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MOISTURE REDISTRIBUTION IN SOUTHERN AFRICAN SOILS
LA REPARTITION DE L'EAU DANS DES SOLS SUD-AFRICAINS
ПЕРЕРАСПРЕДЕЛЕНИЕ ВЛАГИ В ГРУНТАХ ЮЖНОЙ АФРИКИ

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SYNOPSIS. Soil moisture is a dominant factor in the heave and collapse of soils and other foundation properties. The results of observations on soil moisture variations and the associated movements, under different surface covers at five sites in Southern Africa, with different climatic and soil conditions, are presented and discussed. The effect of surface covers on soil moisture conditions is negligible in very wet and very dry climates. In intermediate climates the removal of vegetation is the major factor causing soil moisture changes.

In the field of shallow foundations, soil moisture variations are of significance, particularly in moisture-sensitive soils such as expansive clays or collapsing sands. Thus reliable methods of predicting seasonal fluctuations as well as maximal and minimal moisture states are needed for the prediction of foundation movements.

The moisture regime in the soil is governed by surface boundary conditions, lower boundary conditions, and inherent soil characteristics such as moisture affinity and permeability.

BOUNDARY CONDITIONS

Under natural field conditions, the soil surface is subjected to season-dependent rain infiltration and evapotranspiration flows of moisture, controlled by the microclimate at the site. The depth to which the moisture redistribution is influenced by seasonal variations depends on their amplitude, and on permeabilities in the upper soil region, which vary with the type of climate and the type of soil. Permeabilities are greatly affected by the seasonal opening and closing of fissures and cracks in the upper region of the profiles of soils that show excessive swelling and shrinkage. Additional factors are the type of surface vegetation and the possible existence of a surface mulch, often formed by a layer of sandy material.

Any modification of the natural field condition, such as the shielding of a finite area by an impermeable cover, the installation of

a stabilizing sand blanket, or a change in the existing vegetation, e.g. the removal or the planting of trees, may drastically alter the moisture regime in the neighboring soil.

Under arid and semi-arid climatic conditions and where the water table is deep or non-existent the equilibrium moisture potential under covered areas had been found to be closely associated with the climatic conditions, which has led to tentative attempts to correlate the equilibrium moisture potential under covered areas with Thornthwaite's climatic moisture index I_m (G.D. Aitchison and B.G. Richards, 1965).

The lower boundary of a soil body may either be indistinct (semi-infinite medium), or formed by a water table, which may fluctuate seasonally, or by a layer of unweathered parent rock of poor permeability. This boundary too may have a profound effect on the pattern of moisture redistribution.

Field evidence from a number of countries has shown that where a water table exists relatively close to the surface, i.e. at depths less than 6m in clays, 3m in sandy clays and silts and about 1,5m in sands, the distance to the water table controls the equilibrium moisture condition in a soil when covered by an impermeable layer (G.D. Aitchison et al., 1965). In these cases predictions of the ultimate moisture potential profile may be based on hydrostatic considerations.

Tentative practical prediction methods have also been proposed for the wide range of

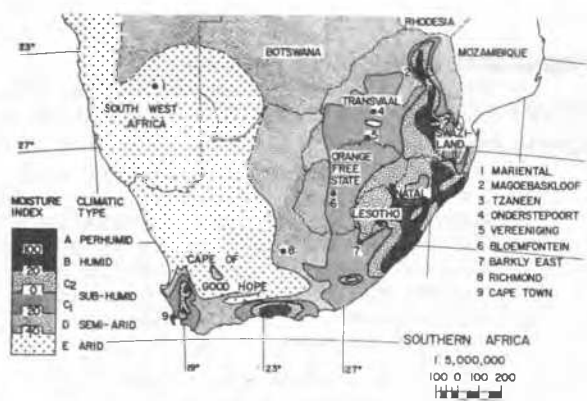


Figure 1. Climates of Southern Africa

situations intermediate between control predominantly by a water table and predominantly by atmospheric conditions, (G.D. Aitchison et al., 1965). A large part of Southern Africa falls into this category.

SOUTH AFRICAN INVESTIGATIONS

In order to establish the effects of climate on moisture redistribution under various types of surface cover and to test the validity of the postulated prediction methods, a series of experimental sites has been established in various climatic regions in South Africa. The first site was established at Onderstepoort near Pretoria in June 1963, (C.M.A. de Bruyn, 1967), followed by sites at Vereeniging, Magoebaskloof, Tzaneen, Bloemfontein, Cape Town, Richmond, Barkly East and also at Mariental in South West Africa. These locations are shown in Fig. 1. For the purpose of this paper, only

the older sites at Onderstepoort, Vereeniging, Mariental, Magoebaskloof and Tzaneen are considered.

