

987

Use of microlysimeters to measure evaporation from sandy soils

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Abstract

Evaporation from soil can be a major component of crop water balance and land surface energy balance. A number of different applications of the microlysimeter method to measure evaporation from soil have been used in recent studies. Microlysimeters were used extensively in three sandy soils for this study. Measurement of evaporation from microlysimeters with different dimensions and of different ages allows discussion of the sources of error inherent in the method.

The evaporation recorded from microlysimeters of diameters 214 mm, 152 mm and 51 mm was not significantly different. A comparison of 100 mm and 200 mm deep microlysimeters showed that depth had no significant influence during the first 2 days after extraction from the soil profile. For periods beginning 2 or more days after rain, significant differences in evaporation owing to depth may not occur for up to 7 days. Soil cores extracted at different times showed significant differences in evaporation immediately following a rain event, and no significant differences 2 or more days thereafter. This period of significant difference was extended to about 4 days when the method was used within a crop (i.e. root extraction of water in the field significant). A protocol for use of microlysimeters is developed from these results.

Introduction

The development of cropping systems that use water more efficiently is becoming increasingly important in the semi arid tropics. In these environments, evaporation from the soil surface is a significant component in the crop water balance (up to 60% of seasonal rainfall, Cooper et al., 1983). Studies of surface energy balance, up to the scale of global circulation models, must also include this latent energy flux. Evaporation from the soil, E_s , can be measured or estimated in a number of ways (e.g. Ritchie, 1972; Arkin et al., 1974;

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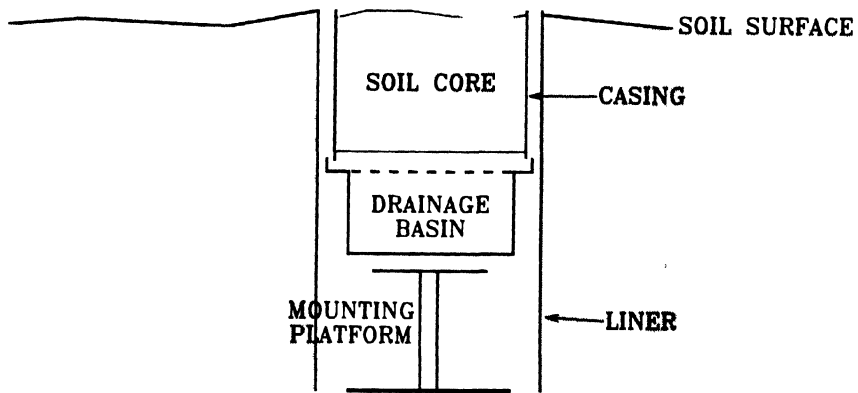


Fig. 1. Microlysimeter (= soil core + casing + drainage basin) mounted in liner tube.

Ashktorab et al., 1989): the microlysimeter method (Boast, 1986) is arguably the most simple, direct and independent measurement of E_s .

Microlysimeters are small isolated volumes of bare soil (typically 1–3 kg) mounted flush with or slightly above the soil surface (Fig. 1) and weighed daily (or more frequently) to determine water loss. These soil cores can be extracted from and mounted in the soil beneath a crop canopy allowing separation of E_s fluxes from transpiration fluxes – an important distinction in crop water balance studies.

Table 1
Dimensions and useable lifetime of microlysimeters used in field studies

Source	Internal diameter (mm)	Depth (mm)	Useable Lifetime (days)
Boast and Robertson (1982) ^a	76	146	–
		106	–
		70	1–2
		120	8–10
Walker (1983) (see also Boast, 1986)	76	120	8–10
Shawcroft and Gardner (1983) (see also Boast, 1986)	203	200	crop season
		100	(water added)
		50	
Martin et al. (1985)	150	200	crop season (water added)
Lascano and Van Bavel (1986)	74	130	1 or 2
Matthias et al. (1986)	76	150	6
Villalobos and Fereres (1990)	200	300	1
Allen (1990)	100	150	2
Wallace et al. (1992)	150	300	1

^a Laboratory experiment.

