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Subfloor Evaporation Rates

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Synopsis

Lysimeters have been used to measure evaporation rates from drying soils in the subfloor area of a house.

Soil evaporation rates are shown to be equal, to those from a free water surface when the soil moisture content exceeds some critical value, which is determined for various soils.

In conditions where the ground-water approaches the surface during winter, subfloor evaporation rates will approximate the lineal relationship.

$$q = 4.0\ (e_g - e_{as})$$

1.0 INTRODUCTION

Current research undertaken by the Building Research Association of New Zealand (BRANZ) in building moisture control is discussed by Trethowen (1983). One aspect of this research, that dealing with ground evaporation, is being carried out by Kingston Reynolds Thom and Allardice Ltd (KRTA) and forms the basis of this paper.

It has long been recognised that large quantities of water evaporate from the ground into the subfloor space beneath buildings. Failure to control such water can lead to various problems of dampness and rot.

The object of the KRTA research is to develop suitable methods of measuring subfloor evaporation rates, to determine the physical parameters dominating evaporation rates and to set up base data of evaporation rates in differing climatic regions in New Zealand.

2.0 PREAMBLE

The method found most suitable for direct measurement of subfloor evaporation rates involves the use of lysimeters, these being simply vessels containing earth which can be weighed periodically or continuously to determine the nett moisture movement. Various methods of producing and using such lysimeters for undisturbed or reconstituted soil samples, expendable or rechargeable lysimeters and variations in design depending on the frequency of weighting aredetailed in "Survey of subfloor moisture - Report on preliminary investigation" submitted to BRANZ in December, 1982, and is not included in this paper.

This paper discussed the effects of various physical parameters, soil type and moisture content on subfloor evaporation rates.

The regional study will commence in February 1983 and be reported to BRANZ later this year.

3.0 EXPERIMENTAL EQUIPMENT AND PROCEDURES

Water loss by evaporation was measured by direct weighing of lysimeters containing either water or the various soil types under investigation. The lysimeters were constructed from 150mm diameter PVC pipe. The bottom end was machined square and closed with a 6mm thick PVC base plate. The pipe/baseplate joint was routed to half depth and a sealing strip glued over the joint to ensure a watertightness.

The work was carried out in two parts: a preliminary investigation and an extended investigation.

In the preliminary investigation, the lysimeters were jacked into the ground to extract an "undisturbed" sample. Two samples one 400mm and one 800mm long of each soil type, clay, volcanic loam and sand, were recovered. One difficulty with undisturbed samples is the lack of control of moisture content in the natural state. An unrealistic comparison could be made between a saturated soil of one type and another type dried to a moisture content well below saturation.

In the extended investigation, all lysimeters were cut down to 200mm in length and samples of clayey topsoil, volcanic loam (2), and sand (2) were artificially wet and recompacted into the lysimeters. The clay lysimeter was merely cut to 200mm so that the bottom 200mm of the original clay sample remained undisturbed.

At the completion of each series, moisture content was measured at one fifth points in each lysimeter. In the extended study, the contents of each lysimeter were split into five approximately equal parts and each part totally dried to determine moisture content. In this manner, the total weight of solids was measured and by progressively adding the evaporative weight losses working back from the completion of the experiment the average moisture content could be calculated at any particular time throughout the duration of the experiment.

The lysimeters were placed in the ground under a timber framed house in Auckland with the top of the sample approximately level with the ground surface.

The subfloor space is typical of many N.Z. houses: Subfloor height varying from 450mm to 1400mm, 200mm x 60mm vents at 2.2 m centres, continuous strip footing along 1½ walls but otherwise a 50mm gap under the basement walls, one access door 700mm x 1300mm which remained open for the duration of the experiment, 150mm clayey topsoil overlying stiff clay, natural drainage poor even though located on sloping land near the top of a ridge.

Each morning (initially 4 times/day) the lysimeters were lifted, washed, dried, weighed and replaced into their holes in the ground. A 24kg Mettler balance with 1gm resolution was used for weighing the lysimeters. With normal daily losses of some 3 to 4 gm/lysimeter the 1gm resolution restricts the conclusions which can be drawn on short duration moisture movement. By weighing each lysimeter fives times (at the four corners and middle of the pan) weights were recorded to the nearest ½gm but confidence in accuracy of better than $\pm$ 3/4gm would be unrealistic.

