

R. WEBSTER

WOSSAC: 25745  
631.432.2  
(676.2)

NOT FOR PUBLICATION

LABORATORY NOTE NO. LN/353/KR.ABB.  
April, 1963.

BOR.78.

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH  
Road Research Laboratory

THE FACTORS INFLUENCING MOISTURE CONDITIONS IN  
SUBGRADES AT SEVEN SITES IN KENYA

by

K. Russam and A.B. Baker

Division:	Materials and Construction
Section	Tropical (R.S. Millard) Soils (D.J. Maclean)
Research Team:	D. Croney, K. Russam, I.M. Fenwick, A.B. Baker, P.K. Roberts, T.E. Jones, J.A. Forse

THE FACTORS INFLUENCING MOISTURE CONDITIONS IN  
SUBGRADES AT SEVEN SITES IN KENYA

SUMMARY

This Note is concerned with the moisture characteristics of soil samples from the subgrades of seven roads in Kenya and with the factors influencing the moisture condition of the subgrades. It is the final report in a series dealing with an investigation of conditions in the base and subgrade of bituminous-surfaced roads in the Kenya Highlands.

The subgrades varied over a range of soil types from red and black clays, sandy clay, to ash and pumice soils. The moisture characteristics of the soils were related to soil type, clay mineralogy and density. The black clay contained a clay mineral of the montmorillonite group and underwent much larger changes of moisture content and volume, under conditions equivalent to normal seasonal variations, than did the red clay, which contained metahalloysite. The sandy clay, ash and pumice soils showed little change in volume with moisture content, mainly because of the grain to grain contact of large particles.

The subgrades were unsaturated, the degree of saturation varying between 0.86 to 0.55 with the air content ranging from 7 to 31 per cent. The suction or pore water tension in the subgrades was highest in the black clay (pF 4) and lowest in the pumice soil (pF 2). The main factors influencing the pore water tension in the subgrades were (a) the permeability of the soil, (b) the local climate and topography, and (c) the construction of the road pavement and verge. Wetting of the road subgrade occurred as a result of lateral flow, from the verge, of water originating from rainfall and run-off from the pavement. The most significant differences in moisture conditions in the black clay subgrades were caused by variations in the road cross-section which impeded in varying degrees the rapid disposal of surface water into the side drains. These effects were still significant on the more permeable red clay or pumice soil but were reduced in magnitude.

Introduction

During the period April 1958 to July 1959 an investigation was carried out in Kenya to determine what changes took place during that period in the strength of the base and subgrade under bituminous surfaced roads. The main engineering conclusions reached in this investigation have been reported in previous research notes.<sup>(1), (2)</sup> The distribution of moisture under the roads was one of the main subjects studied and this note is concerned with the moisture properties of the soils themselves and the factors influencing the moisture conditions of the subgrades "in situ".

Location of sites

The sites investigated were situated in the Kenya Highlands at elevations between 4,900 and 6,900 ft above sea level. Five were within a 30 mile radius of Nairobi and the remaining two in the Rift Valley.

Sites Nos. 1 and 2 were selected on the Limuru "A" Route, near Kiamba village, and on the Thika-Sagana Road  $33\frac{1}{2}$  miles from Nairobi, the soil in each case being a red clay. Three subsites\* giving conditions of cut, fill and level ground were investigated at each site.

Site No. 3 was in a typical black clay area on the Embakasi Plains and was on the Nairobi-Mombasa Road near the 12 mile post. Here 2 to 4 ft of black clay overlay decomposing rock. Later another site, No. 7, was selected on the Ngong Road, at Dagoretti Corner, Nairobi, where the black clay was about 8 ft deep. Site No. 3 contained two subsites both on level ground while Site No. 7 had only one subsite also on level ground.

Site No. 4 was at Mile 27 on the Nairobi-Mombasa Road where the soil was a sandy clay. Two subsites were investigated, both on slight fill, one being near the top of an incline and the other near the bottom.

The remaining two sites, Nos. 5 and 6, were single locations on level roads in the vicinity of Naivasha and Nakuru the positions being on the Nairobi-Nakuru Road, Mile  $50\frac{1}{4}$ , and on the Nakuru-Eldoret Road, Mile 8, respectively. In both cases the soil was composed of volcanic ash and pumice.

Field measurements and sampling procedure

The selected roads had bituminous surfacing varying in width between 19 and 23 ft. At approximately monthly intervals three boreholes, located (i) on the centreline of the road, (ii) 3 ft inwards from the road pavement edge and (iii) in the verge a few inches from the road pavement, were sunk to a depth of 6 ft or to rock if this was encountered closer to the surface. Moisture content determinations were carried out by oven-drying soil samples taken at 1 ft intervals of depth. The measurements showed<sup>(1)</sup> that seasonal fluctuations in moisture content were largely confined to the edges of the roads. With the exception of the Thika Sagana site where significant wetting of the subgrade was taking place under the centreline of the road, the moisture distribution in the central part of the subgrade, i.e. at distances of 3 ft or more from the edge of the pavement, was relatively stable during the period of investigation. Average values of soil moisture content for the period of the observations are summarised in Table I.

/In

\*The annotation of the subsites (a, b, c) was arranged so that the "a" subsite was always nearest Nairobi. The site numbering follows that used in the previous reports.<sup>(1), (2)</sup>

In August/September 1958 lined boreholes to record any water-table levels were sunk to a depth of 12 ft or to a depth where a hard layer was encountered where this was less than 12 ft. Water was found in these boreholes only at the Ngong Road site and this was subsequently found to be due to seepage from the surface down the side of the lining following heavy rainfall. At the Thika Sagana subsite (c), on fill, a permanent stream flowed at the foot of the embankment i.e. at a depth of 10 to 11 ft below the road surface.

At the end of the period covered by the field investigation a further trench was cut across half the width of the road at each subsite and undisturbed samples of the subgrade obtained at various positions. These samples were immediately sealed in airtight aluminium containers and sent by air to the Road Research Laboratory for detailed laboratory testing.

Tests carried out at the Road Research Laboratory

(a) Classification tests. The results of classification tests carried out according to B.S. 1377 (1961) on a sample of soil from each subsite is given in Table II. In order to achieve consistent results in the plasticity tests it was necessary for the soils to be thoroughly mixed with a spatula over a period of 45 minutes before the test was actually carried out. The resulting values for the index tests therefore reflect the clay contents of the soils but in the case of the samples from Limuru and Thika Sagana do not give any indication of the friable free draining nature of the red clays of Kenya. The sites were originally selected along lengths of road where the soil profile appeared from preliminary observations to be uniform so that comparisons could be made of moisture measurements made at similar depths but in different positions along the roads. The classification tests gave results which, with the exception of those for the subsite on fill at Thika Sagana, were within the range of values obtained during the field measurements. The sample from the fill subsite (c) at Thika Sagana had a slightly higher value for the plastic limit than those previously recorded.

(b) Soil moisture condition. The undisturbed soil samples, which were roughly  $2\frac{1}{2}$  in. in diameter and 3 in. in height, were cut into smaller specimens each containing about 10 gms of soil. One specimen was used to obtain the soil moisture content while several of the others were weighed and placed on suction plates or pressure membranes<sup>(3)</sup> operating at various suctions both above and below the estimated suction of the soil. After a few hours the samples were removed from the apparatus and again weighed. At applied suctions higher than the initial suction of the specimen some water was removed from the soil whereas at applied suctions lower than the initial suction, water was absorbed. An estimate of the initial suction of the soil was obtained by deducing the applied suction at which water did not enter or leave the specimen. This suction was assumed to be the same as the suction of the soil immediately following the excavation of the road in Kenya. Justification for this assumption follows from the fact that the measurements of moisture content taken at the time of sampling were in close agreement with those of the samples tested at the Road Research Laboratory and little or no moisture appears to have been lost from the soil sample during transit.

/TABLE I

TABLE I

Average of monthly moisture content measurements carried out over a period of a year

Depth (ft)	Verge		Road, 3 ft from edge		Road, centre-line	
	m/c (per cent)	m/c P.L.	m/c (per cent)	m/c P.L.	m/c (per cent)	m/c P.L.
<u>Limuru "A" Route (a) Fill</u>						
1	38.5	1.01	36.7	0.94	34.0	0.87
2	40.0	1.25	40.5	0.99	33.7	0.84
3	41.5	0.97	40.9	0.95	35.7	0.83
4	40.2	0.98	40.3	0.96	37.2	0.85
5	41.2	0.98	39.6	0.94	36.5	0.91
6	42.5	1.01	40.9	0.97	38.1	0.93
<u>Limuru "A" Route (b) Cut</u>						
1	42.4	0.90	42.3	0.94	39.8	0.93
2	41.7	0.91	42.1	0.96	41.7	0.97
3	41.5	0.97	42.5	0.92	42.3	0.94
4	41.7	0.91	41.9	0.95	41.8	1.04
5	41.8	0.91	42.1	0.94	40.8	0.91
6	42.2	0.96	41.8	0.91	41.1	0.91
<u>Limuru "A" Route (c) Level</u>						
1	32.2	0.86	32.9	0.88	30.3	0.80
2	28.5	0.82	29.8	0.84	27.8	0.79
3	29.4	0.82	24.1	0.72	27.1	0.78
4	31.8	0.83	29.6	0.83	26.0	0.75
5	35.4	0.92	32.7	0.87	28.8	0.83
6	37.4	0.93	36.5	0.95	33.8	0.90
<u>Thika Sagana (a) Level</u>						
1	30.6	1.02	-	-	-	-
2	34.0	0.97	32.5	0.98	29.8	0.90
3	35.4	1.04	34.1	1.00	32.0	0.94
4	36.1	0.95	34.8	0.99	32.8	0.91
5	36.4	1.04	34.8	0.94	33.1	0.95
6	31.8	0.91	34.9	0.97	33.6	0.93
<u>Thika Sagana (b) Cut</u>						
1	29.4	0.95	-	-	-	-
2	36.5	1.01	36.1	1.03	33.9	0.92
3	36.6	1.05	36.4	0.98	34.1	0.97
4	37.1	1.06	36.5	1.01	34.3	0.93
5	40.0	1.08	39.0	1.05	34.0	0.94
6	43.3	1.14	43.1	1.16	35.7	0.99
<u>Thika Sagana (c) Fill</u>						
1	24.6	0.98	-	-	-	-
2	35.7	1.02	33.1	0.97	30.3	0.87
3	37.1	1.06	34.5	1.01	32.3	0.95
4	36.6	1.08	34.6	1.05	33.4	0.98
5	36.8	1.08	34.2	1.04	33.8	1.02
6	37.9	1.15	37.0	1.09	36.2	1.10

/TABLE I (Contd)

TABLE I (Contd)