CHARACTERIZATION OF CLIMATIC CONDITIONS

Reports on heaving in Southern Africa have invariably contained monthly precipitation data. In semi-arid regions, the loss of water through evapotranspiration, however, is as important as the gain of soil moisture by the infiltration of rain-water.

Thornthwaite's (1948) rational classification system is in the first instance based on the concept of moisture surplus or moisture deficiency, and therefore has certain advantages over the 'classic' system (W.Köppen and R.Geiger, 1936). Monthly potential evapotranspiration values are calculated from meteorological data which are readily available for most areas. When, on a monthly basis, infiltration exceeds potential evapotranspiration, a moisture surplus (run-off) will occur if the amount of moisture storage exceeds 10cm and a moisture deficiency when the combined amounts of stored water and infiltration minus the potential evapotranspiration is less than 10cm. By combining the annual moisture surplus and/or deficiency a moisture index I_m is obtained which defines the first parameter of Thornthwaite's rational classification, which has been applied to Southern Africa (B.R.Schulze 1958), as shown in Fig. 1. However, it was devised for conditions existing in North America and has never been fully verified for areas with a markedly different type of climate, such as the South African Highveld. There are also limitations in the method of calculating the potential evapotranspiration and, of necessity, this broad regional classification based on long-term data may be considerably different from the actual con-

TABLE I. CLIMATIC CONDITIONS AT TEST SITES

	ONDERSTEPSOORT	VEREENIGING	MAGOEBASKLOOF	TZANEEN	MARIENTAL	
Latitude	25° 39' S	26° 40' S	23° 53' S	23° 50' S	24° 37' S	
Longitude	28° 11' E	27° 55' E	30° 00' E	30° 10' E	17° 58' E	
Altitude	m	1210	1420	1430	780	1100
Mean Annual Precipitation	cm	71	67	125	100	19
Mean Annual Potential Evapotranspiration	cm	83	78	72	89	94
Annual Moisture Deficiency	cm	12	11	0	7	75
Annual Moisture Surplus	cm	C	0	53	18	0
Aridity Index	I_a	15	15	0	8	80
Humidity Index	I_h	0	0	75	20	0
Moisture Index	I_m	-9	-9	75	15	-48
Thornthwaite Classification	$C_1 B_2' da'$	$C_1 B_2' da'$	$B_3 B_2' ra'$	$C_2 B_3' ra'$	$E B_3' da'$	
Köppen-Geiger Classification	Cwb	Cwb	Cwb	Cwa	BShw	

ditions experienced at any particular site within the region during any particular period. Nevertheless this is the best practical method available at present and the climatic data for the various test sites are given in Table I, and the annual march of precipitation and evapotranspiration is shown in Fig. 2.

FIELD TEST LAYOUTS

The basic experimental installations consisted of three separate areas with different surfaces: (a) one with an impermeable rubber or fibre-glass cover, (b) one with a 15cm-thick layer of coarse sand and (c) one from which the natural vegetation was removed by a chemical weed-killer.

Multiple gypsum block field tensiometers (G.D. Aitchison and B.G. Richards, 1965) were installed to measure moisture conditions at different depths inside and outside the covered areas. Similarly a series of level pegs founded at various depths was installed in and around the experimental covers. Typical site layouts are shown in Fig. 3.

Where possible level sites that would be unaffected by local drainage patterns were chosen. As the project was associated to a large extent with the study of heaving soils where surface movements are a very good in-

dication of moisture redistribution in the soil, the sites were located, where possible, on potentially expansive soil. The relevant soil profiles are shown in Fig. 4.

