68

Available water storage in a range of soils in north-eastern Queensland

R. L. McCown

This paper presents one aspect of a comparative study of the water balance and pasture growth on three soils at the same general location. Two of the soils were members of the solodized solonetz and solodic Great Soil Group, which is widespread in eastern Australia and notorious for low agricultural productivity (Stace *et al.* 1968). In north-eastern Queensland such soils are mainly under native pasture. Results of attempts to increase productivity by applying superphosphate and sowing Townsville stylo differ from soil to soil, presumably due to variation in such features as depth and texture of the A horizon and the structure and permeability of the B horizon (Christian *et al.* 1953; Stirk 1957). The two members of the group selected for these studies differed greatly in productivity after fertilization and in physical description. The third soil was one of the best agricultural soils in the area.

The object of the study was to relate variation in production of Townsville stylo to differences in the hydrology of the soils. The strategy at the outset was to study the soil water balance, changes in internal water status of the plants, and plant growth on these three soils for a sufficient period of years to provide a wide range of conditions. The study was started just after a tropical rainfall depression in February 1968, which resulted in 500 mm rain in 12 days. Although information about soil water recharge progress during this period was missed due to uncompleted measurement facilities, this rainfall event provided a rare opportunity for study of differences in available water storage. The attractiveness of this study situation was further enhanced by the occurrence of only 75 mm rain and nine wet days in the 10 weeks following this full recharge. This paper deals with the differences among the soils in available water storage and methods for its estimation.

The Author—Dr. R. L. McCown, C.S.I.R.O., Division of Tropical Pastures, Pastoral Research Laboratory, Townsville, Queensland.

Sites and methods

The sites

The study was conducted at C.S.I.R.O.'s "Lansdown" Research Station 25 miles south of Townsville, Queensland (latitude 19°26′S). The main features of the agricultural climate of this area are depicted in figure 1. Nearly 80 per cent of the rain falls in December to March, a period of high evaporation and high temperatures. The low reliability of rainfall is shown by the average deviation from the mean for each of the two wettest months ± 60 per cent (125 mm) (Christian *et al.* 1953).

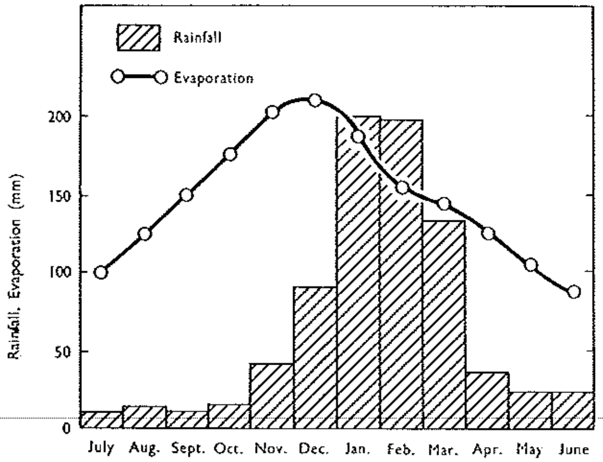

Figure 1—The mean monthly rainfall and Australian tank evaporation for Woodstock, four miles from the study location. (Data from Commonwealth Bureau of Meteorology.)

The three study sites, each about 0.12 ha, are situated on an old alluvial plain within a transect of 0.8 km. The topography of each is very uniform with slopes less than 1 per cent. Water worn gravel is encountered at 1-2 m. The soils have been described by Murtha and Crack (1966). Soil 1 (Lansdown sandy loam) is a solodized solonetz soil with an A horizon 15-20 cm thick. Soil 2 (Stockyard loam) is a solodic soil with an A horizon 25-30 cm thick. In both these soils there is an abrupt transition to a clayey B horizon of low permeability. Soil 3 (Double Barrel loam) is a red podzolic leveé soil with good internal drainage.

All sites had been cleared of timber at least two years before the start of the study. Each had received at least 600 kg per hectare of superphosphate in addition to an initial basal application of both macro and micronutrient elements. In January 1968, all sites were fertilized with 300 kg a hectare of superphosphate and, after intensive seed bed preparation, sown with 60 kg a hectare of Townsville stylo pods.