A number of authors have employed this method (Table 1) and the possible sources of error in the measurement of E_s have been discussed. Errors may occur if the soil within a microlysimeter has a significantly different water content or temperature to that of the surrounding soil. Specifically, if a one-dimensional flux of water and energy can be assumed in the field, the main sources of error are: (1) the boundary to water flow imposed at the base of the microlysimeter at the time of soil core extraction; (2) the termination of root extraction of water from the soil core once it is isolated in the microlysimeter; (3) the disturbance of the soil in the extraction process; (4) the conduction of heat through the microlysimeter casing.

The magnitude of these errors depends on the width and depth of the microlysimeter used and the time since the soil core was extracted from the soil profile. These details of microlysimeter use vary considerably (Table 1).

The laboratory study of Boast and Robertson (1982) and the field study of Shawcroft and Gardner (1983) were the only ones in Table 1 designed to consider the effects of the sources of error of the microlysimeter method. These authors only considered the effect of lysimeter depth (i.e. the boundary to water flow at the base) with Shawcroft and Gardner using the same lysimeters for a whole season (Boast, 1986).

The objective of this paper is to consider which diameter, depth and useable lifetime are the most appropriate for microlysimeters used in field studies on sandy soils. A protocol for use of microlysimeters in water balance studies is proposed.

Materials and methods

The studies described here were conducted in three locations with sandy soils: the ICRISAT Center, Hyderabad, India on an Alfisol-Soil Taxonomy/Luvisol-FAO System (66–79% sand, 6% silt, 15–28% clay); the ICRISAT Sahelian Center, Niamey, Niger on an Alfisol-Soil Taxonomy/Arenosol-FAO System (91% sand, 5% silt, 4% clay); and the University of Reading farm, Sonning, UK on the Rowland Series (80% sand, 12% silt, 8% clay).

The microlysimeter casing and the pipe lining the holes in which the microlysimeters were mounted, were both constructed from unplasticised polyvinyl chloride (PVC) pipe. Unplasticised PVC has a heat capacity of $0.95 \text{ J g}^{-1} \text{ K}^{-1}$ at 25°C (Koleske and Wartman, 1969) and a thermal conductivity of $0.16\text{--}0.17 \text{ W m}^{-1} \text{ K}^{-1}$ between 20 and 90°C (Sheldon and Lane, 1965) (compare with an air-dry sandy soil: heat capacity = $0.80 \text{ J g}^{-1} \text{ K}^{-1}$ and thermal conductivity = $0.25 \text{ W m}^{-1} \text{ K}^{-1}$; De Vries, 1963). The dimensions of the microlysimeters varied between the trials. All trials included lysimeters of the following 'standard' dimensions: length = 100 mm; internal diameter = 152 mm (external 160 mm); liner tube, internal diameter = 170 mm.

Note that care was taken to minimise the gap between lysimeter and liner especially for smaller diameters. Unless otherwise stated, weight loss was recorded at the field site by a portable balance that weighed to ± 1 g (water depth equivalent = ± 0.055 mm, for an i.d. = 152 mm). The lysimeter casing was inwardly tapered to a cutting edge at one end.

Soil cores were taken manually by alternately inserting the lysimeter casing 2–3 cm and then excavating a slightly oversized pillar of soil to a depth 2–3 cm below the base of the core. When the required depth was reached the core were trimmed flush at the base and were placed on a sheet metal base plate or a drainage basin and sealed with waterproof tape. The microlysimeter was then mounted in a liner tube, with its surface slightly above the soil surface to prevent 'run-in' (Fig. 1). In some trials a mounting platform separated the base of microlysimeter and the underlying soil (Fig. 1); in others the microlysimeter rested directly on the soil. The liner positions were fixed throughout the season in an area that was left undisturbed.