RESULTS FROM EXPERIMENTAL SITES

Onderstepoort

The site is situated on the almost flat pen-

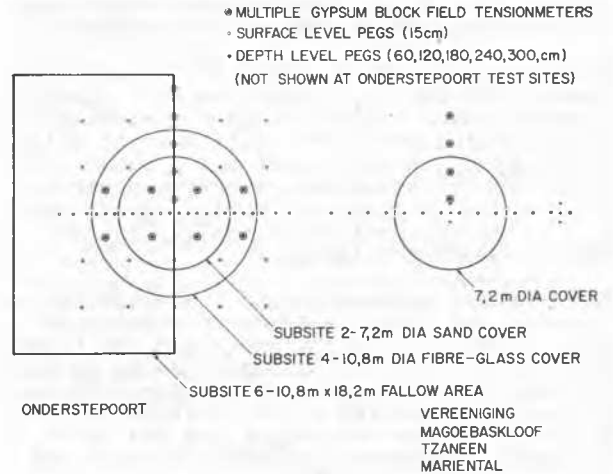


Figure 3. General Lay-out of Test Sites

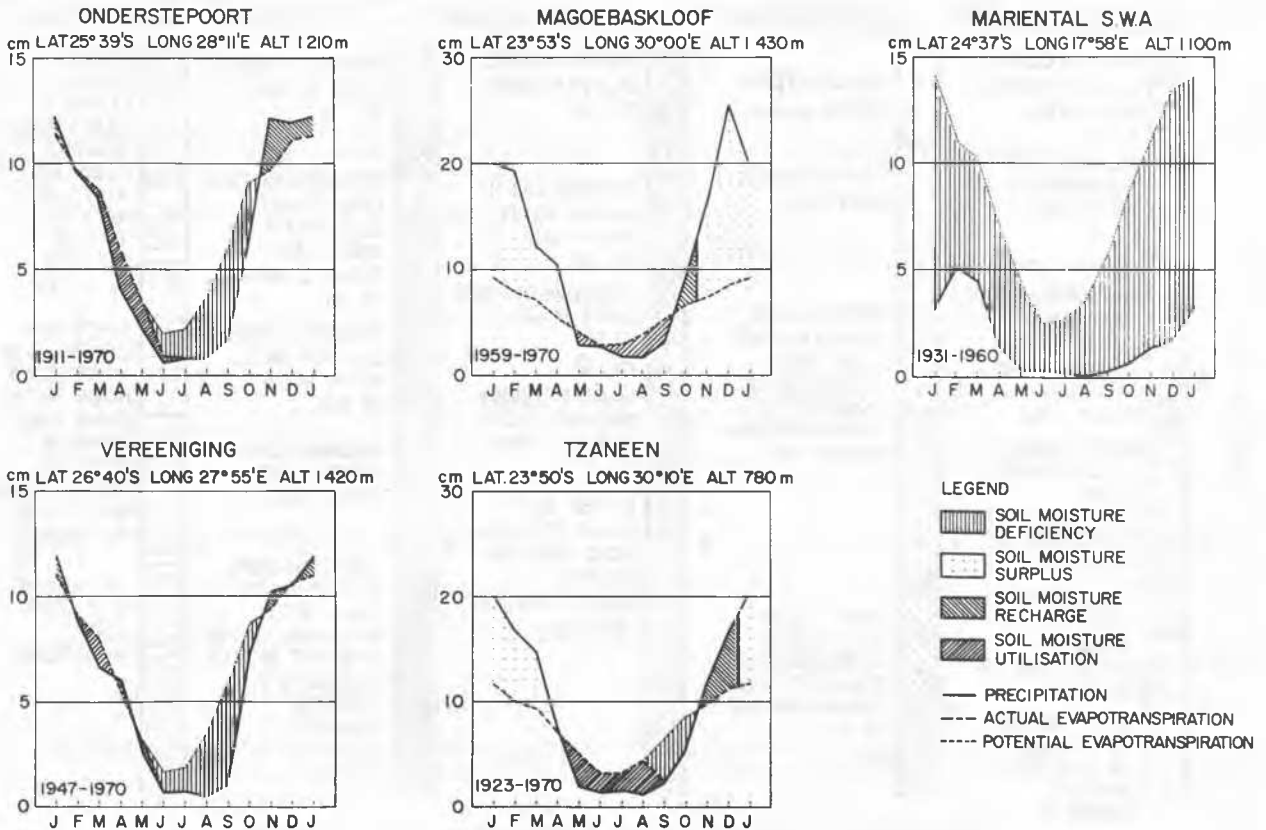


Figure 2. Annual March of Precipitation and Evapotranspiration at Test Sites

plain of the weathered norite (gabbro) of the Bushveld Igneous complex. The upper soils are classified in the highly to very highly expansive range (D.H. van der Merwe 1964), but below 2m depth the expansiveness decreases. Similar results, which are shown in Fig. 5, were obtained from the volumometer test (C.M.A. de Bruyn, 1963(a)). The profile is also characterized by a large moisture affinity (C.M.A. de Bruyn, 1963(b)). The soil is in fact more expansive than any other South African soil so far analysed.

There is no permanent water table above the unweathered norite. Thornthwaite's climatic classification C_1B_2da' defines a subhumid mesothermal climate with little or no moisture surplus in any season and a summer concentration of potential evapotranspiration of less than 48 per cent of the annual total (a'). The designation a' applies to the whole of Southern Africa.