Germination took place following 120 mm rain over four days in mid-January. At the onset of a 12-day rainy period beginning February 6, there was a vigorous sward of legume and volunteer annual grasses at all sites. At the end of this period, the grass was severely shading the Townsville stylo. To favor growth of the legume, all sites were mown to a height of 18-20 cm and the cut material was removed. The areas were then grazed for a few days by young cattle, which at this stage in the growing season, preferentially graze the grass. Following the removal of the cattle, the swards were trimmed to a height of 6-8 cm.

Sampling and measurements

During periods when appreciable changes were taking place, soil water measurements were made at weekly intervals. During relatively static periods, with low rain and low soil water status, this interval was increased. Volumetric soil water was determined by the fast neutron scattering technique and from gravimetric water content and bulk density determinations. (Volumetric water content = gravimetric water content × bulk density). From soil cores approximately 4.5 cm diameter, gravimetric water and bulk density were determined on segments representing various strata. The bulk density was based on the volume calculated from core segment length and sampling tube cutting ring diameter. On soil 3, beginning on February 22, neutron measurements were made at 25 cm intervals from 25 cm to 150 cm at eight locations. Each day that neutron measurements were made, eight cores were taken in the 0 to 12.5 cm stratum for gravimetric water and bulk density. On soil 1 and soil 2 less reliance was placed on neutron measurement due to the large sample volume of the probe in relation to the abrupt change in water contents across the transition between A and B horizons. Eight core samples, 50-60 cm deep, well into the B horizon, were taken on these sites. These were stratified in 6.25 cm intervals with samples in the A and B horizons referenced to the surfaces of their respective horizons. Beginning March 30, neutron measurements were made at six locations on each of these sites to depths varying from 85 to 115 cm.

Root length density was measured by the method used by Torssel *et al.* (1968). Soil auger samples from eight locations in each site and from each 10 cm stratum were collected in May 1968. The samples were air dried and bulked across strata. Roots were recovered by water elutriation from 50 g subsamples and deposited on filter paper within an area 10 cm in diameter. Intersects with superimposed grid lines along a total of 80 cm were counted and total root length calculated. By the time samples were taken, there were few active ("white") roots, and it was decided to count all roots not in an advanced stage of decomposition. Such roots were assumed to have been produced in the 1968 growing season. In view of the difficulties in interpreting absolute root length densities (cm cc^{-1}) under these circumstances, root length in each 10 cm stratum is expressed as a per cent of the total in the profile (figure 3).

Total soluble salt concentration was estimated from measurement of electrical conductivity of a 1 : 5 soil suspension on samples taken when access tubes were installed.

Measurements of 15-bar water content were made with pressure membrane apparatus on < 2 mm samples.

Field capacity was measured on 1 m^2 field plots. Water was ponded for one day, the plots covered with plastic, and core samples taken for five days after cessation of water application. A field capacity value was chosen as the water content on the day after which the rate of water content decline was low.

Results

Soil water recharge

Study of the daily rainfall records for Woodstock (four miles from the study location) indicates that there have probably been no rainfall periods in the last 70 years that would have provided more optimum recharge conditions than those of February 5-16, 1968. Although the progress of recharge was not documented, the measurements of February 22 provide the basis for comparison among soils as to total amounts of available water in the profile after full recharge. The rainy period concluded with a 15 mm fall on February 16. An estimate of the maximum amount of available water in the profiles can be made by adding a depth of water equal to the evaporation from an Australian tank evaporimeter for the period February 17-22 to the soil water contents of February 22. This is shown in figure 2 as the water content profile for February 17. This is probably an underestimate of the actual water contents due to presumed lateral drainage losses from the A horizons of soils 1 and 2 and vertical drainage from soil 3.

The most obvious difference among profiles is in the amount of available water stored in the B horizon (figure 2). It is apparent that soils 1 and 2 have low subsoil permeabilities. Other studies have shown that water permeates into these soils to a great extent only with prolonged flooding (McCown, unpublished data).