Depth (ft)	Verge		Road, 3 ft from edge		Road, centre-line	
	m/c (per cent)	m/c P.L.	m/c (per cent)	m/c P.L.	m/c (per cent)	m/c P.L.
<u>Mombasa Road Mile 12 (a) Level</u>						
1	14.7	-	-	-	-	-
2	34.1	1.00	32.1	0.97	27.0	0.82
3	24.3	0.66	29.2	0.83	27.7	0.79
<u>Mombasa Road Mile 12 (b) Level</u>						
1	19.7	-	-	-	-	-
2	37.4	1.13	35.4	1.04	22.5	0.73
3	29.7	0.90	33.6	1.02	25.3	0.77
<u>Ngong Road Level</u>						
1	29.9	0.81	-	-	-	-
2	37.6	0.94	34.1	0.90	36.3	0.96
3	36.8	0.99	36.8	1.05	37.2	0.98
4	38.1	1.03	37.0	1.03	37.5	1.07
5	37.6	0.99	38.1	1.09	38.1	1.06
6	37.1	0.98	37.8	1.02	37.0	1.00
<u>Mombasa Road Mile 27 (a) Fill</u>						
1	13.4	0.84	-	-	-	-
2	13.9	0.93	14.9	0.99	12.3	0.76
3	13.9	0.99	14.1	1.01	10.0	0.77
4	19.3	0.97	18.3	1.02	11.4	0.76
5	25.7	0.92	29.2	1.08	22.5	0.87
6	-	-	-	-	26.2	0.85
<u>Mombasa Road Mile 27 (b) Fill</u>						
1	17.6	-	-	-	-	-
2	14.3	0.99	20.3	1.13	19.1	1.01
3	11.8	1.07	17.9	1.19	18.9	0.86
4	14.6	0.95	12.7	1.15	7.6	0.66
5	24.1	1.34	16.2	1.25	6.7	0.61
6	30.0	1.11	27.8	0.96	-	-
<u>Naivasha Level</u>						
1	19.3	0.85	30.2	1.21	27.8	1.07
2	20.9	0.87	32.1	1.21	30.9	1.14
3	20.9	0.87	25.2	1.01	26.2	1.09
4	20.1	0.80	27.3	1.05	27.9	1.12
5	23.1	0.92	27.7	1.07	25.9	1.13
6	24.7	0.95	28.9	1.16	28.2	1.13
<u>Nakuru Level</u>						
1	38.7	0.91	46.1	0.98	41.8	0.85
2	41.8	0.93	41.3	0.91	42.8	0.83
3	41.1	1.06	38.9	0.95	38.8	0.97
4	49.6	1.18	43.6	1.04	42.5	0.99
5	49.2	1.12	46.9	1.00	44.3	1.01
6	57.8	1.20	56.3	1.23	54.7	1.12

/TABLE II

TABLE II

Results of classification tests\*

Location	Specific gravity	Liquid limit (per cent)	Plastic limit (per cent)	Casagrande classifi- cation
Limuru (a) Fill	2.80	100	43	MH
Limuru (b) Cut	2.80	85	49	MH
Limuru (c) Level	2.74	78	41	MH
Thika Sagana (a) Level	2.85	62	32	MH
Thika Sagana (b) Cut	2.86	77	40	MH
Thika Sagana (c) Fill	2.83	77	43	MH
Mombasa Rd M12 (a) Level	2.57	99	37	CH
Mombasa Rd M12 (b) Level	2.64	79	34	CH
Ngong Rd Level	2.61	104	41	CH
Mombasa Rd M27 (a) Fill	2.63	44	19	CI
Mombasa Rd M27 (b) Fill	2.59	46	19	CI
Naivasha Level	2.56	46	29	MI
Nakuru Level	2.46	62	47	MI

\*Note: The sample of soil used for the specific gravity test was oven-dried prior to the test while the soil in the liquid and plastic tests was adjusted from the natural moisture content.

The suction (s) measured in the laboratory was that of the soil free from the influence of external stresses. In order to estimate the pore water pressure or tension (u) of the soil "in situ" it was necessary to allow for the effect of the overburden pressure (P) due to the weight of the soil and pavement above the sample, using the equation

$u = \alpha P + s$  where  $\alpha$  is the fraction of the normal pressure that is effective in changing the suction of the soil. The fraction  $\alpha$  was obtained from the slope of the volume/moisture relation referred to later in this note while P was obtained from the measured bulk density and thickness of the various layers of overburden and pavement.<sup>(3)</sup> The results are given in Table III.

The results show that the subgrade samples from all the sites investigated were capable of absorbing additional moisture if this was made available at atmospheric pressure. The samples thus were deficient in soil moisture. The extent of this moisture deficiency can be associated with soil type, local environment, type of road pavement etc. and this will be discussed later.

/TABLE III

TABLE III

Subgrade moisture condition at time of sampling, June-July, 1959

Limuru "A" Route (a) Fill										
*Position	1/-1	1/1	1/3	1/5	1/7	1/9½	4/0	4/2	4/4	4/6
**Log u	2.7	2.6	2.8	3.4	4.1	3.9	2.5	2.9	2.9	2.9
m/c	36.5	35.3	35.8	32.9	36.6	34.7	33.0	37.9	37.8	37.8
Limuru "A" Route (b) Cut										
Position	1/-1	1/1	1/3	1/5	1/7	1/10	3/0	3/3	3/5	6/10
Log u	3.6	2.9	2.7	2.7	2.7	2.6	3.6	3.1	2.7	3.5
m/c	38.6	41.9	39.6	40.3	41.6	41.2	39.0	34.8	41.7	40.0
Limuru "A" Route (c) Level										
Position	1/2	1/4	1/6	1/8	1/10	3/2	3/5	3/7	3/9	6/9
Log u	3.6	3.9	3.7	4.1	3.8	3.3	3.8	3.6	3.4	3.2
m/c	28.8	27.7	28.8	29.0	28.5	28.3	29.8	24.5	22.7	39.5
Thika Sagana (a) Level										
Position	1½/-1	1½/1	1½/3	1½/5	1½/7	1½/10	3¾/0	3¾/2	3¾/8	6/10
Log u	2.5	2.4	2.5	2.5	2.6	2.7	2.5	2.4	2.5	2.5
m/c	32.6	31.2	31.5	29.5	28.0	27.9	36.1	36.7	35.4	34.7
Thika Sagana (b) Cut										
Position	1½/0	1½/2	1½/4	1½/6	1½/8	1½/10½	3¾/1	3¾/3	3¾/5	3¾/9
Log u	2.5	2.3	2.0	2.3	2.2	2.3	2.1	2.1	2.1	2.1
m/c	35.6	35.3	36.1	36.9	35.3	34.3	36.2	37.2	36.3	36.3
Thika Sagana (c) Fill										
Position	1¾/1	1¾/3	1¾/5	1¾/7	1¾/9	1¾/11	3¾/0	3¾/2	3¾/6	6/10
Log u	2.5	2.6	2.6	2.8	2.7	2.7	2.2	2.3	2.5	2.5
m/c	33.8	33.4	32.9	31.2	30.8	32.0	36.3	33.0	37.2	39.0
Mombasa Road Mile 12 (a) Level										
Position	1¾/-1	1¾/1	1¾/2	1¾/3	1¾/4	1¾/6	1¾/9	1¾/12		
Log u	2.9	3.1	3.7	3.8	3.9	4.2	4.2	4.2		
m/c	24.3	36.1	35.6	32.2	29.5	28.5	23.8	28.4		
Mombasa Road Mile 12 (b) Level										
Position	2/0	2/2	2/4	2/6	2/9					
Log u	2.9	2.7	2.9	4.0	3.5					
m/c	42.8	41.1	32.9	26.7	31.4					
Ngong Road Level										
Position	1¾/-1	1¾/1	1¾/3	1¾/5	1¾/7	1¾/10½	3¾/2	3¾/4	3¾/7	6/10½
Log u	3.9	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1
m/c	38.2	35.0	34.8	37.5	37.5	37.5	37.7	37.8	38.0	38.7
Mombasa Road Mile 27 (a) Fill										
Position	2/-1	2/1	2/3	2/5	2/8	2/11½	4/0	4/4	4/8	
Log u	2.9	2.6	2.3	2.5	2.3	2.3	2.4	2.6	2.7	
m/c	24.3	19.6	14.8	17.2	11.4	14.8	15.7	17.3	13.2	
Mombasa Road Mile 27 (b) Fill										
Position	2/0	2/2	2/4	2/6	2/9	2/11½	4/5			
Log u	2.3	2.2	2.2	2.3	2.5	2.5	2.7			
m/c	17.4	20.7	22.5	20.4	21.2	17.9	7.6			
Naivasha Level										
Position	1/-1	1/1	1/3	1/5	1/7	1/9½	2/0	2/4	2/8	6/9½
Log u	3.1	2.9	2.9	2.7	2.8	2.5	2.9	2.7	2.7	2.7
m/c	21.2	21.5	22.0	29.4	25.0	27.5	19.7	22.9	24.6	25.2
Nakuru Level										
Position	1/-1	1/1	1/3	1/5	1/7	1/10¾	3½/3	3½/6	3½/9	6/10¾
Log u	2.1	2.3	2.3	2.3	2.3	2.3	2.5	2.3	2.4	2.3
m/c	23.0	52.7	54.5	37.2	38.5	51.2	37.8	36.6	33.8	60.5

\*Position is given by Depth/Distance from edge of road pavement.

\*\*Tension in the pore water given as the common logarithm of u cms of water as in the pF scale. (4)

The moisture content of the subgrades varied across the width of the roads investigated being a maximum near the edge of the pavement and decreasing towards the centre-line of the pavement. The undisturbed soil samples were taken during June-July 1959 about one month after the end of the main rainy season. The suction measurements on these samples however showed that the pore water tension at the majority of sites was relatively uniform across the road section. There would be little or no tendency therefore for moisture to move from the zone of high moisture content near the edge of the pavement towards the subgrade with a lower moisture content under the central part of the road. The gradient of moisture content across the subgrade was thus probably due to the hysteresis between the wetting and drying characteristics of soil. In the case of the site at Mombasa Road mile 12 and to a less extent on the fill subsites at Limuru and Thika Sagana, the pore water tension near the edge of the pavement was lower than near the centre of the road. In the circumstances further movement of moisture towards the centre of the road subgrade would probably take place and the central part of the subgrade at Mombasa Road mile 12 and the fill subsites at Limuru and Thika Sagana may become wetter.

(c) Relation between suction and moisture content. Small specimens of the undisturbed soil were allowed to reach moisture equilibrium on the suction plate apparatus at a suction of about 15 cms of water. The suction was then progressively increased using the suction plate, pressure membrane and vacuum desiccator apparatus, the equilibrium wet weight being obtained at each suction and the corresponding moisture content calculated from the oven-dry weight determined at the conclusion of the test. The procedure was then reversed and the soil progressively allowed to wet. The suction/moisture content curves obtained for the soils are given in Figs. 1 to 7, the suction being expressed on the pF scale (the common logarithm of the suction expressed in cm of water).

The relations between suction and moisture content for the red clays, Figs. 1 and 2, show a comparatively large change in moisture content of the order of 7-11 per cent, between suctions pF 1 and pF 2.4. A large change in moisture content of this type, associated with a bend in the suction curve at about pF 2.4 is unusual for a clay; experience suggests that it would be related to the emptying of large pores within the crumb structure of the soils and it would be indicative of a relatively high permeability. On increasing the suction of pF 5 a further loss of about 10 per cent of moisture occurred in a manner more typical of British clays. (5) The vacuum desiccator tests at high suctions showed a marked decrease in moisture content as the red clays dried from pF 5 to pF 5.5 This latter moisture change is apparently characteristic of friable red clays and is thought to be due to very finely divided iron oxide coating the soil particles. (6)

The heavy black clays from Mombasa Road mile 12 and the Ngong Road, Figs. 3 and 4, had similar suction properties to a British Gault clay. The moisture loss with increasing suction took place in a uniform and continuous manner up to oven-dryness. Similarly the suction/moisture content characteristics for the sandy clay from Mombasa Road mile 27, Fig. 5, was typical for this class of soil.