The seasonal appearance and disappearance of fissures and cracks extends to a depth of about 1,5m (G.E. Blight and A.A.B. Williams, 1971) and a clear distinction has to be made between the rapid penetration of rain-water through this portion of the profile at the beginning of the wet season and the slow diffusion process taking place through the uncracked portion of the soil. The expanding clay causes the cracks to close, resulting in an extremely low overall permeability

of the soil, which retards drying during a subsequent arid period; at Onderstepoort this does not last long enough to re-establish the initial state under a covered area, so that successive seasonal cycles lead to a stepwise accumulation of moisture and heave. This effect is further enhanced by the existence of an impermeable layer of unweathered parent material at a depth of about 3,5m on which a perched water table

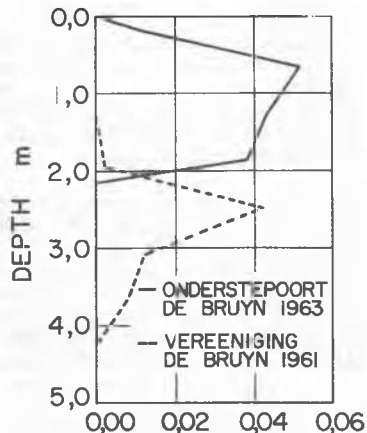


Figure 5. Potential Expansiveness at Onderstepoort and Vereeniging

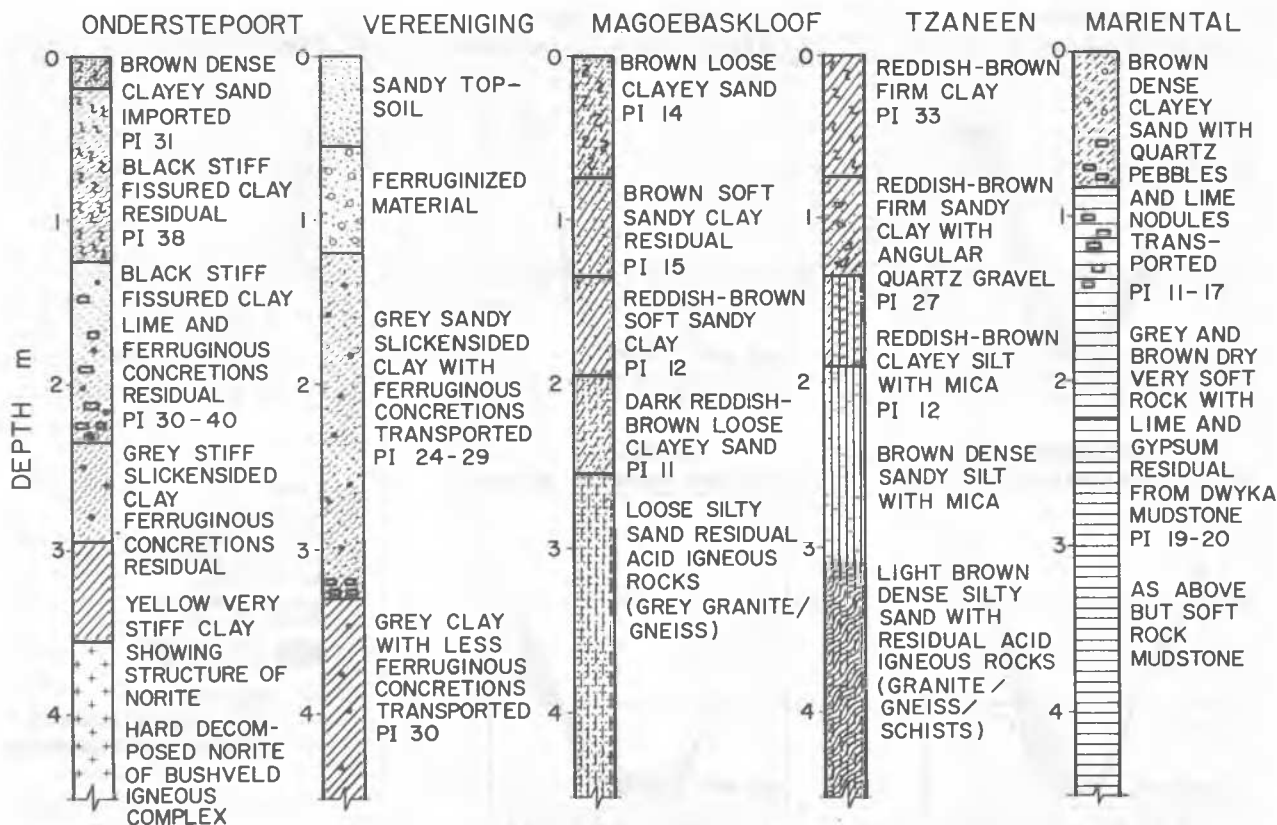


Figure 4. Soil Profiles at Test Sites

may be formed during part of the year. (C.M.A. de Bruyn, 1967).

A rectangular area of 'fallow' ground was also used at Onderstepoort. Typical pF profiles towards the end of dry seasons are shown in Fig. 6. Under the covered and fallow areas the soil remained practically at field capacity down to the bottom of the weathered layer, whereas considerably drier conditions appeared under the natural field condition, the sorption exponent remaining, however, below the permanent wilting point (pF 4,2).