Differences in total available water storage capacity to 150 cm were:

	Soil 1	*Soil 2*	*Soil 3*
A	49 mm	73 mm	—
B	33	80	—
Total	81	153	180

Although soil 3 appears to have only a moderately greater storage than soil 2, it must be remembered that the measurements for soil 3 were not made sufficiently deep to include the entire zone from which water was removed. The difference between soils 1 and 2 was due mainly to the B horizon, but there was also a considerable effect from the A horizon. About 90 per cent of the difference in the A horizons was due to variation in the depth of this stratum and the remainder to differences in the available water range.

Soil water depletion

The patterns of water depletion in the three soils differed markedly (figure 2). In the case of soil 1, initial water loss was mainly from the top 18 cm, the A horizon, with large losses from greater depths occurring only as the available water content in the

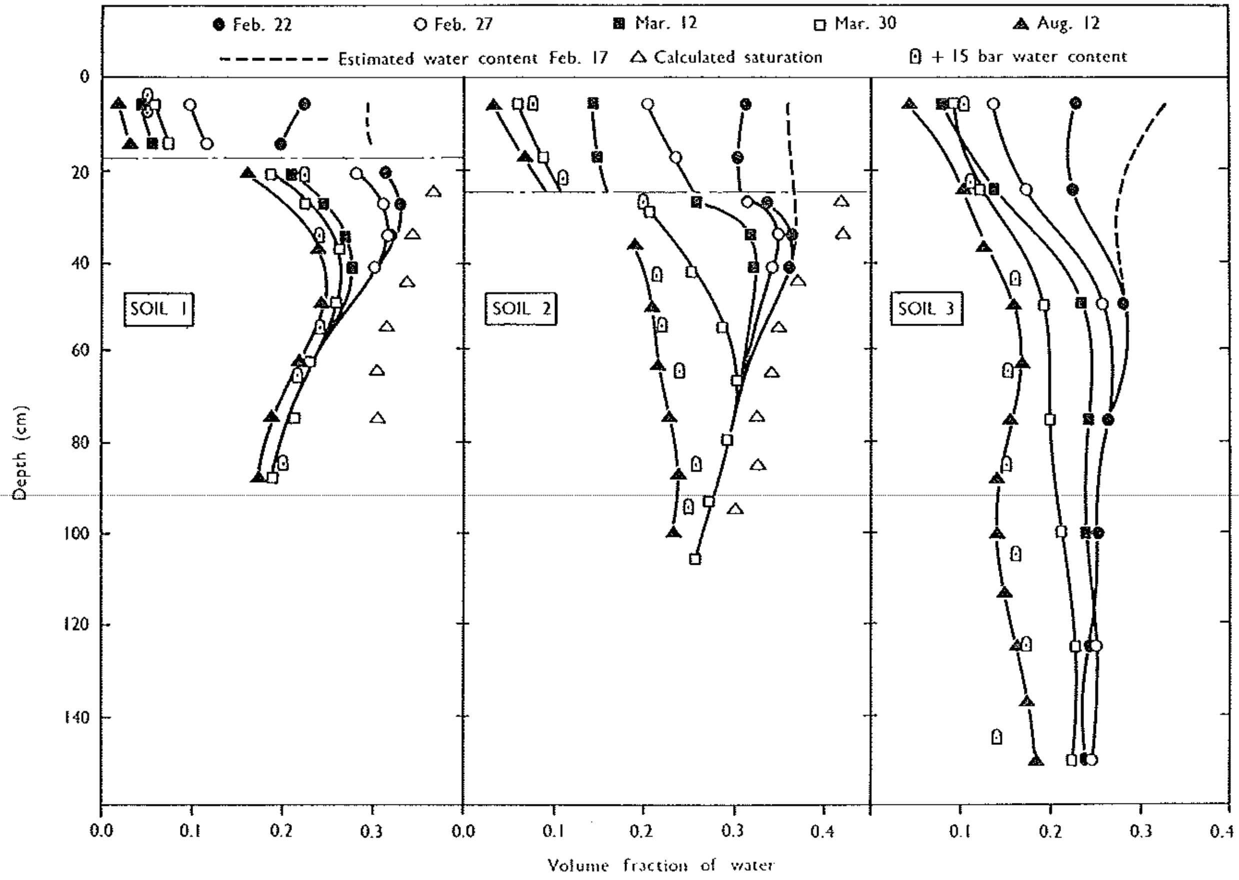

Figure 2—Water content profiles for three soils on Feb. 22, Feb. 27, Mar. 12, Mar. 30, and Aug. 12. Estimated water contents on Feb. 18, calculated saturation (Δ), and −15 bar water content. (The horizontal lines denote the interface between the A and B horizons in soils 1 and 2).

A horizon neared depletion. In comparison, progressive losses were distributed much more uniformly through the profile of soil 3. The pattern in soil 2 was intermediate to these.

As an aid to interpretion of these differences the vertical distribution of roots in each soil was measured (figure 3). These values represent root densities integrated over the entire growing season. The relative root distribution in each of the three soils shows a pattern similar to the