Continuous recording was made of subfloor air temperature (dry bulb), air temperature (wet bulb) and ground temperature and outdoor air temperature (dry bulb and wet bulb) using a six-point recorder with platinum resistance sensors. Air temperatures were recorded at 400mm above the ground and the ground temperature probe extended to 200mm into the ground. In the preliminary investigation windspeed was recorded with a hot-wire anemometer but these records were discontinued in the extended investigation.

The temperature records were digitised at 1 hourly internals and using the relationships given in IHVE guide (1970) for vapour pressures:

$$\log e' = 28.59051 - 8.1 \log (t' + 273.16) + 2.4804 \times 10^{-3} (t' + 273.16) - 3142.31/(t' + 273.16)$$

where e' = s.v.p. in bar over water at temperature t'

and $e = e' - 1013.25\, A\, (t-t')$

e = v.p. in mbar

where $A = 6.66 \times 10^{-4}\ {}^{o}C^{-1}$ when $t' \quad 0^{o}C$

e' = s.v.p. at temp t' (in mbar

t = air temperature (dry bulb)

t' = wet-bulb temperature (sling)

the relevant vapour pressures at ground temperature and air temperature could be calculated.

4.0 RESULTS

4.1 Preliminary Investigation

In broad terms, evaporation rates measured, varied from $30 gm/m^2/day$ to $750 gm/m^2/day$ but were generally 150 to $250 gm/m^2/day$. Evaporation rates at night are generally 50% to 100% higher than those during the day, although the rather course resolution of the balance prevented accurate determination of weight loss over short duration.

The subfloor airspace is very sheltered. It was not possible to measure average air speed with the recorder used; the chart speed of 20mm/hr being so slow that over-writing destroyed all but extreme readings. With a pen of 1mm diameter only the highest and lowest reading in any 3 minute period would be visible on the chart. during the month of operation (July 1982) more than 60% of the time air movement was to slow to record i.e. less than 0.1 m/s. Even in a strong north-east blow gusting over 40 knots outside the peaks of the zephyrs recorded in the subfloor space reached about 0.4 m/s. Although wind speed has been shown to have significant (and at higher speeds, dominant) effect on evaporation rates from fields, lakes and the ocean, no effect from the low air speed in the subfloor area could be detected in the subfloor evaporation rates. The only significant effect of subfloor air speed is to ensure adequate air change. Then a relatively high rate of 10 changes/hour over a 10 m length represents only 2.8×10^{-4} m/s average velocity.

Detailed results of the preliminary investigation are included in the December 1982 report to BRANZ and will not be included in this paper. The total evaporative weight losses during the preliminary investigation between 22/7/82 and 4/8/82 is shown in Table 1.

Table 1 Evaporative weight loss - preliminary investigation

Sample	Lysimeter length (mm)	Weight loss (mm)
water (1)	200	54
water (2)	200	59
sand	400	38
loam	400	10
clay	400	51
sand	800	49
loam	800	40
clay	800	65

The 400mm long sand sample and the two loams were very dry and showed lower evaporative loss. All other samples showed evaporative loss similar to that of the water lysimeters. The results suggested that evaporation rates might be independent of soil type provided the soil moisture content is above some minimum value for that particular soil. In the extended investigation the hypothesis was tested by using the same soil samples, artificially wetting them as necessary and using lysimeters each 200mm in length.

4.2 Extended Investigation

The total weight loss from each of the lysimeters is of little significance since the sealed bases prevent the natural recharge of lost moisture. The results, therefore, are presented in figure 1 in relation to the evaporative loss from a free water lysimeter.