Heave against time curves are shown in Fig.7 and conditions of heaving at the end of dry periods in Fig. 8. It will be noticed that practically the same amount of ultimate heave (13cm) was found at both the fibre-glass covered area and the fallow area. The ultimate heave at both areas can thus be ascribed entirely to termination of the evapotranspiration effect, of which transpiration by the grassy vegetation appears to constitute the major part. During rainless periods the top soil layer in the fallow area dries out rapidly and apparently becomes an excellent vapour barrier (mulching effect).

An ultimate heave of about 17cm was found under the sand cover. In this case a mulching effect is caused by the top part of the sand layer. It was also observed that the lower part of this layer remained water saturated even after prolonged droughts (March - November 1966) and apparently functioned as a permanent plane source of moisture for the underlying expansive clay layer of low permeability.

Fig. 8 also shows conditions of heaving shortly after an exceptionally rainy period (9-6-67). The expansive soil layer is sit-

uated near the surface and seasonal level variations of the natural soil were found to be from 7 to 9 cm.

Vereeniging

The Vereeniging test site is situated on a

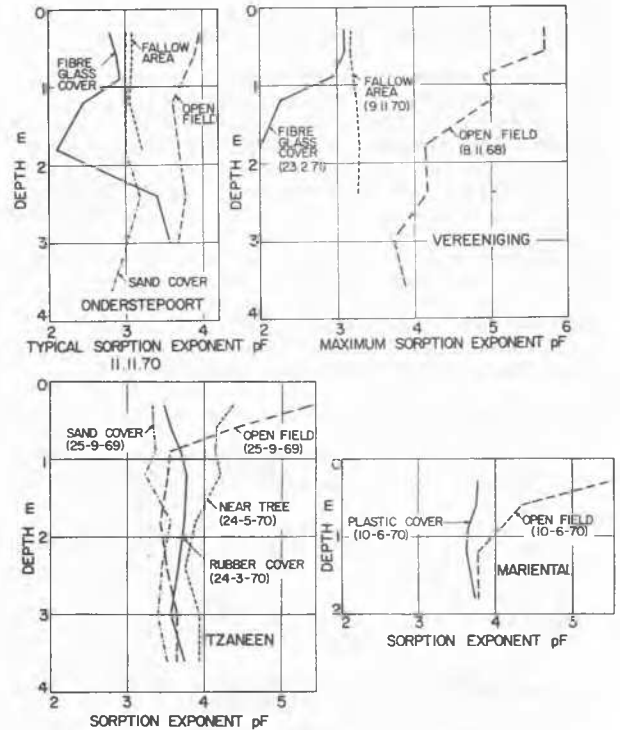


Figure 6. Sorption Exponent at Test Sites

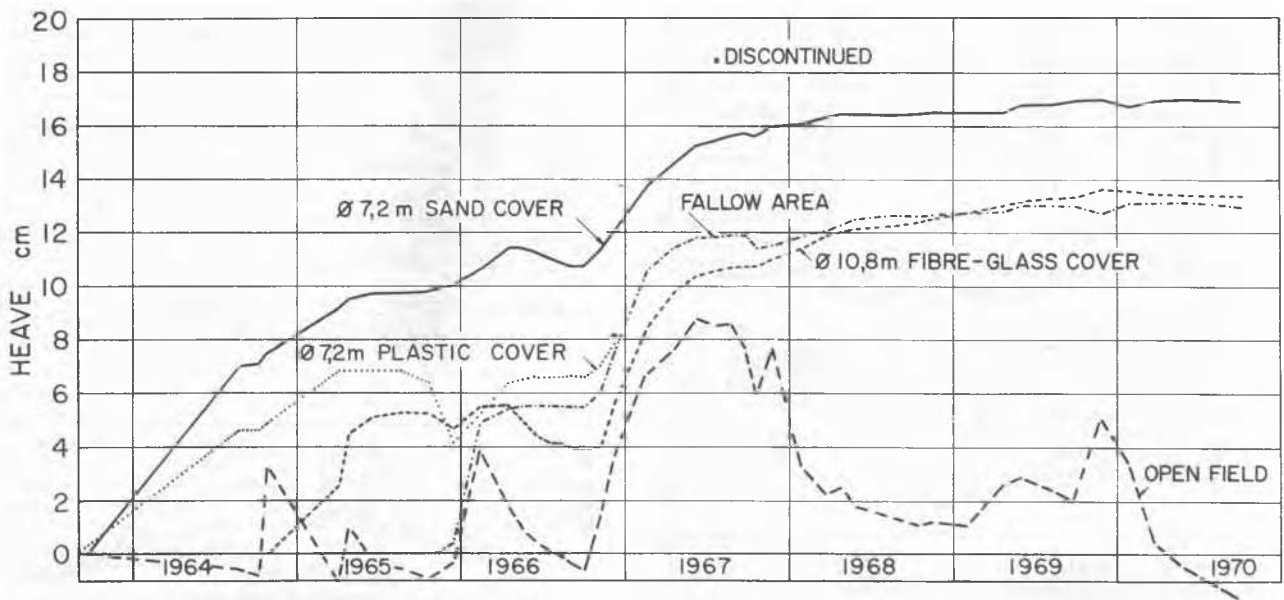


Figure 7. Heave against Time Curves for Onderstepoort

wide flat plain of lacustrine deposits on the old floodplain of the Vaal River. The upper layers of the profile are non-expansive, but they do affect the moisture redistribution and heaving pattern by acting as a natural mulch (G.E. Blight, 1965). The sandy clay and clay layers can be classified as highly expansive and the volumometer results are shown in Fig. 4. From Fig. 2 and Table I it will be seen that the climate is similar to that at Onderstepoort.