The pumice soils had very variable porous structures, particularly the soil from Nakuru, and the relations between suction and moisture content for these soils, Figs. 6 and 7, can be taken only as indicative of their general characteristics. The amount of void space in the soils was very dependent on the level of compaction and this affected the amount of water retained at suctions up to pF 3. At suctions greater than this level a high proportion of the held water was retained in the small pores of the pumice. The porous structure of these soils results in a large hysteresis effect which may be present between the wetting and drying conditions.

/(d)

(d) Relation between volume and moisture content. The shrinkage characteristics of the soils were determined using the optical projection method.<sup>(5)</sup> The method requires the preparation of cylindrical specimens of soil, approximately  $\frac{3}{4}$  in. in height and diameter, which are cut from the larger undisturbed samples with the aid of a thin-walled cutter. The use of this cutter caused some disturbance to the specimens and in particular tended to increase the initial density of the red clays. The increase in density, while reducing the total voids in the soil, would not have materially affected the changes in volume that took place on drying. The shrinkage curves given in Figs. 1 to 7 are representative of a number of curves at various densities which were obtained.

In order to assess the volume and moisture condition of the natural soil at the time of sampling, the remainder of the undisturbed soil sample was coated with wax and the bulk density and moisture content determined as described in B.S. 1377 (1961). The average values for the dry density, moisture content, air content and degree of saturation for the subgrades are given in Table IV.

TABLE IV

The black clay from Ngong Road behaved as a typical heavy clay a shrinkage, equal to the volume of moisture lost, occurring until near the shrinkage limit of about 12 per cent, Fig. 4. The black clay from Mombasa Road mile 12 had similar shrinkage properties Fig. 3, but with a slight reduction in the volume changes at moisture contents above 35 per cent. The results of the laboratory tests give an explanation to the observed fact that black clays are more likely than the red clays to cause difficulties and cracking of road structures where differential moisture changes occur in the subgrade.

The sandy clay from Mombasa Road mile 27 exhibited a relatively small change in volume on drying out, Fig. 5, the potential volume change of the clay fraction being inhibited by grain to grain contact of the coarser sand fraction. The diffusivity of the heavy black clays from of subgrades at Ngong Road and Mombasa Road, Mile 12, using the moisture transfer technique<sup>(15)</sup> showed that the diffusivity of the clay varied little over the range pF 4 to pF 2.5 and was of the order of  $10^{-6}$  to  $10^{-5}$  cm<sup>2</sup>/sec. Calculation of the diffusivity of the non-shrinking pumice from the relation between suction and moisture content<sup>(16)</sup> showed that the diffusivity varied from  $10^{-5}$  cm<sup>2</sup>/sec. at pF 4 to  $10^{-1}$  cm<sup>2</sup>/sec. near

The greater the variation of permeability with the soil suction the lower the ultimate pore water tension under the centre part of the road. The permeability of heavy consolidated clays does not vary much whereas the permeability of sands can vary inversely as the 3rd or 4th power of the suction. In a given environment, therefore, clay subgrades will tend to reach equilibrium with a higher soil moisture tension than sand subgrades. Climate and other environmental factors will, however, affect the moisture distribution and in certain cases may dominate the effect due to the soil permeability.

(b) Local climate and topography. The overall availability of moisture during the year can be assessed from the balance between rainfall and evaporation but within a given climatic area local topographic variations cause differing amounts of run-off and concentration of water. Undulating or hilly terrain contains a wider range of soil moisture conditions than a comparatively flat area with the same climate. The monthly rainfall and potential evapo-transpiration at the seven sites are shown in Fig. 10, and it is apparent that there was a considerable surplus of rainfall over the potential evapo-transpiration during the wet season which would have caused high moisture contents in the verges of the roads at that time.

The sites at Naivasha and Nakuru were in relatively flat areas, the ground at Naivasha having a sidelong slope of about 1 in 20 but a longitudinal slope of less than 1 in 100, while at Nakuru the slopes were less than 1 in 100. The wetter climate at Nakuru, (Thorntwaite Moisture Index + 20),<sup>(17)</sup> is probably responsible for the lower tension in the pore water of the subgrade as compared with Naivasha, (Thorntwaite Moisture Index - 14), both subgrades being of pumice soil.

At Mombasa Road, Mile 27, where the subgrade is a sandy clay, the climate is dry sub-humid, (Thorntwaite Moisture Index - 20). The low value of the pore water tension is primarily due to the very permeable nature of the loose sandy clay. Sub-site (a), situated on a longitudinal slope of 1 in 50, is better drained than sub-site (b), which is at the bottom of the slope, hence the slightly wetter condition found at sub-site (b).

Both sites on friable red clay have a wet climate and the subgrade moisture condition may have been expected to be slightly drier than the field capacity where the soil moisture tension is about pF 2.5 for this type of soil.<sup>(18)</sup> At Thika Sagana, sub-site (a), near the top of a hill, and sub-site (c), on a 10 ft high embankment at the bottom of the slope, the subgrades appear to be approaching this ultimate moisture condition. A ground water-table may affect the wetting process at sub-site (c) and an incipient water-table is responsible for the wetter condition at the cut sub-site (b). The effect of the water-table is discussed later. At Limuru, the site with the wettest climate (Thorntwaite Moisture Index + 37), the road runs across and down the face of a steep slope. Sub-sites (b) and (c) are thus well drained longitudinally and culverts also enable side-long drainage to take place. The moisture condition at sub-site (b) which is in a side cutting is wetter than sub-site (c) where the road is raised on a 2-4 ft high embankment. Sub-site (a) is near the bottom of the slope on an embankment approximately 8 ft high and here the central part of the road subgrade has a high pore water tension while the edges and the deeper soil under the centre of the road are wetter with a pore water tension of pF 2.9 or below. The variations in the moisture distributions at the latter sites are an indication of the influence that topography has on subgrade conditions.

The sites at Mombasa Road, Mile 12, and the Ngong Road are situated on relatively impervious heavy black clays and since the potential evapo-transpiration is greater than rainfall over approximately half of the annual cycle the subgrade moisture condition, as would be expected, is of the order of pF 4. The drainage at the Mombasa Road, Mile 12, is slightly better than at the Ngong Road since there is a longitudinal slope of 1 in 40 whereas the latter site has a slope of 1 in 100. Of the two sub-sites at Mombasa Road, Mile 12, the subgrade under the centre

/part

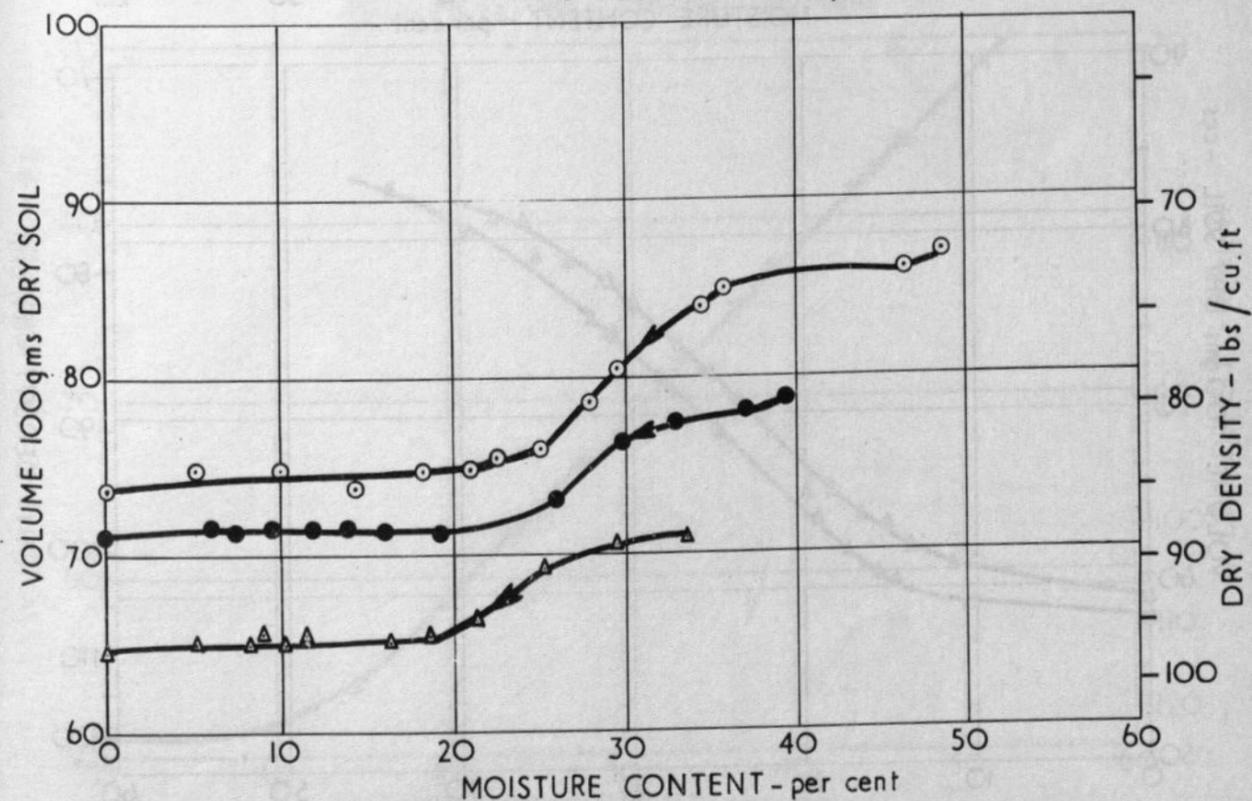
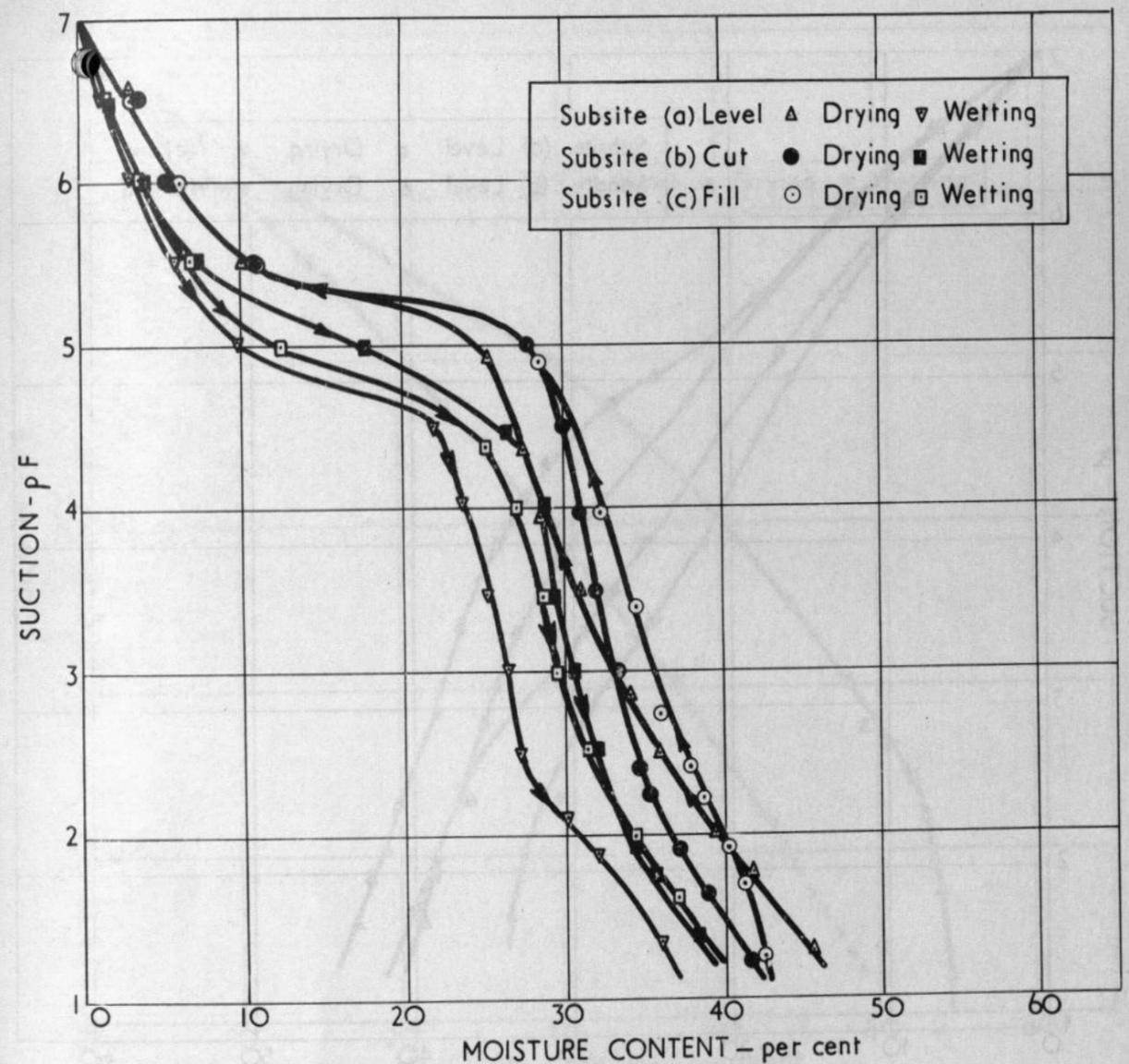