Comparison of microlysimeter and gravimetric methods

A soil bed (1.2 m \times 2.4 m; 0.25 m deep) containing sieved Rowland Series soil was prepared in a glasshouse at the University of Reading. A gravel layer was laid beneath the soil to assist drainage to zero matric potential at the base, otherwise the walls and base of the soil bed were impervious. Prior to the measurement of evaporation the soil was saturated and left to drain and equilibrate while under covers for several days. After 10, 13 and 18 days of evaporation, gravimetric water content measurements were made (8 or 12 replications) from soil depths 0–5, 5–10, 10–18 and 18–25 cm. Four 'standard' soil cores were extracted, weighed and mounted centrally along the axis of the soil bed (4 h after the gravimetric sampling on Day 10). The microlysimeters were weighed daily initially and less frequently toward the end of the experiment on Day 18. The bulk density was measured and used to calculate volumetric soil water contents and hence the evaporative loss from the surface of the soil bed in terms of equivalent depth of water.

Microlysimeter diameter comparisons

In Niger, microlysimeters of three internal diameters (214, 152 and 56 mm) were used to record E_s . This experiment was repeated in England using internal diameters of 152 and 51 mm over a period including several rain events. The lysimeters used in these experiments were all 100 mm deep (with 6 or 12 replicates) and used soil cores that were taken on the day of recorded measurement or the day before. The smallest lysimeters were weighed to ± 0.1 g or better.

In Niger, temperatures beneath the 214 and 56 mm diameter microlysi-

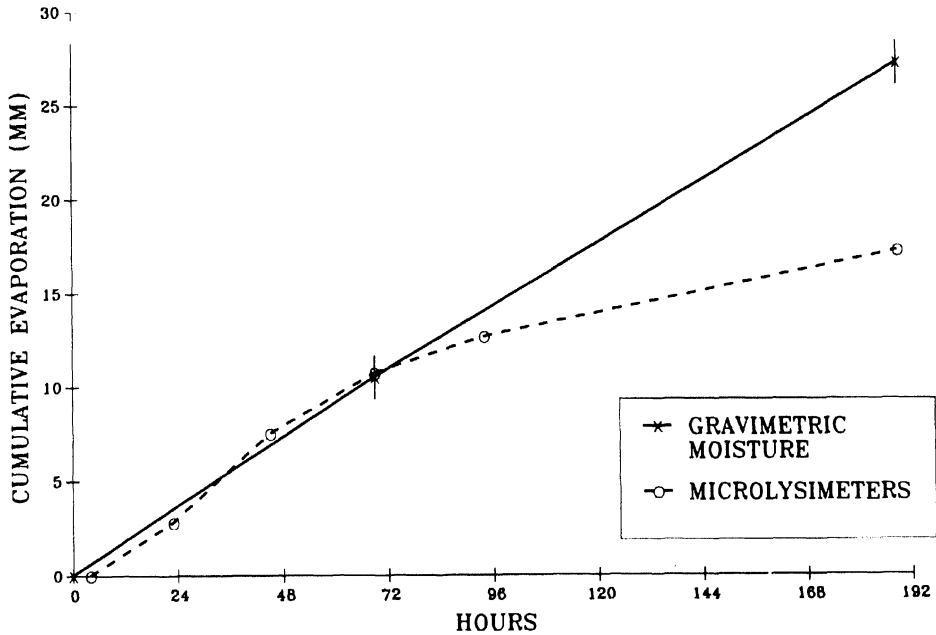


Fig. 2. Cumulative evaporation from a glasshouse soil bed with imposed zero flux plane at 250 mm. Evaporation estimated by gravimetric soil survey to 250 mm and the microlysimeter method (microlysimeters 100 mm deep).

the University of Reading, calculated by changes in gravimetric water content of the profile and by the microlysimeter method. The largest standard error for estimation of gravimetric soil water content was 0.00156 g g^{-1} which gives an uncertainty of 1.2 mm in each estimate of cumulative evaporation (assuming a known value of bulk density). The standard error of the mean evaporation for each interval measured by the four microlysimeters is 0.1 mm. Earlier measurements of water loss from wet soil indicated an evaporative demand of approximately 3.5 mm day^{-1} in the glasshouse environment on sunny days.