The weight loss from each of the soil lysimeters is plotted against the average of the weight losses from the two water lysimeters. In figure 1a the ratios are plotted for each period of approximately one week duration. The date given indicates the end of the period. Figure 1a shows a distinct scatter in results most of which can be attributed to the accuracy of the weighing. With average weight loss of say 30gm for each period and assuming a maximum error of ± 3/4gm at the beginning and end of each period for each lysimeter, the weighing error plotted could be 31.5 - 28.5/31.5 = 9.5%. To reduce the effect of weighing accuracy figure 1b has been plotted from figure 1a by successively averaging every three consecutive results. The random error then reduces to about ± 3% and gives a more useful representation of the results.

The moisture contents determined at the end of the extended investigation are shown in Table 2.

Table 2 Moisture Content at 27/1/83

lysimeter portion	sand 1	sand 2	loam 1	loam 2	topsoil	clay
top 20%	2.5	1.5	25	19	22	19
20% → 40%	3.4	2.4	21	19	19	20
40% → 60%	3.8	2.9	20	19	22	20
60% → 80%	4.5	3.1	21	19	22	19
bottom 20%	4.3	3.2	19	14	20	20
Total soil (dry weight gm)	6210.4	6274	4082.4	4374.7	4541.0	4895.1
Total water (gm)	230.1	161.2	861.8	772.6	955.0	954
Av. m.c. (%)	3.7	2.6	21	18	21	19

By adding the weight loss during each successive period from the termination of the experiment, the average moisture content was calculated at the end of each (approximately weekly) period. The results are given in Table 3.

Table 3 Average moisture content (as percentage by weight) at the date specified

Date	sand 1	sand 2	loam 1	loam 2	topsoil	clay
5/08/82	15	9	35	31	34	32
12/08/82	15	9	35	30	33.3	31.5
19/08/82	14.6	8.4	33.9	29.6	32.8	30.8
26/08/82	14.1	8.0	33.4	29.1	32.3	30.3
2/09/82	13.7	7.6	32.8	28.6	31.7	29.7
10/09/82	13.1	7.0	32.1	27.8	31.1	29
17/09/82	12.7	6.6	31.5	27.3	30.5	28.5
28/09/82	12.4	6.2	30.9	26.7	30.0	28.0
12/10/82	11.2	5.3	29.6	25.5	28.8	26.8
20/10/82	10.7	4.8	28.9	24.9	28.2	26.2
27/10/82	10.2	4.5	28.3	24.3	27.6	25.6
4/11/82	9.8	4.2	27.9	23.9	27.3	25.3
11/11/82	9.6	4.1	27.7	23.6	27.0	25.0
18/11/82	8.9	3.8	26.9	22.9	26.3	24.3
26/11/82	8.3	3.5	26.3	22.3	25.8	23.7
3/12/82	7.6	3.3	25.6	21.6	25.1	23.1
10/12/82	7.3	3.3	25.2	21.3	24.8	22.8
20/12/82	6.5	3.1	24.4	20.5	24.0	22.2
26/12/82	6.1	3.0	24.0	20.1	23.6	21.8
20/01/83	4.2	2.7	21.9	18.3	21.7	20.1
27/01/83	3.7	2.6	21	18	21	19

The results given in figure 1b are combined with the data of table 3 and plotted on figure 2 to show the evaporative weight loss from a soil at various moisture contents as a proportion of that from a free water surface.

The preceeding results relate to average evaporative weight loss over approximately weekly periods. Evaporative weight loss has been analysed on a daily basis in relation to vapour pressures. A full tabulation of results is too extensive to include in this paper but will be reported in full to BRANZ in about April 1983. In summary, the range of temperature and relative humidity is given in table 4.

Table 4 Range of Temperature, relative humidity and vapour pressure

	November		December	
	Max	Min	Max	Min
Ground temperature	17.59	13.88	18.59	14.11
Air temperature (subfloor)	21.85	17.46	23.72	11.76
Relative humidity (subfloor)	98.27	81.56	101.60	81.17
Air temperature (out-door)	27.18	8.13	27.32	8.03

In table 5, a typical example of the digitised results from temperature measurements and subsequent calculations is shown.