Fig. 2 RELATIONS BETWEEN SUCTION/MOISTURE CONTENT AND VOLUME/MOISTURE CONTENT FOR RED CLAY - THIKA SAGANA

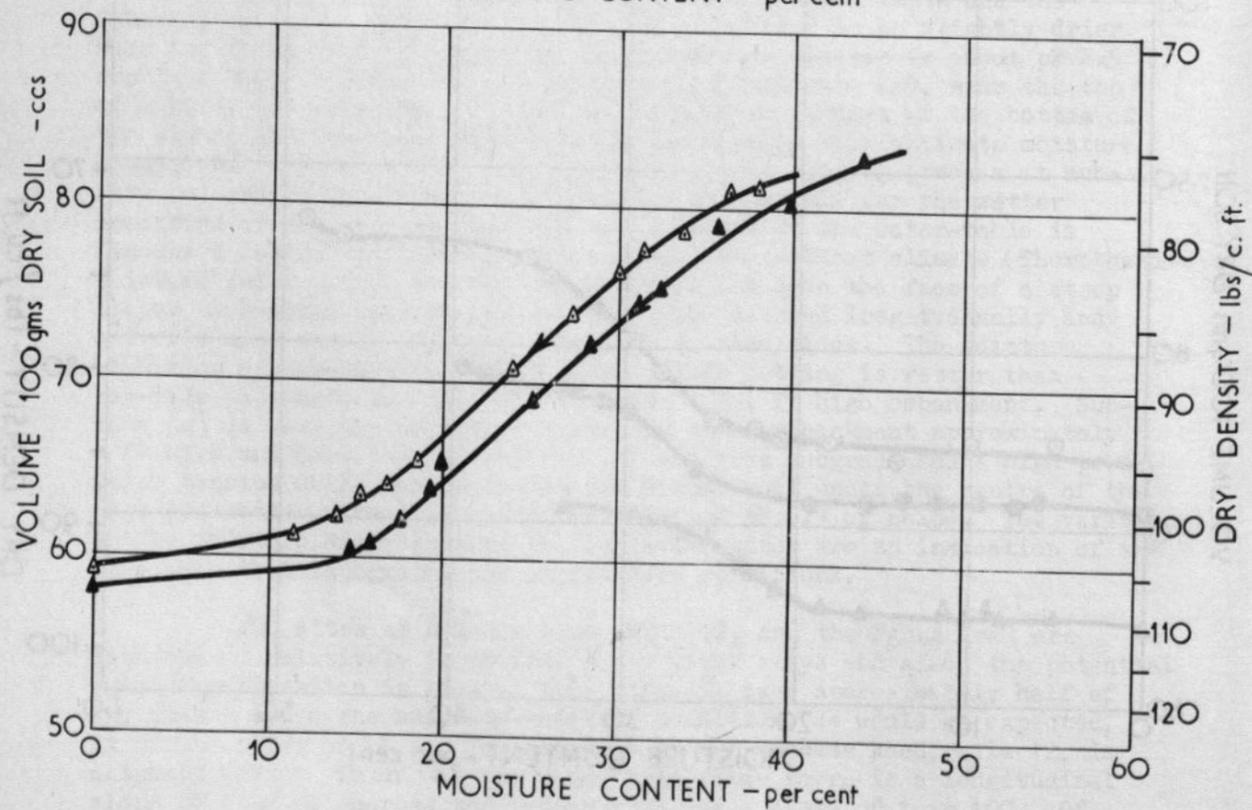
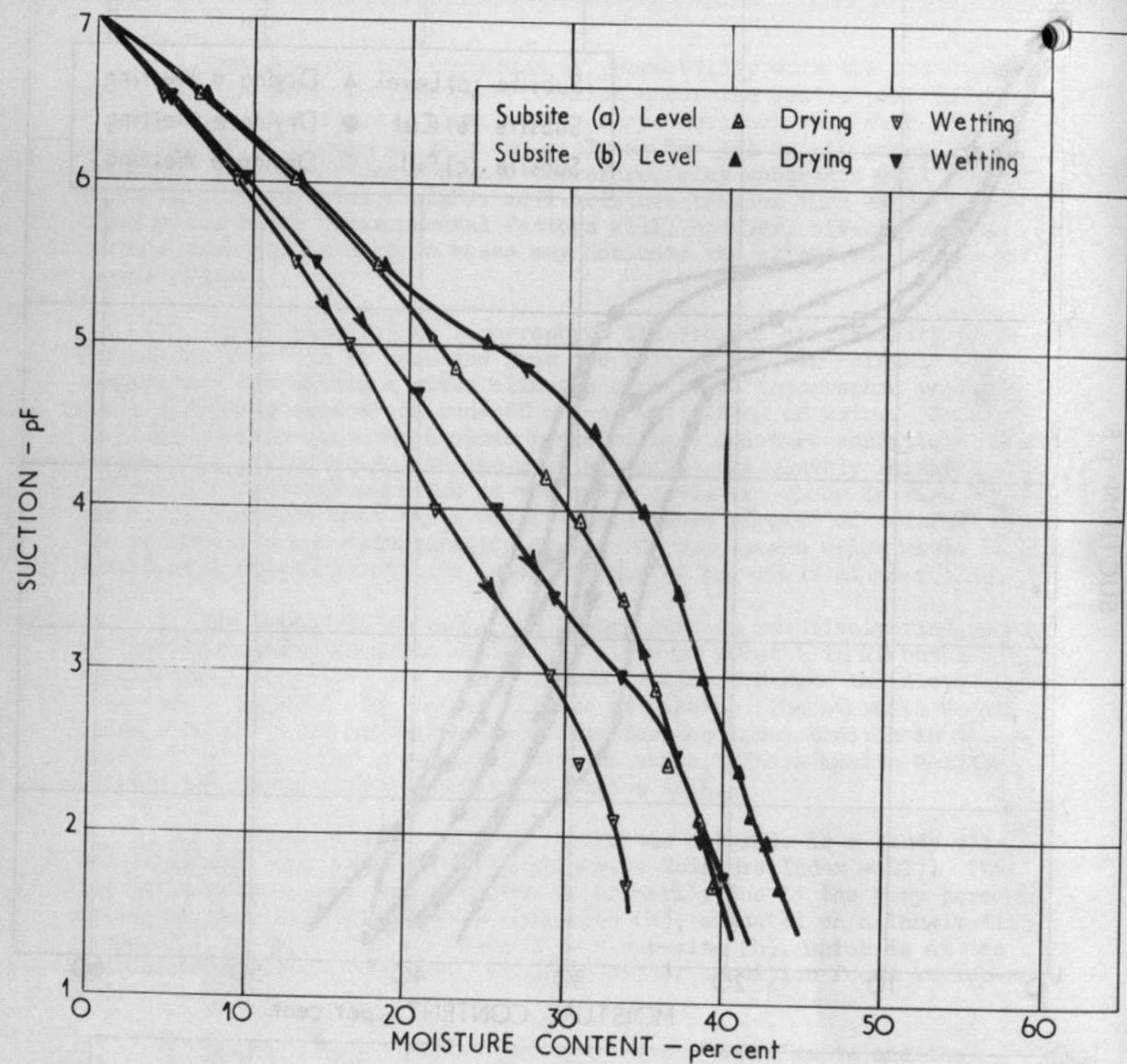