Sorption exponent (pF) values measured in the upper part of the soil profile were found to be extremely variable with time and depth, dry patches alternating with soaked ones, apparently as a result of the high permeability in this region. Only characteristic maximal values are therefore given in Fig. 6. Under covered areas, pF values usually remained below pF 2,0 but after dry periods maximum values up to pF 3,1 and 3,2 were observed under the impermeable cover and fallow area respectively. Outside the covered areas, fluctuations occurred between less than pF 2,0 and more than pF 5,6.

Heave against time curves for three subsites

are given in Fig. 9 and some intermediate stages in Fig. 10. Because of the depth of the expansive part of the soil profile and the presence of the sandy top layer, heaving occurred much more gradually than at Onderstepoort. An equilibrium condition had obviously not been reached after four years of observation.

Here again, practically the same amount of heave occurred under both the fibre-glass cover and the fallow area (7cm) indicating that termination of the evapotranspiration effect of the natural grassy vegetation was apparently the main cause of the heaving. At an additional subsite the natural vegetation was continually cropped but this did not result in any difference in vertical movements inside or outside the test area.

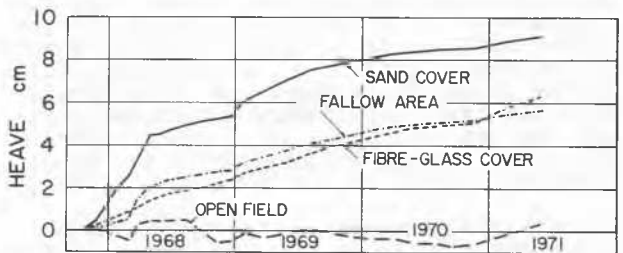


Figure 9. Heave against Time Curves at Vereeniging test sites

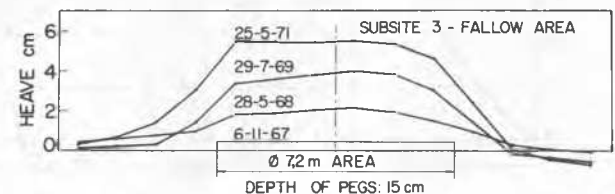
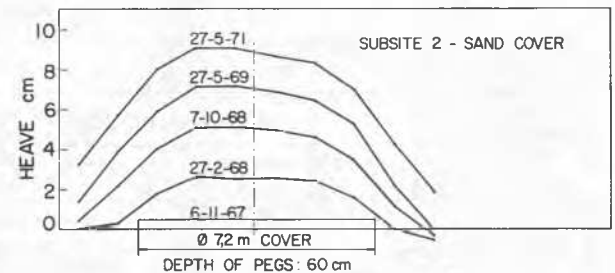
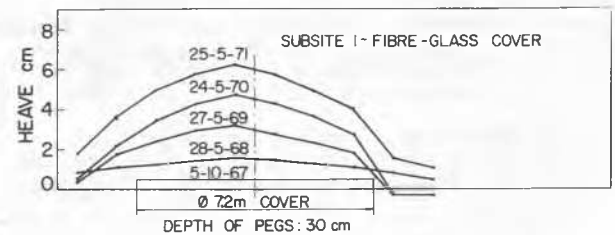