Table 5 Temperature measurements, calculated relative humidities and vapour pressures for the period 8-00 hrs 15/11/82 to 9-00 hrs 16/11/82

Date	Time	T_g	T_{as}	T_{ws}	T_{ao}	e_g	e_{as}	RH_s	$(e_g - e_{as})$
15/11/82	8.00	13.88	14.21	12.19	15.26	15.85	12.83	90.39	3.02
	9.00	13.98	14.68	12.50	16.14	15.96	13.02	89.86	2.94
	10.00	13.98	15.33	12.70	17.86	16.13	12.90	87.90	3.23
	11.00	14.15	15.47	12.29	17.87	16.02	12.12	84.91	3.90
	12.00	14.04	15.45	12.62	17.07	16.01	12.70	86.95	3.31
	13.00	14.03	15.87	12.67	19.53	16.12	12.49	85.25	3.63
	14.00	14.14	16.25	12.95	20.16	16.21	12.69	85.05	3.52
	15.00	14.23	16.43	13.27	18.44	16.44	13.11	86.03	3.33
	16.00	14.45	17.54	13.61	19.96	16.65	12.92	82.96	3.73
	17.00	14.64	17.56	14.03	20.25	16.72	13.63	85.13	3.09
	18.00	14.71	16.94	13.64	17.60	17.02	13.38	85.74	3.64
	19.00	14.98	16.44	13.68	16.54	17.04	13.79	88.12	3.24
	20.00	14.99	15.76	13.07	15.32	17.04	13.23	87.94	3.81
	21.00	14.99	15.27	12.94	14.69	16.93	13.33	89.44	3.60
	22.00	14.90	15.02	12.84	14.02	16.94	13.34	90.06	3.60
	23.00	14.86	14.81	12.75	13.93	16.89	13.33	90.54	3.56
	24.00	14.83	14.83	13.04	14.10	16.85	13.80	91.95	3.06
16/11/82	1.00	14.77	14.80	13.25	14.25	16.79	14.17	93.13	2.63
	2.00	14.81	14.62	13.12	14.03	16.83	14.07	93.30	2.76
	3.00	14.77	14.49	12.92	13.85	16.79	13.84	92.90	2.95
	4.00	14.70	14.45	12.96	13.84	16.72	13.92	93.26	2.30
	5.00	14.71	14.50	12.95	13.79	16.73	13.37	92.97	2.86
	6.00	14.65	14.33	12.81	13.29	16.66	13.76	93.08	2.90
	7.00	14.66	14.35	12.32	13.90	16.67	13.75	92.39	2.92
	8.00	14.57	14.27	12.35	14.25	16.58	13.04	90.95	3.53
	9.00	14.50	14.70	12.61	15.53	16.51	13.17	90.29	3.33

Lysimeter weighing commenced at 8-08 hrs on 15/11/82 and at 8-36 hrs on 16/11/82. The respective weights are given in table 6.

Table 6 Lysimeter weight records 15/11/82 and 16/11/82

Date	time	water 1	clay	sand 1	sand 2
15/11/82	8-08	3796.5	6926	7619	7366
16/11/82	8-36	3790.5	6921	7613	7363

Calculation shows evaporation losses to be

water 1	0.245	gm/hr
clay	0.204	gm/hr
sand 1	0.245	gm/hr
sand 2	0.123	gm/hr

and average $(e_g - e_{as})$ - 3.26 mbar

These quantities along with other days when measurements were made are plotted on figure 3. The straight lines drawn on figure 3 are calculated on a least squares fit. The problem of resolution of the balance over short durations is largely responsible for the scatter in the results. However, note that the slopes of the November (clay), November and December (sand 1) lines are very close to that of water 1. The lesser sloping lines represent decreased evaporative loss and occur after the lysimeter material has dried to below the critical moisture content required to maintain free water evaporation rates.

5.0 DISCUSSION OF RESULTS

Consider the information plotted in figures 1 to 3 inclusive for each of the materials.

5.1 Sand

Sand 1 started with an average moisture content of 15% by weight. Figure 1b shows evaporation from this lysimeter to be comparable with that of water i.e. generally ± 5% with two excursions to 10-12%. Figure 1a then shows a sudden drop when the moisture content has decreased to 5 or 6%.