Evaporation from the microlysimeters was consistent with the evaporation calculated by gravimetric survey until Day 4 after core extraction. The good agreement between the two methods confirms the result of Allen (1990) that microlysimeters provide an accurate measurement of E_s during rain-free periods. Figure 2 suggests that microlysimeters 100 mm deep remain representative of surrounding soil for 3 days under these conditions of drainage and evaporative demand. The study of Boast and Robertson (1982) suggested a lifetime of about 2.5 days for microlysimeter soil cores 70 mm deep exposed to a similar evaporative demand. These results both suggest that soil disturbance during lysimeter extraction and heat conduction through the lysimeter casing do not have a significant effect on E_s , because these effects would be noted in the first 3 days.

It can be assumed in this trial that the zero flux plane was at the base of the

meters were compared with those recorded in the soil profile at 100 mm depth. Copper-constantan thermocouples were connected to a data logger to record these temperatures continuously for several days (two replicates). The microlysimeters used in this trial were seated on the soil at the base of the liner with the thermocouples between lysimeter base and soil.

Microlysimeter 'age' comparisons

Evaporation from two sets of microlysimeter soil cores extracted from soil profile at different times was recorded in Hyderabad and in Niger. Measurements were made in either bare soil plots or very sparse millet crops in both locations. Results were not likely to be affected by the crop. Cores were extracted from the soil at a range of different times after the most recent rainfall. The microlysimeters were of 'standard' size at both locations.

In addition to these measurements, E_s was measured beneath a mature millet crop in Hyderabad grown in the 1990 dry season with regular irrigation. The height of the crop was 1.5 m, row spacing 0.5 m and leaf area index 2. Following an irrigation of 45 mm, E_s was measured by 12 microlysimeters, six of which were newly extracted from the plot every 2 days so that each microlysimeter was used for 4 days before being discarded. Microlysimeters were taken in pairs, one close to the row and the other mid-row.

Microlysimeter depth comparisons

In Niger 1991, E_s from bare soil was measured by microlysimeters 100 and 200 mm deep containing soil cores extracted simultaneously (three replicates). E_s was recorded for 14 time intervals of average length 24 h at a range of times after last rainfall. Soil cores were discarded after one or two intervals of measurement.

In Hyderabad during the dry season in 1990, a bare soil plot was ploughed by bullock and then sprinkler irrigated on 18, 19 and 20 January with a total irrigation depth of 100 mm. On 22 January, 6 mm × 100 mm and 6 mm × 200 mm deep cores of standard diameter were extracted from the soil at random locations within the irrigated area. They were weighed from 22 January on seven occasions during a 13 day period. A second set of cores were extracted on 21 February and weighed thereafter for 7 days. There was no rain during this experimental period.

