a better indication of field capacity from the point of view of available moisture.

Mr. Gosnell: Field capacity is an unsatisfactory term. Gravitational moisture is a very important part of the moisture available to a plant and yet it is completely neglected in field capacity.