Fig.3. RELATIONS BETWEEN SUCTION/MOISTURE CONTENT AND VOLUME/MOISTURE CONTENT FOR BLACK CLAY - MOMBASA ROAD, MILD 12

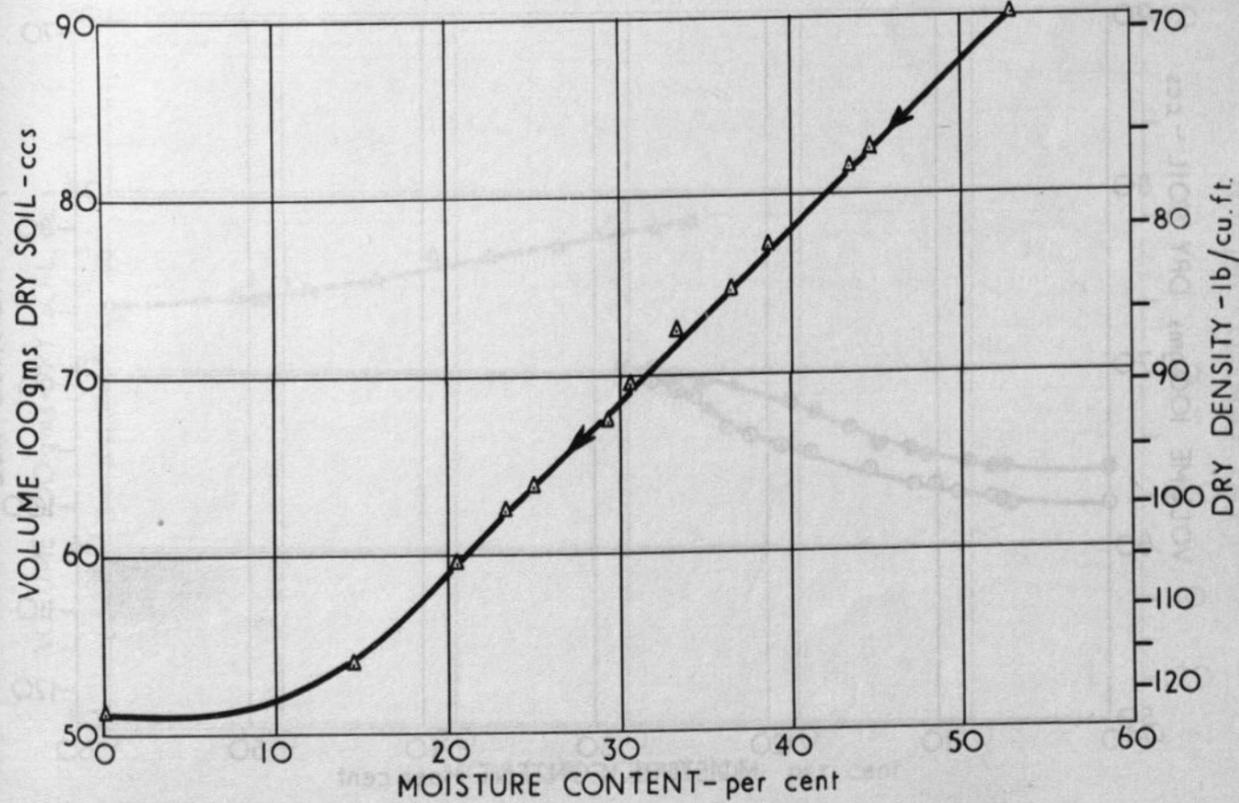
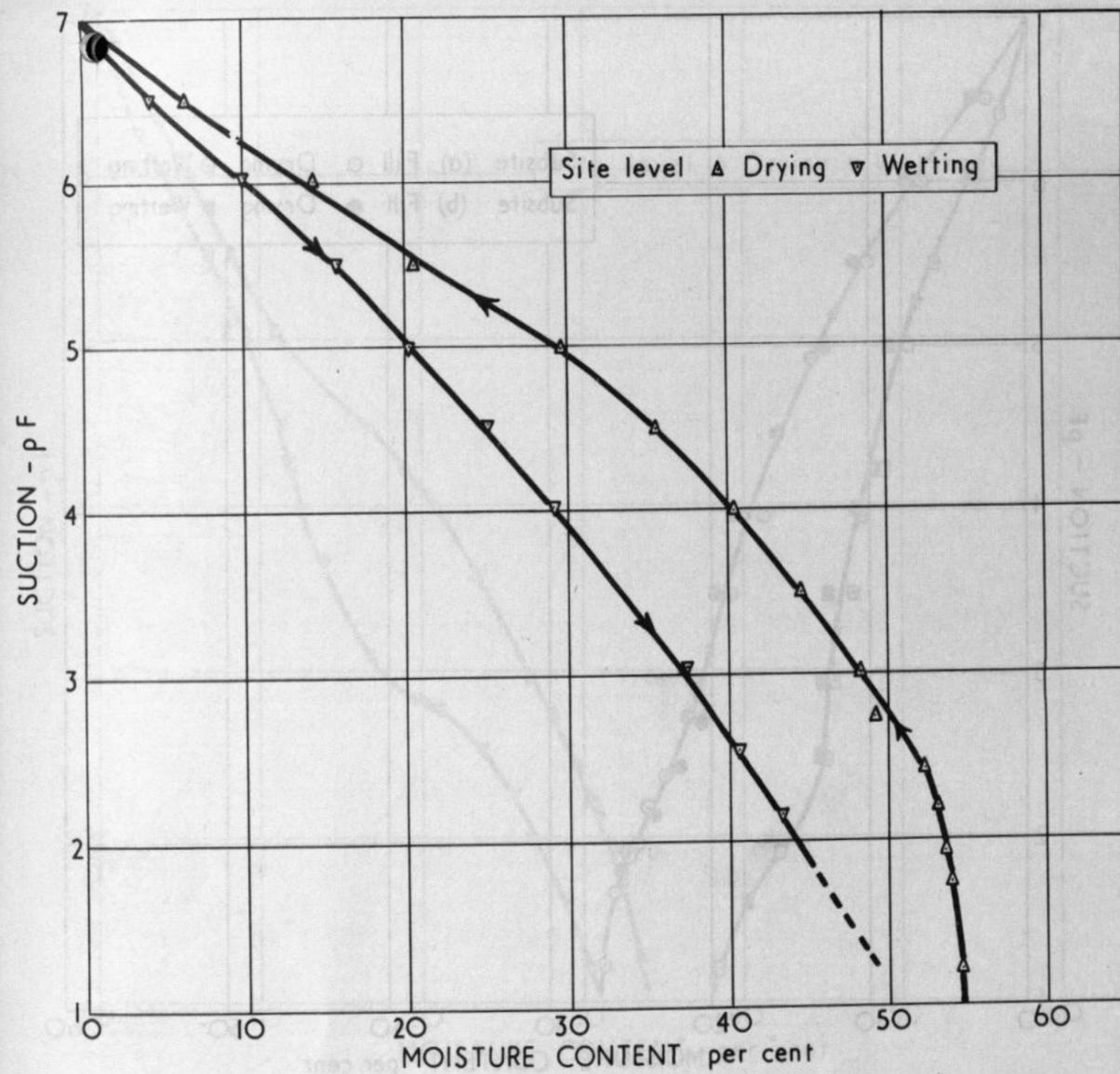


Fig 4 RELATIONS BETWEEN SUCTION/MOISTURE CONTENT AND VOLUME/MOISTURE CONTENT FOR BLACK CLAY - NGONG ROAD

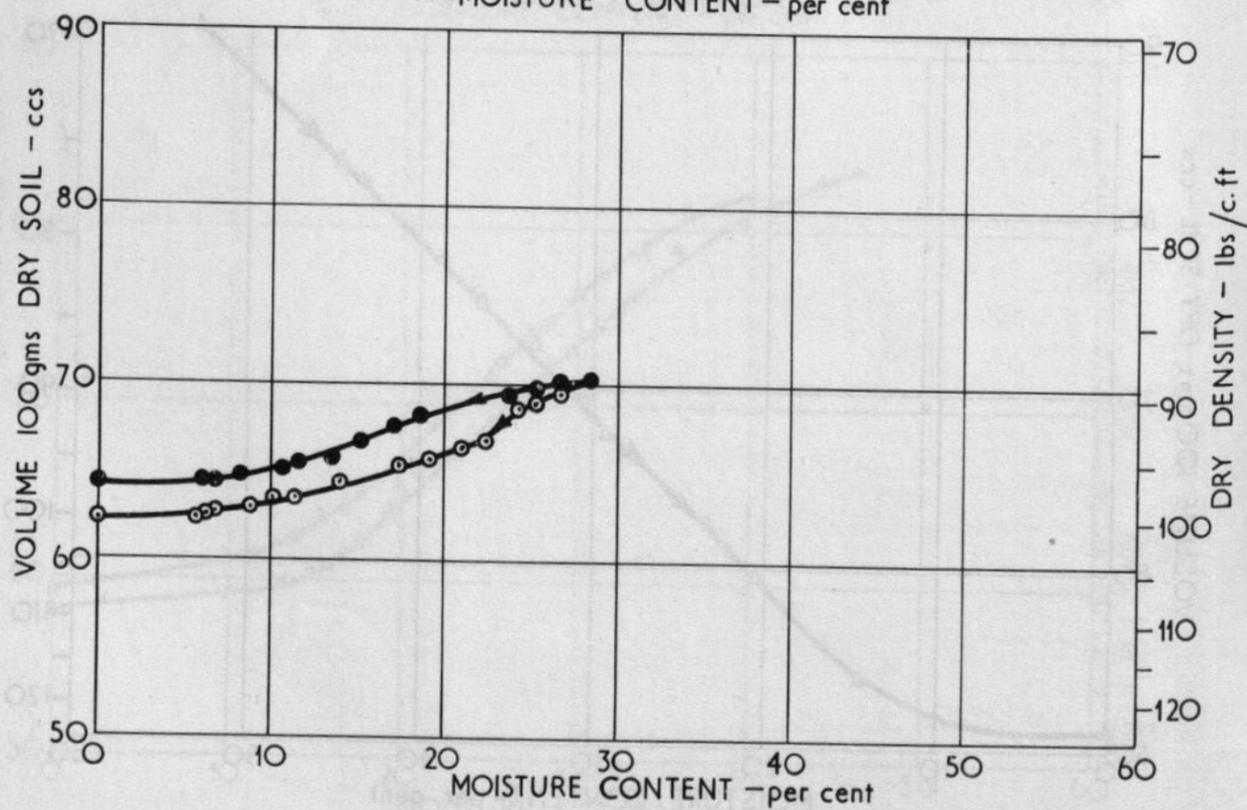
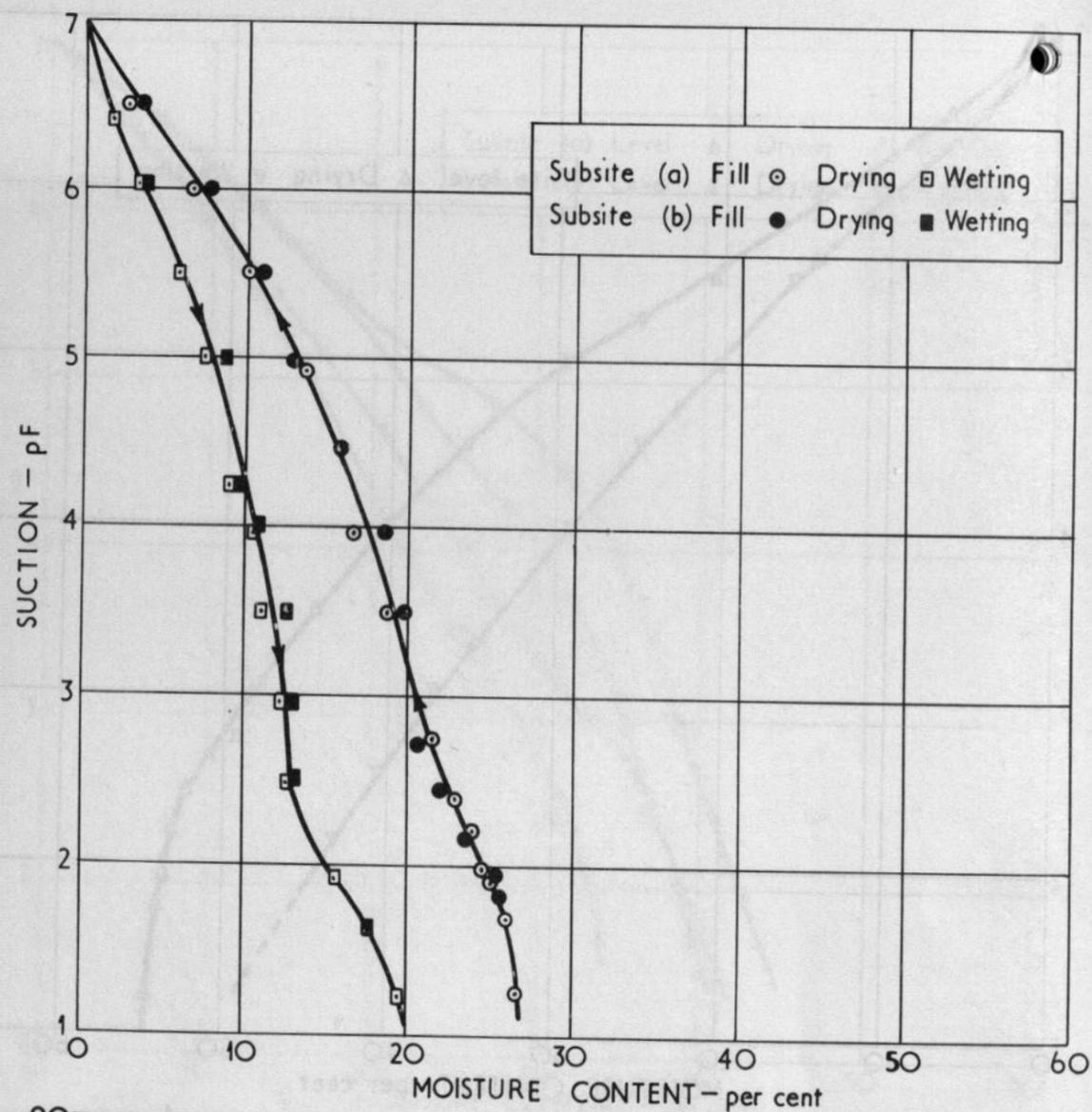