Figure 10. Heave at Vereeniging Subsites

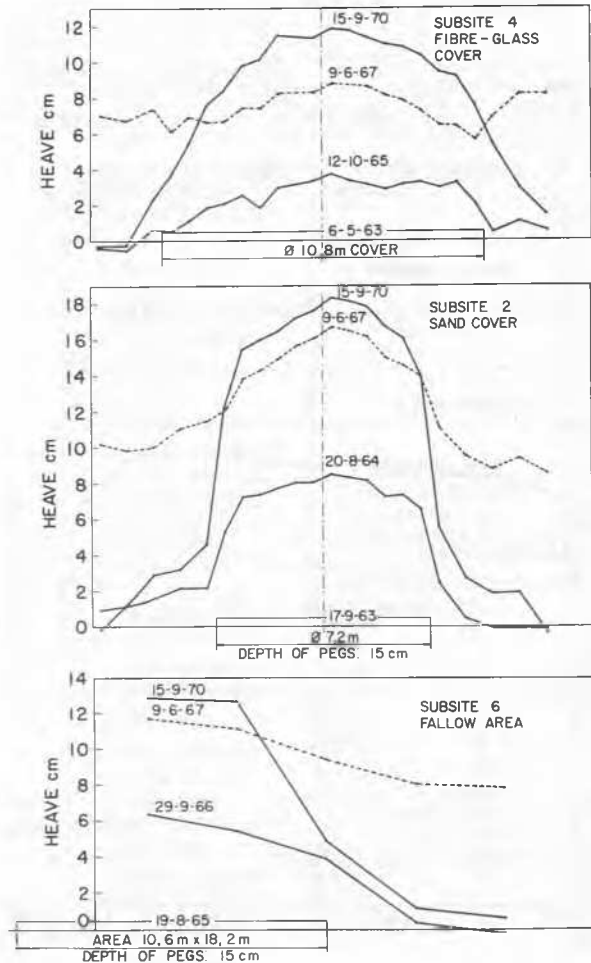


Figure 8. Heave at Onderstepoort Subsites

Evapotranspiration was apparently not influenced by cropping.

Under the sand cover a heave of 9cm was observed, the sand probably acting as a semi-continuous source of water.

Seasonal level variations outside the test areas were found to be much smaller than at Onderstepoort (less than 1cm).

Magoebaskloof

The Magoebaskloof test site was laid out near the upper edge of the Northern Transvaal Escarpment. Although the surrounding countryside is irregularly undulating the site is on a gentle slope (about 5°).

The deep weathered ferralitic soil formed by the disintegration and decomposition of the parent granite and gneiss, contains appreciable amounts of kaolinite and is classified as non-expansive.

The humid mesothermal climate has no moisture deficiency in any season.

Inside and outside the three subsites, the soil remained practically soaked, pF less than 2,9, during the entire period of observation (October 1968 - January 1972) and no vertical movements took place. These results are in accordance with the large annual moisture surplus and the absence of potential expansiveness.

Tzaneen

The local topography consists of rolling irregular plains. The test site, which is almost level, is on top of a slightly elevated area. Tzaneen is 25km east of Magoebaskloof at the foot of the Escarpment but the soil profiles are similar. The upper 0,5m of clay may be classified as medium to highly expansive. The climate is described as moist subhumid mesothermal.

Under the rubber-covered area no major change in sorption exponent (pF) occurred and the soil never became saturated. Immediately outside this site and under the sand cover, pF profiles showed a considerable seasonal variation, down to at least 3,6m, between pF less than 2,0 and the observed maximum values given in Fig. 6. Immediately after precipitation the soil reached field capacity but it soon dried out, owing, apparently, not to evapotranspiration losses but to the downward movement of the moisture through the fairly permeable soil on this well-drained site.

Only slight seasonal upward and downward movements, between +0,3 and -0,6 cm, were measured under the rubber and sand covers in accordance with the slight potential expansiveness of the soil.

At a third subsite, a settlement of 2,0cm developed near a large tree (eucalyptus) during the entire period of observation

(January 1969 - January 1972) and a settlement of 1,2cm at a distance of 6,0m from the stem. The influence of the transpiration effect of the tree on the pF profile is given in Fig. 6 and was still noticeable at a depth of 3,6m.

Mariental

The test site is on a practically level area which is typical of Mariental and its surroundings. As this area is flooded periodically, the surface soil layers are often of alluvial origin, and can be classified as medium expansive, while the lower half of the profile consists of residual material which may just be classified as medium expansive.

Rainfall is often very erratic and occurs mainly in the form of heavy downpours lasting a short time, usually in January, February or March. Throughout the year there is a considerable moisture deficit and the actual evapotranspiration is therefore invariably the same as the precipitation.

Two subsites, a fibre-glass cover and a sand cover, were included in the experimental site which was installed in March 1968.

Exceptionally dry conditions with practically no rainfall were experienced until September 1971, resulting in maximum settlements of 1 to 2cm in the open field and under the edges of the sand cover, but only small settlements occurred below the impermeable cover.

Stable pF values in the range pF 3,6 to 3,8 were measured beneath the fibre-glass cover, whereas values well above the permanent wilting point (pF 4,2) were found in the top soil layer in the open field and under the sand cover (Fig. 6).

Heavy downpours occurred during October and December 1971 and January 1972, causing some wetting of the soil outside the covered areas to a depth of about 30cm, but without any immediate significant effect on the level pegs.