corresponding vertical distribution of available water (figure 2). About 40 per cent of root length in all soils was in the top 10 cm stratum. Below this, in soil 1, the decline was very rapid whereas in soil 3, it was quite gradual. Again, the situation in soil 2 was intermediate to these.

Soil water store boundaries

Critical water contents (cc cm^{-3} × 100) were:

Soil	Depth	15 bar	Field capacity	Saturation
1	0-18 cm	3	17	43
2	0-25 cm	10	24	46
3	0-20	11	33	44

The estimated water content profiles for February 17 (figure 2) can be taken as the upper limit of water storage in these soils. In the freely draining soil 3, this corresponds closely to independent measures of field capacity. With soils 1 and 2, where the concept of field capacity is obviously not applicable, saturation water contents were calculated. In the A horizon, the water content was midway between saturation and field capacity. The water contents in the B horizons correspond to about 92 per cent saturation throughout the zone where appreciable water content changes occurred, i.e. down to 50 cm and 100 cm respectively for soils 1 and 2. Figure 4 shows the distribution of total soluble salts for these two soils. The peak concentration in both cases corresponds well with the maximum depth of appreciable wetting (figure 2).

The lower limit of availability is represented by the water content profile of August 12 (figure 2). At depths greater than 25 cm these values compare closely with 15 bar water contents. At depths less than 25 cm water was removed against suctions considerably greater than 15 bars presumably due to direct drying.

Discussion

Apart from chemical deficiencies, readily overcome with appropriate fertilizers, the low productivity of