Fig. 5. RELATIONS BETWEEN SUCTION/MOISTURE CONTENT AND VOLUME/MOISTURE CONTENT FOR SANDY CLAY - MOMBASA ROAD, MILE 27

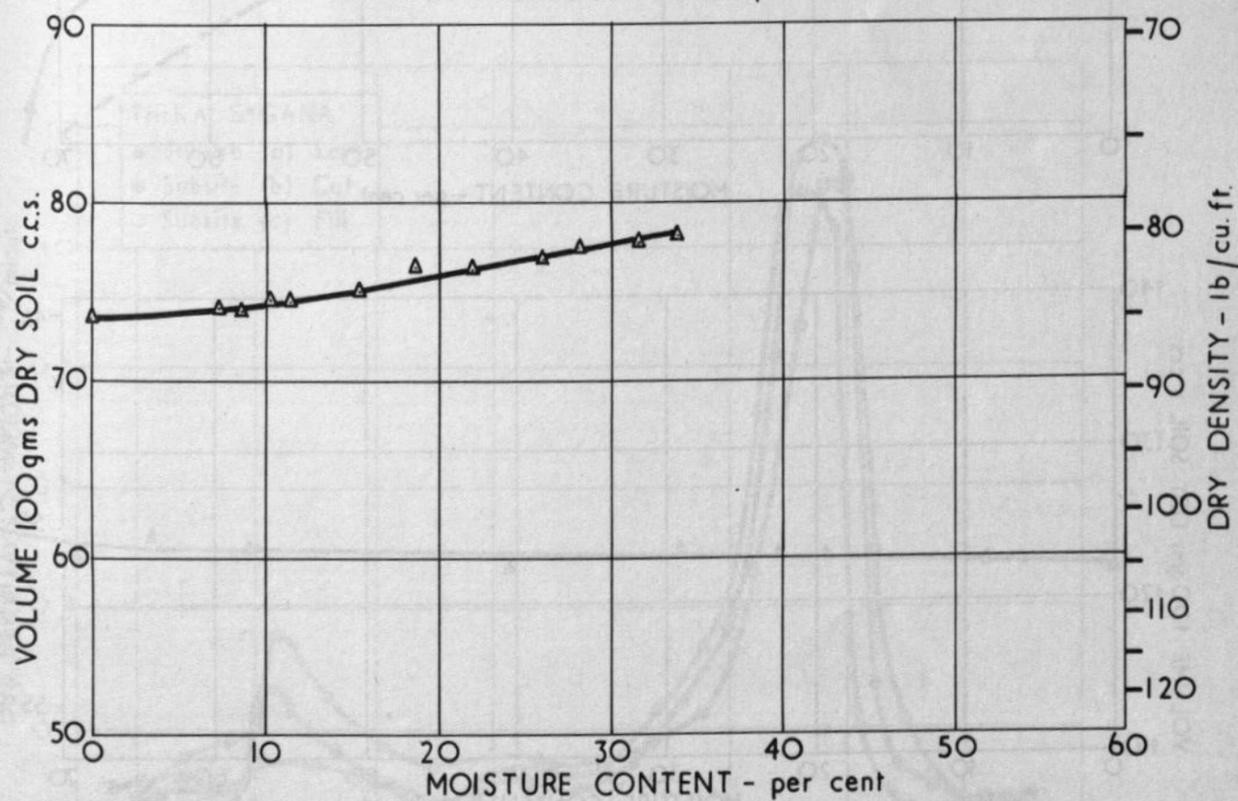
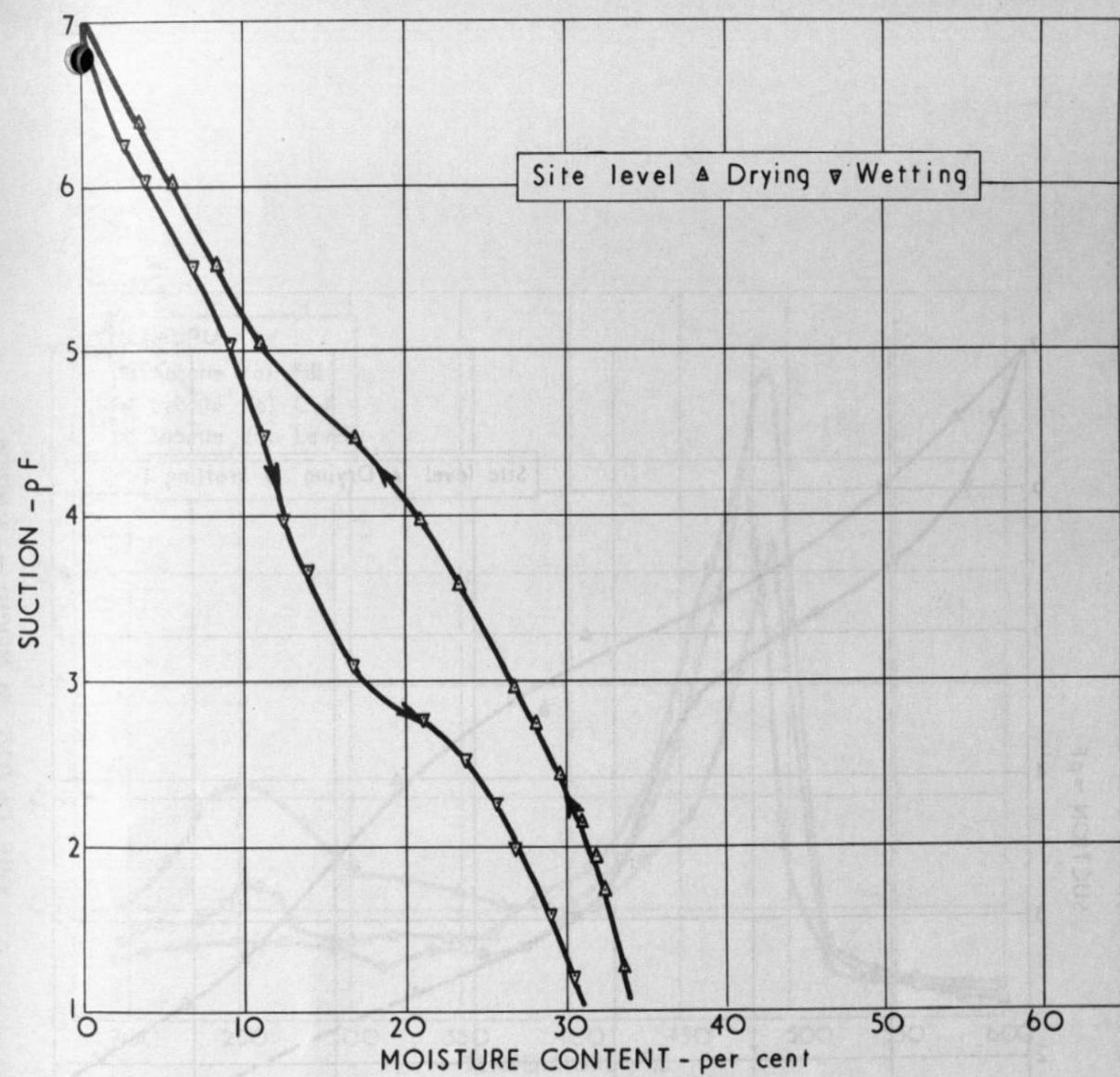