Results and discussion

Comparison of microlysimeter and gravimetric methods

Figure 2 shows cumulative evaporative loss from the glasshouse soil bed

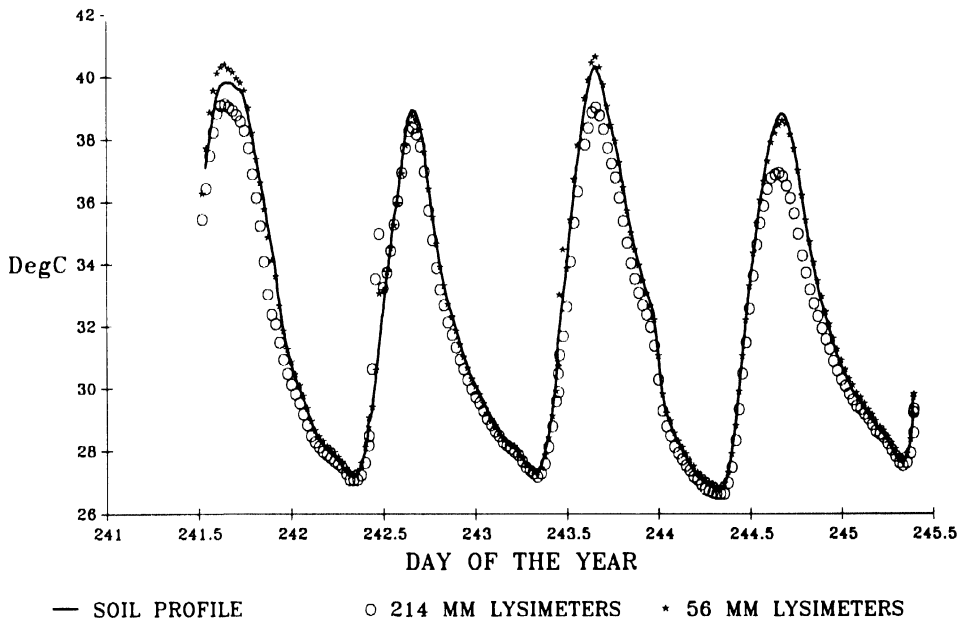


Fig. 3. Soil temperatures at 100 mm depth in the soil profile and at 100 mm directly beneath lysimeters of 214 and 56 mm diameter. (The short increase in temperature observed beneath lysimeters in the morning on Days 242 and 243 was the result of lysimeter removal for weighing.)

at 100 mm directly beneath 56 mm and 214 mm diameter lysimeters. The temperatures were virtually identical.

These findings indicate that lysimeters as small as 50 mm internal diameter can be used to measure E_s , although more replicates may be needed to achieve the same accuracy of measurement for smaller diameters. This implies that conduction of heat through the microlysimeter casing and disturbance of soil in the extraction process are not important because no significant difference in E_s or soil temperature was noted between diameters. This may not be true if lysimeter casing or liners are of metal construction.

Villalobos and Fereres (1990) inserted perforated steel microlysimeter tubes at the beginning of the season and then excavated these tubes when required for use. This practice overcomes the problems of soil disturbance and microlysimeter insertion, but may alter the distribution of water and roots within the microlysimeter prior to use (Villalobos and Fereres, 1990). The soils used in the present study caused no major problems for extraction of cores and therefore they could be taken immediately before the period of use. In problem soils, the sampling approach of Villalobos and Fereres may be an appropriate compromise.

Microlysimeter age comparisons

Table 3 allows comparison of evaporation from microlysimeters containing soil cores that were extracted from the soil profile at different times. An

Table 2

Mean daily evaporation (mm) from sets of microlysimeters of three diameters. Analysis of variance showed that diameter was not a significant factor in Niger or Sonning. Variability of E_s measurements for a given diameter is described by the standard error of all measurements at a site

Date	Internal Diameters		
	214 mm	152 mm	56 mm
<i>Niger</i>			
27 August	0.75	0.81	0.77 ^a
28 August	0.46	0.51	0.51 ^a
30 August	1.71	1.65	1.75 ^a
4 October	1.44	1.49	1.45
6 October	1.12	1.07	0.85
7 October	0.78	0.74	0.78
8 October	0.62	0.63	0.61
9 October	0.53	0.53	0.50
Standard Error ^b	0.057	0.076	0.077
<i>Sonning</i>			
7 July	–	0.69	0.71
10 July	–	1.14	1.20
17 July	–	1.77	1.75
18 July	–	1.68	1.85
23 July	–	1.50	1.53
24 July	–	1.25	1.25
Standard Error		0.068	0.102

^a Twelve replicates were used to calculate these means, all other means were calculated from six replicates.

^b The standard error given is for daily means of the same diameter assuming six replications.

soil bed (250 mm), well below 100 mm at the time the cores were extracted. Thus any flux at a depth of 100 mm would have been upward throughout the period following extraction and would have been exaggerated by the restricted drainage. Drainage is often unrestricted in wet field soils. Thus Fig. 2 suggests that the boundary to upward flow at the base of the microlysimeter cores imposed at the time of extraction does not have a significant effect on cumulative E_s for 3 days.