Permeability of the soil is apparently extremely low and the major portion of any rainfall runs off or is re-evaporated before it can cause any swelling.

Under these conditions, the vertical movements due to natural variation in climatic conditions are small. However, appreciable upward movements can still result from slow moisture accumulation caused by damaged water supply or drain pipes. It is believed that this is the cause of severe damage to some buildings in the area.

CONCLUSIONS

In very humid regions (Magoebaskloof) or very arid regions (Mariental) the construction of roads or buildings will not affect the soil moisture regime to any significant

degree.

The importance of soil moisture permeability and internal drainage is shown by the results obtained at Tzaneen where, in a moist subhumid climate, there was no cumulative moisture gain under the covered areas, nor even a seasonal moisture gain under the impermeable cover, owing to the fact that the moisture ingress was passed directly down the profile to drain away.

In the dry subhumid climate, where both sites had far poorer drainage and a higher water affinity (Onderstepoort and Vereeniging), marked cumulative moisture gains were registered under the various surfaces. The virtually identical values obtained for impermeable covers and fallow areas show that the elimination of transpiration losses is the major effect of constructing roads and buildings in these areas, leading to increases in moisture content under such structures.

The reaction of a surface layer of very fissured highly expansive soil (Onderstepoort), as compared with a deeper seated, somewhat less active soil (Vereeniging) under almost identical climatic conditions, is shown in the very much greater seasonal movement of the natural soil at Onderstepoort.

This brief review of results confirms general views and theories expressed on this subject (G.W. Donaldson 1969). In all cases only the effects of natural factors have been studied and it must be realized that extraneous influences such as artificial drainage, moisture supply and desiccation can severely distort the natural moisture redistribution pattern. The analysis of these results, together with those from the more recently established sites, should provide reasonably accurate methods of evaluating the effects of all the relevant factors in predicting soil moisture redistribution under the conditions experienced in Southern Africa.

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REFERENCES

- AITCHISON, G.D. et al.(1965), "Statement of the review panel", Moisture equilibria and moisture changes in soils beneath covered areas, Butterworths, Sydney, pp. 7 - 21.
- AITCHISON, G.D. and RICHARDS, B.G.(1965), "A broad-scale study of moisture conditions in pavement subgrades throughout Australia", Moisture equilibria and moisture changes in soils beneath covered areas, Butterworths, Sydney, pp. 184 - 232.

BLIGHT, G.E.(1965), "The time-rate of heave of structures on expansive clays", Moisture equilibria and moisture changes in soils beneath covered areas, Butterworths, Sydney, pp. 78 - 88.

BLIGHT, G.E. and WILLIAMS, A.A.B.(1971), "Cracks and fissures caused by shrinkage and swelling", Proceedings Fifth Regional Conference for Africa on Soil Mechanics and Foundation Engineering, Luanda, Vol. I, (1963a), pp. 1/15 - 1/21.

DE BRUYN, C.M.A.(1963a), "Swelling characteristics of a decomposed norite soil profile at Onderstepoort, Transvaal", Proceedings Third Regional Conference for Africa on Soil Mechanics and Foundation Engineering, Salisbury, Vol. I, pp. 27 - 30.

DE BRUYN, C.M.A.(1963b), "Moisture sorption characteristics of the expansive soil profiles at Lynwood, Vereeniging and Onderstepoort", Proceedings Third Regional Conference for Africa on Soil Mechanics and Foundation Engineering, Salisbury, Vol. I, pp. 23 - 6.

DE BRUYN, C.M.A.(1967), "Annual vertical movements and soil moisture redistribution at the Onderstepoort test site", Proceedings of the Fourth Regional Conference for Africa on Soil Mechanics and Foundation Engineering, Cape Town, Vol. I, pp. 235 - 42.

DONALDSON, G.W.(1971), "The ups and downs of heaving soils". Construction in Southern Africa, Johannesburg, Vol. 16, No. 4.

KÖPPEN, W. and GEIGER, R.(1936), "Das geographische System der Klimate", Handbuch der Klimatologie, Vol. I, part C, Gebrüder Borntraeger, Berlin.

SCHULZE, B.R.(1948), "The climate of South Africa according to Thornthwaite's rational classification", S.Afr. Geogr. J., Johannesburg, Vol. 40, pp. 31 - 53.

THORNTHWAITTE, C.W.(1948), "An approach toward a rational classification of climate", Geographical Review, Vol. 38, pp. 55 - 94.

VAN DER MERWE, D.H.(1964), "The prediction of heave from the plasticity index and percentage clay fraction of soils", Trans. S.Afr. Instn Civ. Engrs, Vol. 6, No.6, pp. 103 - 107 and Vol. 6, No.12, pp.226 - 8.