Fig. 6 RELATIONS BETWEEN SUCTION/MOISTURE CONTENT AND VOLUME/MOISTURE CONTENT FOR PUMICE SOIL - NAIVASHA

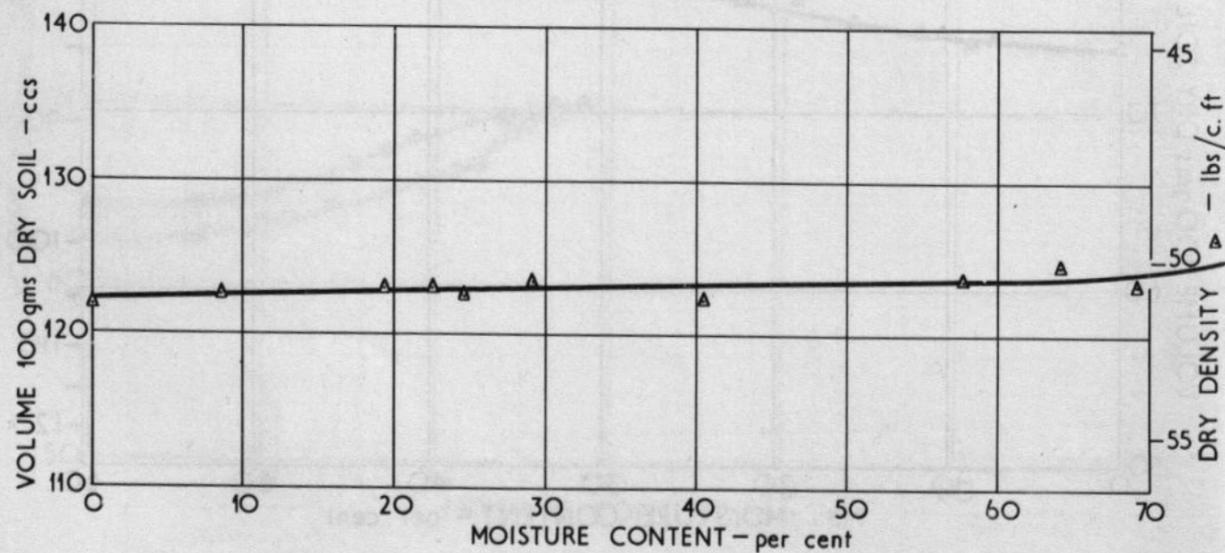
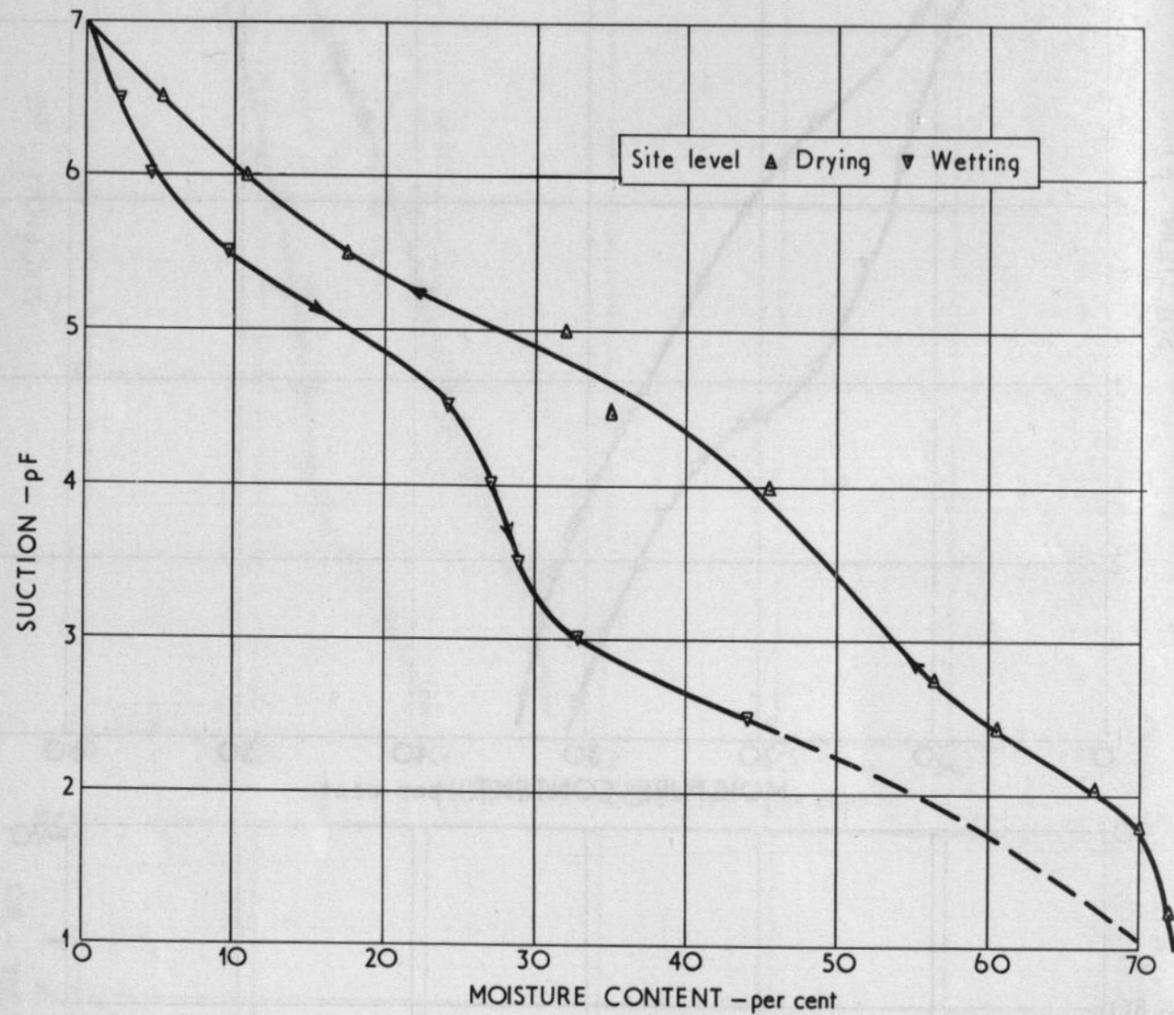


Fig. 7. RELATIONS BETWEEN SUCTION/MOISTURE CONTENT AND VOLUME/MOISTURE CONTENT FOR PUMICE SOIL - NAKURU

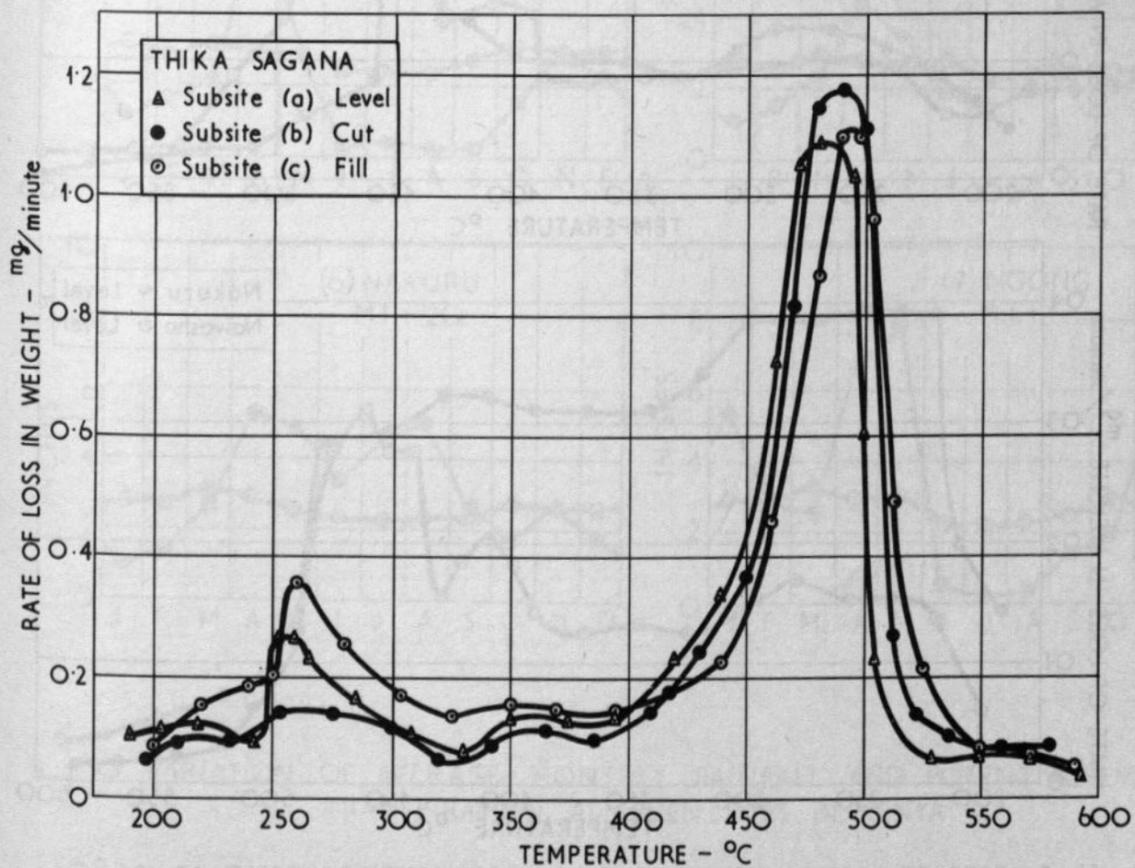
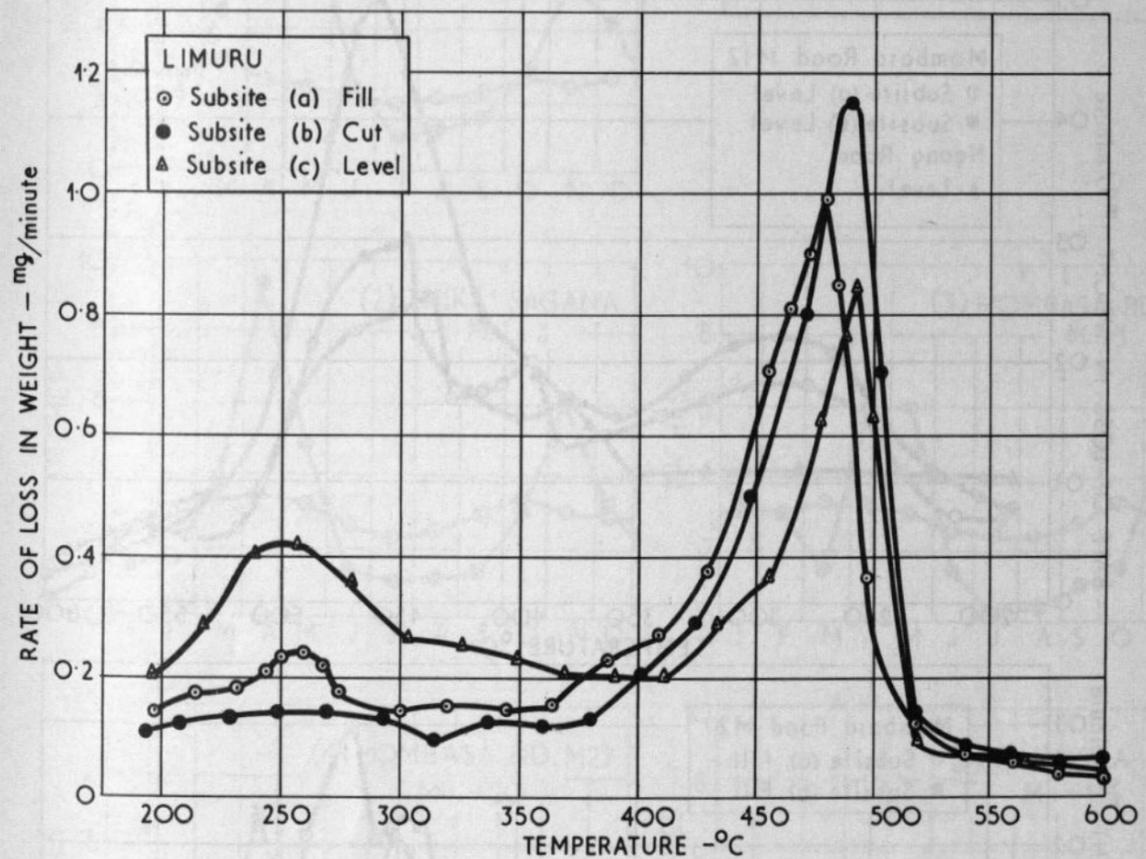