Microlysimeter diameter comparisons

Table 2 presents evaporation data from lysimeters of three diameters. Diameter had no significant effect on mean evaporation at either site (even at $P = 0.1$). In Sonning, the standard error of mean evaporation was markedly different for the two diameters. In Niger the standard error did not follow this pattern suggesting that the increase in variability with decreasing diameter may not be large for all soils.

Figure 3 shows average temperatures at 100 mm depth in the soil profile and

Table 3

Mean evaporation (mm) from two sets of microlysimeters. Set 1 was extracted from the soil profile at an earlier time (column X) than Set 2 (column Y). Times of extraction and the evaporation measurement period are given as hours after rain

Last Rain (mm)	Evap. Period (hours after rain)	Lysimeter Set 1		Lysimeter Set 2		Reps.	Sig. ^a
		Time of extraction X (hour after rain)	Evap. (mm)	Time of extraction Y (hours after rain)	Evap. (mm)		
<i>Niger — very sparse millet crop</i>							
5.9	10–34	– ^b	2.8	10	1.7	6	**
14.7	20–92 ^c	–	13.2	20	3.9	6	**
34.0	20–45 ^c	1	3.5	20	2.0	6	**
8.6	32–56	7	1.7	32	1.3	6	**
34.0	45–69	20	1.2	45	1.3	6	NS
14.7	94–118	20	1.1	94	0.6	6	**
8.4	96–120	72	0.9	96	0.7	6	NS
40.0	104–128	80	0.6	104	0.6	6	NS
8.4	120–144	96	0.6	120	0.5	6	NS
40.0	128–151	104	0.4	128	0.4	6	NS
<i>Hyderabad — bare soil</i>							
22.5	6–54		3.7	6	2.7	2	*
40.0	12–60 ^c		8.1	12	6.2	5	**
22.5	54–102	6	4.6	54	4.6	2	NS
22.5	102–150	54	2.9	102	2.5	2	NS
25.0	108–136	60	2.1	108	1.9	2	NS
<i>Hyderabad — Millet crop, following irrigation</i>							
45.0	48–96	1	4.9	48	3.8	6	**
45.0	96–151	48	3.2	96	2.5	6	**
45.0	151–197	96	1.5	151	1.7	6	NS
45.0	197–242	151	0.8	197	0.7	6	NS
45.0	242–317	197	1.2	242	1.2	6	NS

^a Significance of difference of means from the two sets of lysimeters (see text): NS, not significant; * significant at $P = 0.05$; ** significant at $P = 0.01$.

^b A negative sign (–), is displayed when the lysimeters were extracted before the rain and were subjected to rainfall in-situ. Under these conditions impeded drainage can result in high evaporation being sustained for prolonged periods.

^c Marked evaporation periods are tested for significance separately, not as part of one of the three data groups.

analysis of variance of each of the three groups of data (Niger, Hyderabad-bare, Hyderabad-millet) provided standard errors for differences of mean evaporation in each group. Significance of the differences in mean evaporation from sets of lysimeters of different age was tested for each evaporation period using the t statistic. Data transformation was not required. The sig-

nificance of each of three 'outlier' evaporation periods (marked in Table 3) was evaluated separately and was in agreement with the other results. Note that the data sets of Table 3 were collected in a wide range of conditions (e.g. antecedent soil water content, depth of preceding rainfall, evaporative demand) which may influence the result.

The boundary to water flow at the base of the microlysimeter and the loss of water resulting from extraction by roots (if a crop is present) will be the two factors likely to determine how long a microlysimeter remains representative of surrounding soil (its useable lifetime).

When microlysimeter Set 1 was extracted prior to rain (or during the 24 h following rain) evaporation is likely to be significantly higher than for Set 2 (Table 3). In these instances lysimeter Set 1 was often visibly distinguishable, having a wetter, darker surface than Set 2 and the surrounding soil. Impeded drainage in lysimeter Set 1 (extracted earlier) is the most likely cause of this enhancement of evaporation. In addition, microlysimeters subjected to rainfall in situ often have a weight gain larger than the equivalent depth of rain (c.f. Allen, 1990). No significant differences in E_s from bare soil were observed between sets of lysimeters extracted 72 h or more after rain. This suggests that at these times the boundary to upward or downward movement of water at the base does not significantly influence E_s over periods of 1 to 2 days. Thus, new sets of soil cores should be extracted at least once daily for an estimated 2 days after rain, and less frequently thereafter.