Sand 2 was initially drier than sand 1 at 9% moisture content by weight. Figure 1 shows evaporation from the sand lysimeter to be very close until 28/9/82 when the sand 2 plot suddenly dips. Table 3 shows the moisture content at 28/9/82 to be 6.2%. Figure 2 shows evaporation rates similar to that of water until drying to a moisture content of 6-7%. Figure 2 also indicates an equilibrium moisture content for sand 2 of about 3%.

This figure compares well with TRRL (ref 5) in figure 16.15 which indicates equilibrium moisture content of 3 to 4% for relative humidity of 80 to 90%. There is no indication of sand grain size.

Figure 3 shows evaporation rates of sand 1 during November and December to be comparable with that of water. After drying to below 6% moisture content in late January, the evaporation rate has dropped well below that of water.

5.2 Clay

Figure 1 shows an evaporation rate of 10 to 20% in excess of that of free water. Figure 2 shows that the evaporation rate of the clay sample dropped below that of water when its moisture content reached about 28%. A smoothed curve over figure 1b might indicate this critical moisture content to be reached at about the 4th to 6th week i.e. at a moisture content of 28 to 30%. There is insufficient data to determine whether evaporation rates in excess of those for free water could be maintained at higher moisture contents. In sand, it appears not with moisture contents of 2.5 times critical showing no further increase in evaporation rate. The higher rates recorded in the clay sample may be attributable to shrinkage which caused cracking of the sample in the second week which effectively increases the surface area from which evaporation could take place.

TRRL (ref 5) indicates equilibrium moisture content of clay to be 12 to 14% for relative humidity of 80 - 90%. Extrapolation of the figure 2 clay plot is likely to produce similar results.

5.3 Topsoil

Figure 1b indicates that the evaporation rate from the topsoil lysimeter was always below that of the free water lysimeter. However, with only a small extrapolation of figure 1b and figure 2 it can be seen that free water evaporation rates would be achieved with a moisture content of approximately 35%.

5.4 Loam

As with topsoil the loam samples were always too dry to achieve free water evaporation rates. Extrapolation of figure 2 indicates the critical moisture content to be about 37 to 38%. The initial moisture contents of loam 1 and loam 2 were 35 and 31% respectively.

5.5 General discussion of results

A summary and comparison of many established formulae for evaporation from water surfaces (lakes or the ocean) is given in Abbott (1970). Nearly all such formulae are of the form:

$$q = f(u) \quad (e_w - e_a)$$

where q = evaporation rate

e_w = saturation vapour pressure at the temperature of the water surface (or soil surface here)

e_a = vapour pressure of the air (at some distance above the air/soil surface)

$f(u)$ = some function involving wind-speed, barometric pressure, or surface area of the body of water or combinations thereof.

Figure 3 shows the same relationship to hold for subfloor evaporation rates. Subfloor wind-speed has been shown to have negligible effect with normal subfloor ventilation and f(u) has been reduced to a constant.

From figure 3, the slope of the free water plot is seen to be 0.07. Converting to unit surface area gives the relationship.

$$q = 4.0\ (e_g - e_{as})$$

where q = evaporation rate $gm/m^2/hr$

e_g = saturation vapour pressure at ground temperature (mbar)

e_{as} = vapour pressure in subfloor airspace. (mbar)

The scatter shown in figure 3 is greater than desireable, however, as an engineering tool the results achieved will have sufficient accuracy for some time to come until a far better understanding of moisture movement within and out of the subfloor airspace, subfloor air changes and larger scale meteorological conditions can be achieved.

The variation in figure 1 is not entirely attributable to the accuracy of the weighing. It is found that each of the depressions in figure 1a is caused by a sudden cold snap on one particular day. These occurred on 19/8, 3/9, 30/11. The response of the free water lysimeter on each particular day was greater than that of the soil lysimeters. The ratio then plots lower on figure 1a. Conversely, the slightly lighter results (e.g. 3/12 to 26/12) relate to warmer weather with no sudden changes in temperature.