Fig. 8. RATE OF LOSS IN WEIGHT OF 0.5gm SOIL SAMPLES HEATED AT 125°C per/h LIMURU AND THIKA SAGANA

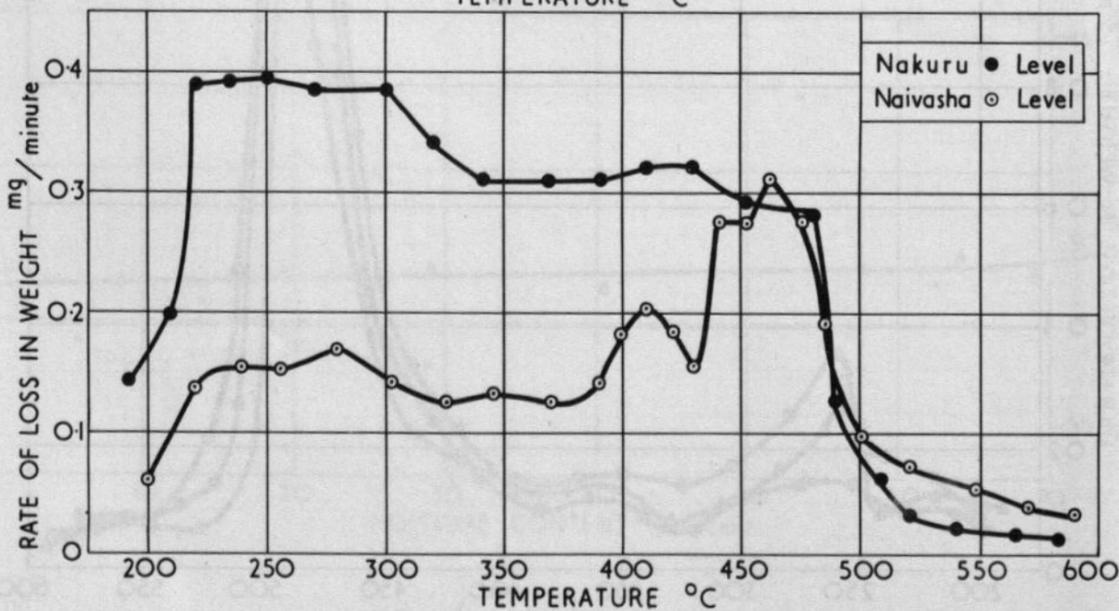
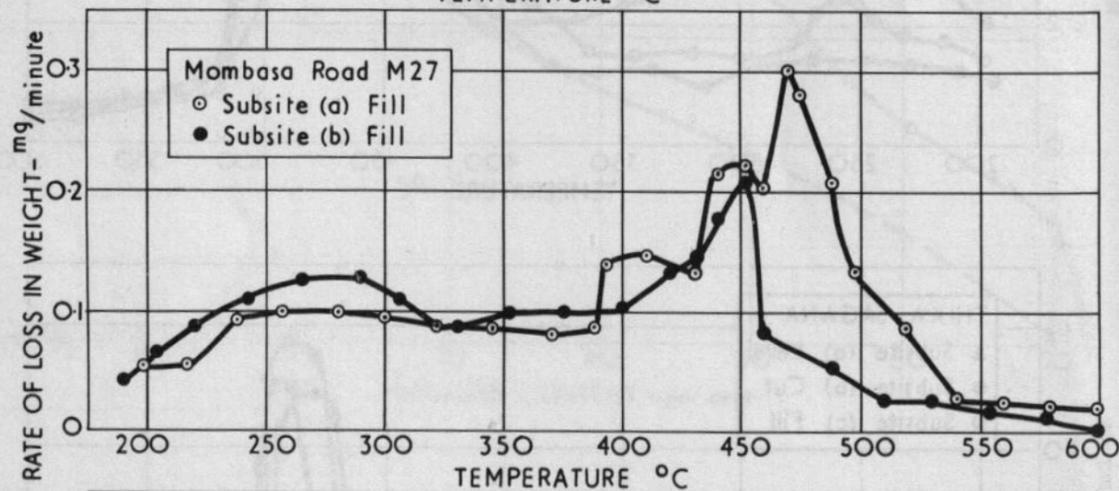
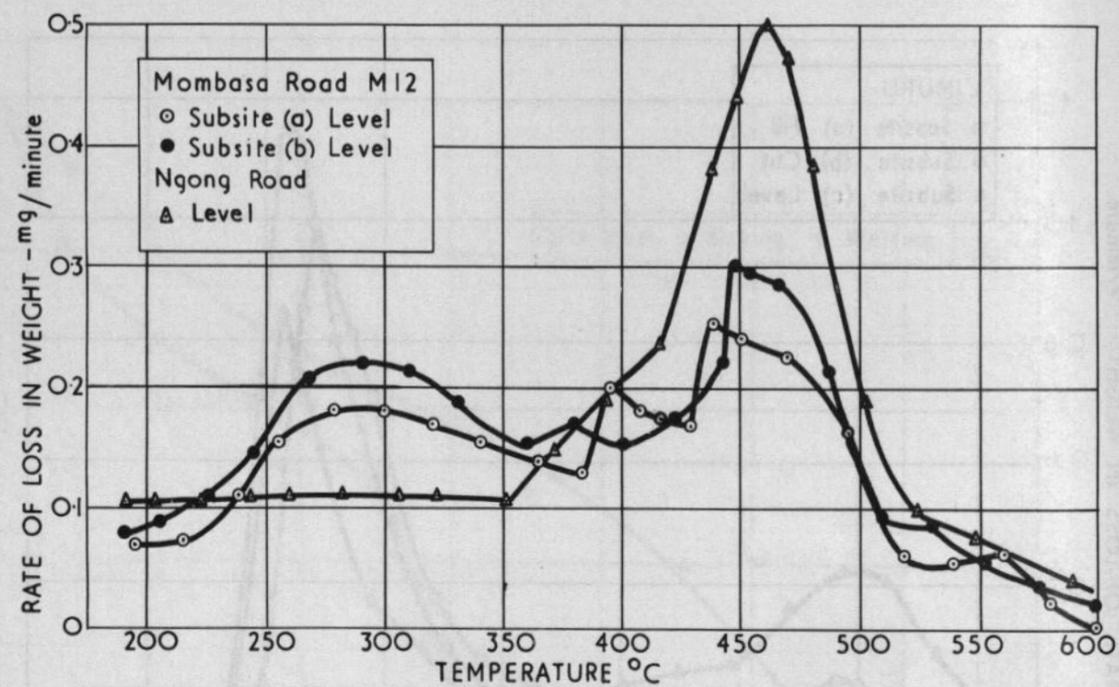
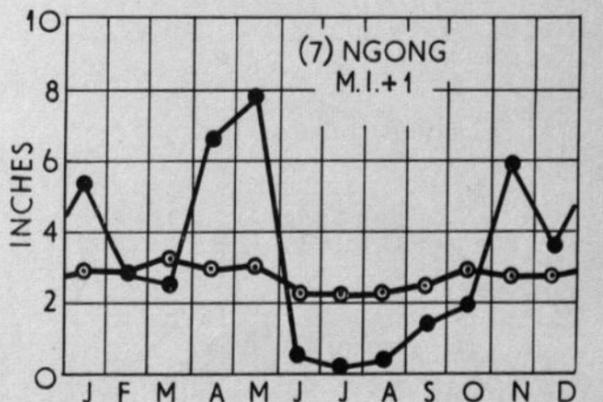
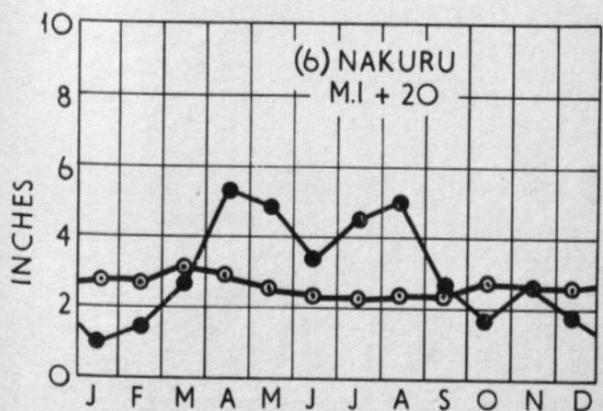
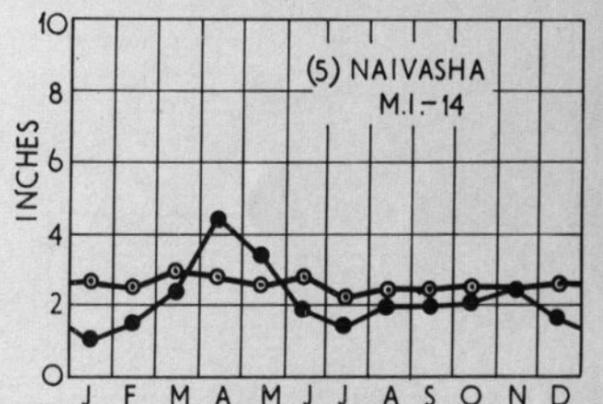
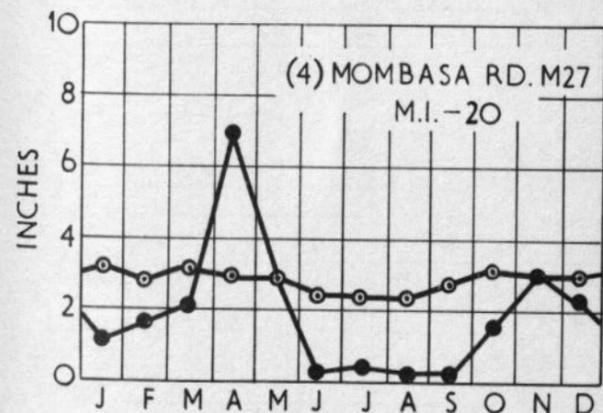
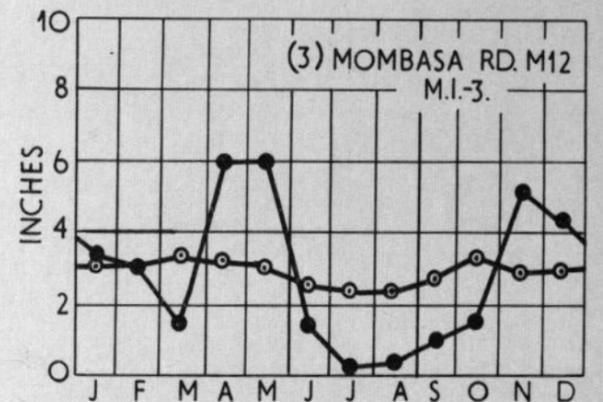
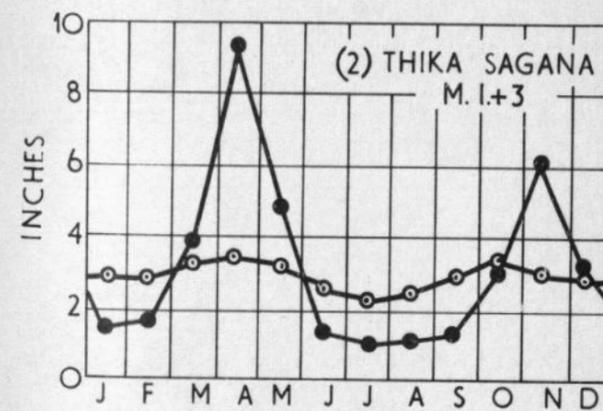
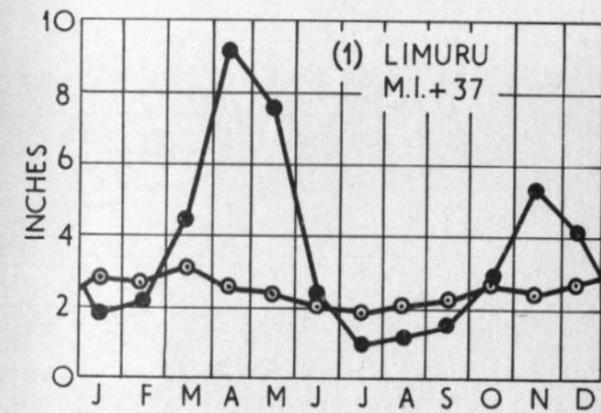


Fig 9 RATE OF LOSS IN WEIGHT OF 0.5 gm SOIL SAMPLES HEATED AT 125 °C PER HOUR - NGONG ROAD, MOMBASA RD, M12 AND M27, NAKURU AND NAIVASHA



●—● Precipitation  
○—○ Potential evapo-transpiration  
M. I. = Thornthwaite moisture index

Fig. 10. VARIATION OF AVERAGE MONTHLY RAINFALL AND POTENTIAL EVAPO-TRANSPIRATION AT SEVEN SITES IN KENYA