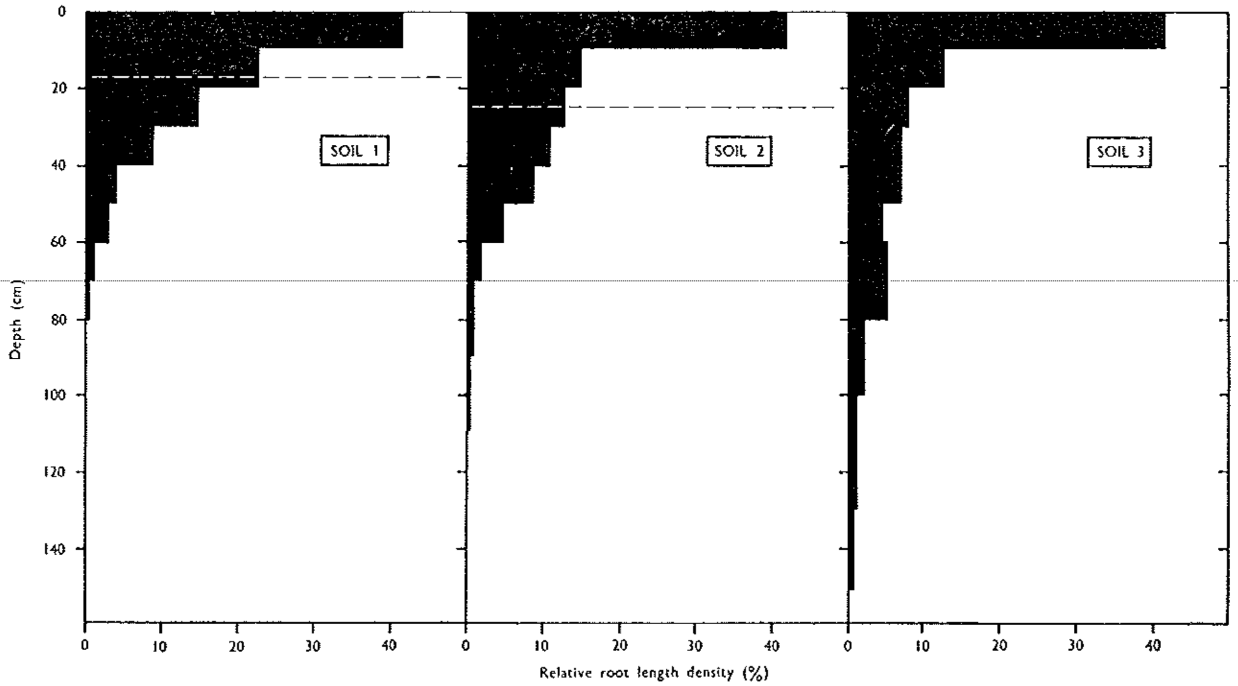

Figure 3—Profiles of root length density (cm cm^{-3}) as a per cent of the total in each of three soils. (The horizontal lines denote the interface between the A and B horizons of soils 1 and 2.)

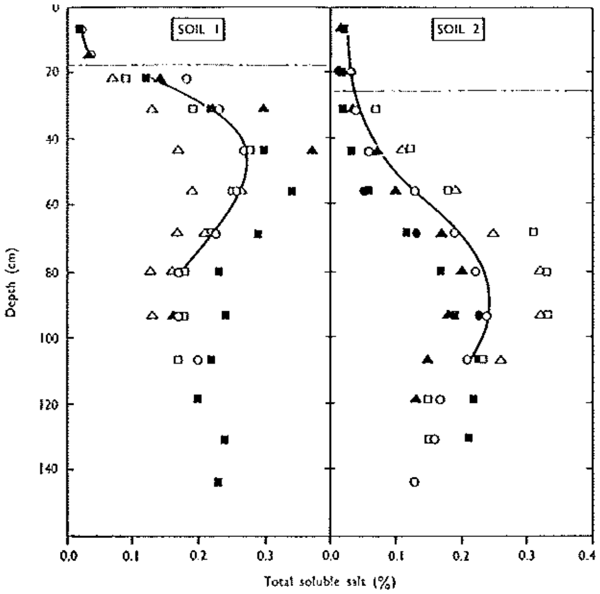

Figure 4—Profiles of total soluble salt contents in the poorly drained soils. Data from each of five locations on soil 1 and six from soil 2 are represented by the various symbols. The curves intersect the mean values. (The horizontal lines denote the interface between the A and B horizons.)

solodized solonetz and solodic soils is due to their unfavourable physical properties. Although amelioration of these conditions is technically feasible (Cairns 1961), it is not likely to become economic in the foreseeable future. Thus, the value of this study lies primarily in defining the factors limiting production on these soils and in devising practical means of evaluating the production potential of such soils using these factors.

The principle physical problem as shown in this study is low subsoil permeability to water. Difference between soils in this characteristic is the most important source of variation between sites. The fact that in both of these soils, all the available water in the profile was extracted indicates that the size of the soil water store was determined mainly by the amount of water entry and not on any direct soil restrictions on root growth. Although at high water content the air space as a percentage of total porosity was low (0.08 compared with the 0.1 suggested by Marshall (1959) as an average low tolerable limit), there was no evidence that plants were suffering from inadequate aeration.