Note that all results presented in figures 1 to 3 inclusive were compiled from 200mm long lysimeters with sealed bases and no replenishment of lost moisture from below. In Auckland, and probably most of New Zealand the water table is usually within 2-3 m of the ground surface and in winter is often at the ground surface. In the protected subfloor area, out of direct sunshine and sheltered from the wind, soil moisture contents generally remain high, except for a thin dry surface crust. Consider the clay lysimeter initial moisture content 32% drying to 29%. The loss of water would be 147gm. Thus the same drying of a one metre long lysimeter (of 150mm diameter) would be 735gm. The evaporation from the free water lysimeter (and the sand 1 lysimeter) over nearly 6 months (5/8/82 to 27/1/83) were both less than 750gm. In other words, if the high winter water table were to suddenly drop 1 m, there is sufficient moisture held in that metre of soil to maintain full free water evaporation rates for 6 months without any replenishment of moisture from below.

It follows that in most cases in New Zealand, and certainly where subfloor moisture is a problem, subfloor evaporation rates comparable with that from a free water surface will occur irrespective of soil type and surface moisture content. Only when the soil moisture drops below the critical level for that particular soil for some significant distance below the subfloor ground surface will subfloor evaporation rates decrease. Such cases have not been persued in the present investigation.

6.0 CONCLUSIONS

Soil evaporation rates are shown to be equal to those from a free water surface when soil moisture content exceeds a critical value. These critical values were found to be 5-6% for a sand, 28-30% for a clay, 35% for topsoil, 37-38% for a volcanic loam.

In conditions where ground-water approaches the surface during winter, sufficient moisture is available in about one metre thickness of soil to maintain moisture contents above the critical value for about 6 months. Under these conditions, subfloor evaporation rates are independent of soil type and actual moisture content and are shown to approximate $q = 4.0\ (e_g - e_{as})$ where e_g is a function of ground temperature only and e_{as} is a function of both temperature and humidity in the subfloor airspace. Subfloor air-speed for low airchange rates subfloor relative humidity will become effected.

LIST OF SYMBOLS

e_g = saturation vapour pressure at ground temperature

e_{as} = subfloor air vapour pressure

e' = saturation vapour pressure of temperature T' (mbar) or (bar)

q = evaporation rate $gm/m^2/hr$

T = air temperature (dry bulb) ^oC

T' = wet bulb temperature (sling) ^oC

T_g = ground temperature ^oC

T_{as} = subfloor air temperature (dry bulb) ^oC

T_{ws} = subfloor wet-bulb temperature ^oC

T_{ao} = air temperature (dry bulb) outside ^oC

RH_s = relative humidity (subfloor)