Sets of lysimeters extracted 2 and 4 days after irrigation in the millet plot had significantly different values for E_s . This is most likely the effect of root extraction of water depleting the soil profile and causing microlysimeters to be unrepresentative of the surrounding soil. Daily extraction of soil cores may need to continue for about 4 days after rain or irrigation in cropped soil.

The practice of adding water to an existing lysimeter after irrigation (Shawcroft and Gardner, 1983; Martin et al., 1985) is not advisable as drainage occurring in the soil profile can not be accounted for in a microlysimeter and evaporation may be over-estimated (Sadras et al., 1991).

Microlysimeter depth comparisons

Evaporation from 100 and 200 mm deep lysimeters in Niger is presented in Table 4. Analysis of variance showed that depth had no significant effect ($\alpha = 0.1$) on E_s or its log transformation during either Day 1 or 2 of use.

Figure 4 shows the mean cumulative evaporation from 100 and 200 mm deep microlysimeters in Hyderabad during periods beginning 24 January and 4 February. For a given date, an analysis of variance was used to test the significance of difference in mean values of both the cumulative evaporation since the start of the period and evaporation during the interval since the last measurement. No significant difference in cumulative evaporation from the

Table 4

Mean evaporation (mm) from microlysimeters 100 or 200 mm deep in Niger (three replications). The standard error for differences of means with data not transformed (see text) was 0.37 mm

Date	Lysimeter Depth	
	100 mm	200 mm
8 June	2.2	2.0
9 June ^a	2.9	3.5
10 June	0.5	0.6
13 June	2.5	2.3
16 June	3.6	3.9
18 June	0.6	0.8
19 June ^a	0.6	0.7
21 June	2.5	1.8
27 June	2.3	2.4
28 June ^a	1.5	1.5
4 July	1.2	1.4
5 July ^a	2.3	2.4
8 July	1.8	2.0
9 July ^a	1.4	1.6

^a Indicates soil cores used for this interval were also used in the preceding interval (i.e. the line above)

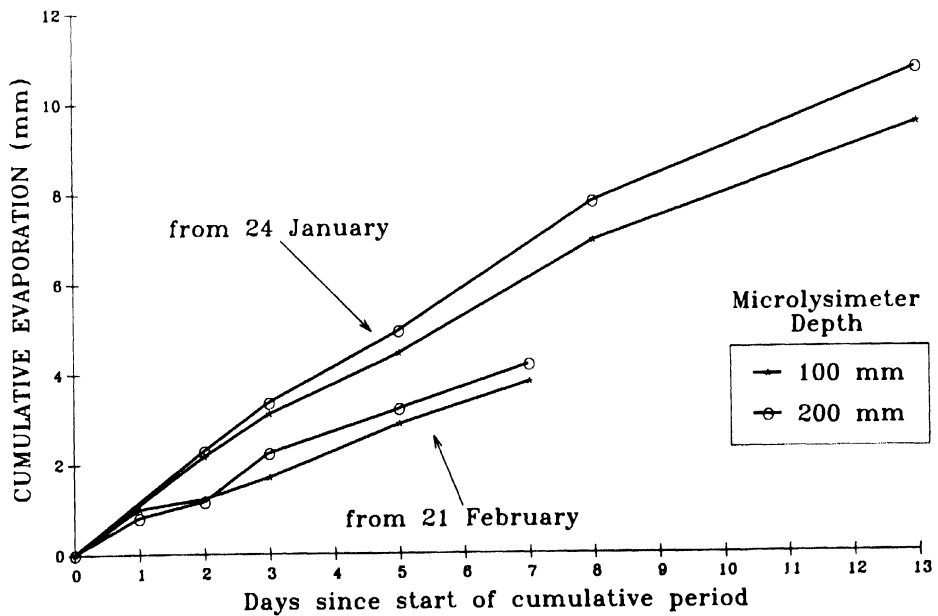


Fig. 4. Cumulative evaporation from 100 and 200 mm deep microlysimeters for two periods after irrigation at Hyderabad. Irrigation finished 20 January 1990, first set of cores extracted from soil profile on 22 January, second set of cores extracted 21 February.