In view of the importance of stored water to plants in this environment and the magnitude of the differences in available water storage capacity among these soils, it is important that this parameter be readily estimated from soil measurements. In general, an estimate requires the range of volumetric fractions of available water as well as the depth of root penetration. A 15 bar water content is frequently used as an estimate of the lower limit of the available water range, and it provided a good estimate on all three of these soils. In the case of a freely draining profile such as soil 3, neither field capacity estimates or rooting depth presents any problem.

In the case of the poorly drained soils 1 and 2, however, a field capacity estimate is not valid. In this study, the A and B horizons were near saturation when rain stopped. Although water could not drain vertically, evidence of lateral drainage from the A horizon was observed. Thus, as an estimate of the upper limit of available water, the saturation value was too high and the field capacity too low. An arbitrarily chosen intermediate value would suffice for most purposes. The depth of A horizon, a major source of variation in this study, is readily measured. In the case of the B horizon of these two soils, to a certain depth the maximum wetness is determined only by the volume of total pore space and the portion of this that contains trapped air. It appears that a water content equivalent to 90 per cent of total pore space may be a good first approximation (Baver 1956; Williams 1955) and that further measurements will further define soils of different texture, e.g. 92 per cent for local soils similar to soils 1 and 2 in this study. The functional depth of soil, in this case the depth of wetting, was closely approximated by the depth of peak concentration of soluble salts. Theoretical substantiation of this relationship and some evidence of its generality has been given by Yaalon (1965).

Measurements used in describing the soil-plant system should be as compatible as possible with conventional soil survey methods. Of the properties shown by these studies to be valuable in estimating the available water storage capacity, the 15 bar water contents, salt contents, and root length densities can be determined from auger samples. Although bulk density, necessary for determination of total porosity, and field capacity estimates are ideally measured on "undisturbed" cores, such samples are increasingly available with increased use of power coring equipment.

REFERENCES

Baver, L. D. (1956)—"Soil Physics". Third edition. (John Wiley and Sons, Inc.: New York.)

Cairns, R. R. (1961)—Some chemical characteristics of a solonetzic soil sequence at Vegreville, Alberta, with regard to possible amelioration. *Canadian Journal of Soil Science* 41 : 24.

Christian, C. S., Paterson, S. J., Perry, R. A., Slatyer, R. D., Stewart, G. A., and Traves, D. M. (1953)—Survey of the Townsville-Bowen Region, North Queensland, 1950. C.S.I.R.O., Australian Land Research Series No. 2.

Marshall, T. J. (1959)—Relations between water and soil. Commonwealth Agricultural Bureau, Commonwealth Bureau of Soils, Technical Communication No. 50.

Murtha, G. G., and Crack, B. J. (1966)—Soils of the C.S.I.R.O. pasture research station "Lansdown", Townsville, Queensland. C.S.I.R.O., Australia, Division of Soils Report 1/66.

Stace, H. C. T., Dubble, G. D., Brewer, R., Northcote, K. H., Sleeman, J. R., Mulcahy, M. J., and Hallsworth, E. G. (1968)—"A Handbook of Australian Soils." (Rellim Technical Publications: Glenside, South Australia.)

Stirk, G. B. (1957)—Physical properties of soils of the lower Burdekin Valley, North Queensland. C.S.I.R.O., Australia, Division of Soils Report 1/57.

Torssell, B. W. R., Begg, J. E., Rose, C. W., and Byrne, G. F. (1968)—Stand morphology of Townsville lucerne (*Stylosanthes humilis*); Seasonal growth and root development. *Australian Journal of Experimental Agriculture and Animal Husbandry* 8 : 533.

Williams, O. B. (1955)—Effects of moisture content on porosity and air space in a Riverina clay under irrigated pasture. *Journal of the Australian Institute of Agricultural Science* 21 : 91.

Yaalon, D. H. (1965)—Downward movement and distribution of anions in soil profiles with limited wetting. In *Experimental Pedology*, Proceedings of the Eleventh Easter School in Agricultural Science, University of Nottingham, 1964: p. 157.

Received for publication October 19, 1970