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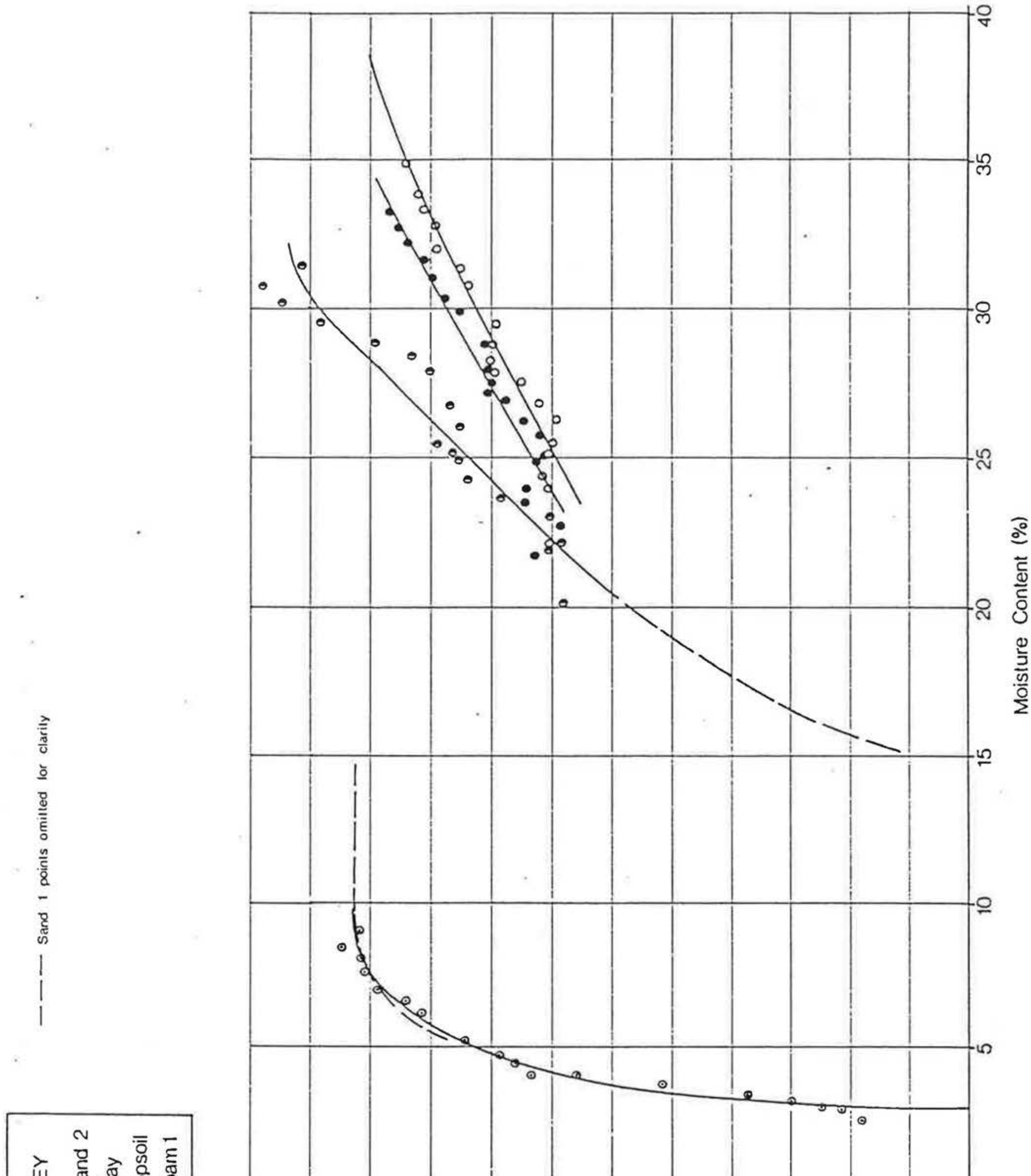

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Figure 2

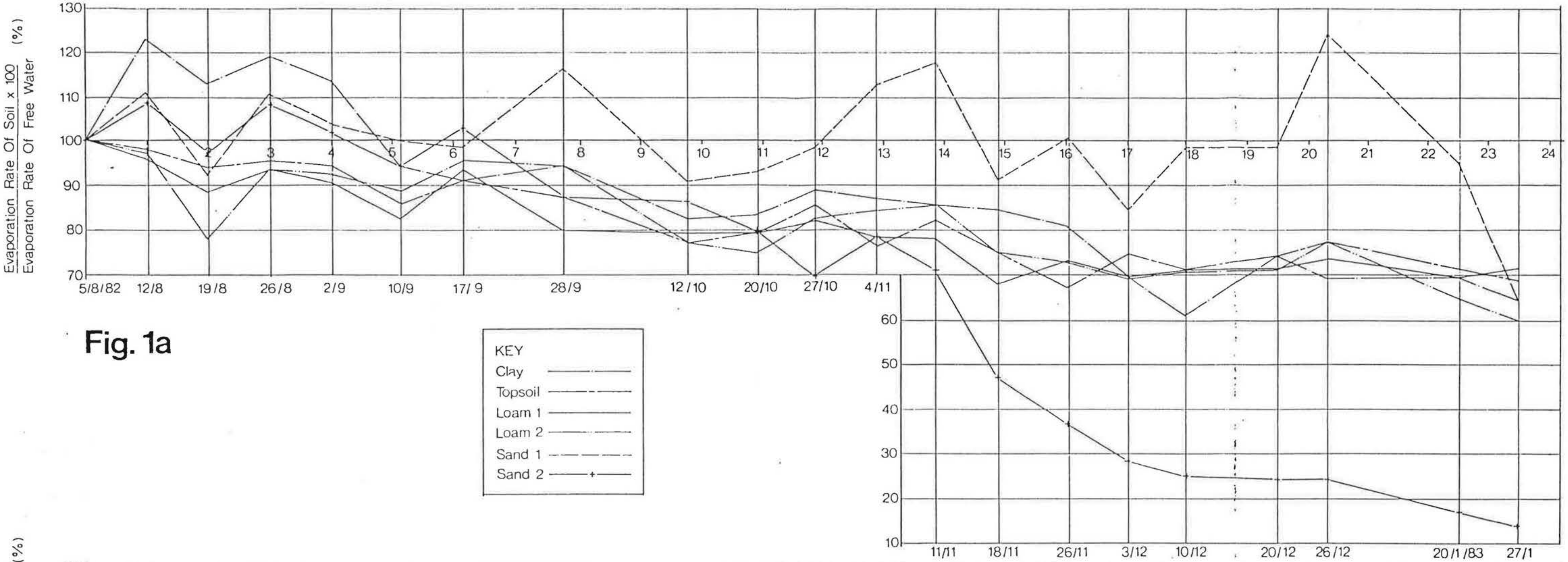

Fig. 1a

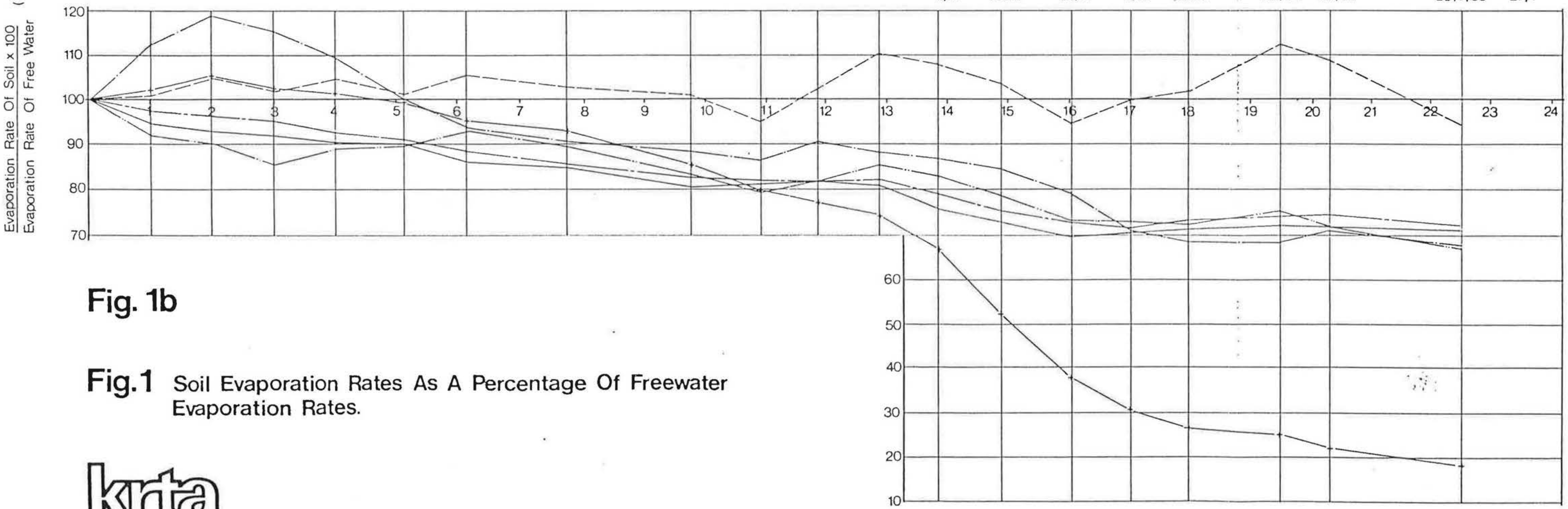

Fig. 1b

Fig.1 Soil Evaporation Rates As A Percentage Of Freewater Evaporation Rates.

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