microlysimeters 100 mm deep and 200 mm deep occurred at any time during the two periods considered. For the first cumulative period, the differences in E_s for the intervals between 5 and 8 days and 8 and 13 days were almost significant at $P = 0.05$ and significant at $P = 0.01$ respectively. (Note that the soil cores were extracted from the profile two days before the start of this period, but 2 days after irrigation had ceased.) In the second cumulative period no significant differences in E_s from the two depth microlysimeters were observed for any interval.

Boast and Robertson (1982) assessed the performance of short lysimeters (44 and 70 mm deep) by comparison with deeper lysimeters (106 and 146 mm deep) assuming that the deeper lysimeters remained representative of 'field behaviour' for a longer period. They found that a 0.5 mm decrease in mean cumulative E_s from the 70 mm lysimeters relative to the mean cumulative E_s from 106 and 146 mm lysimeters occurred between 1.4 ± 0.8 and 4.0 ± 2.0 days, depending on initial soil water content and evaporative demand. Our results (Fig. 4) suggest that 100 mm deep microlysimeters can be used for periods of 7 days provided they have been extracted from a bare soil profile 2 or more days after rain. As discussed earlier (Table 3) useable lifetimes of 1 day are required immediately following rain.

The results so far indicate that the main source of error in E_s measurement using the microlysimeter method on bare soil is the boundary to water flow imposed at the base of the microlysimeter (depth = z_{base}) at the time of soil core extraction. This can act as a boundary to drainage, or to upward flux of water, i.e. z_{base} is the depth of an imposed zero flux plane. If the actual zero flux plane in a bare soil profile is at a different depth such that significant water fluxes occur at depth z_{base} , then differences in E_s would be expected to occur between lysimeter and the bulk soil. Differences in E_s recorded from microlysimeters 100 mm and 200 mm deep would also be expected to occur, but are not observed.

Internal drainage experiments in Niger (Hartmann and Gandah, 1982; Payne et al., 1991) indicate that more than 80% of the drainage from the top 200 mm of the profile occurs in the first 2 days. The added effect of evaporation at the soil surface would be expected to cause the zero flux plane to reach 100 mm or deeper. For these sandy soils it is reasonable to assume that drainage at 100 mm (and 200 mm) will no longer be significant if soil cores are extracted 2 or more days after irrigation or rainfall.

In Niger, Payne et al. (1990) found that the zero flux boundary in bare soil plots was located between 0 and 250 mm for most of the 1985 growing season and their data indicate it was often at 100 mm. In Hyderabad on a fallow soil, Simmonds and Williams (1989) showed that the zero flux plane had only reached 300 mm after 36 days of drying. Thus, upward flux of water at 200 mm is not likely to be large because the depth of soil contributing to E_s will seldom be greater than 200 mm in these sandy soils during a rainy season.

Figure 1 also indicates that when upward flow of water is exaggerated by maintaining zero suction at approximately 250 mm, the effects of the boundary at the base of the microlysimeter ($z_{\text{base}} = 100$ mm) were insignificant for 3 days. It therefore seems reasonable that any upward flux of water at 100 or 200 mm may not influence evaporation significantly for a cumulative period of up to 7 days provided measurement started 2 or more days after rain. The length of this period may change with soil type and may not be applicable after 1 month or more without rain.

In a cropped soil, soil water contents and the zero flux plane will be lowered by root extraction. The extraction of water from the profile is expected to prevent significant upward fluxes in the soil at the level of the bare soil zero flux plane and at depth z_{base} in these sandy soils. Therefore the above argument is still applicable. However, root extraction of water will not occur within the microlysimeter (as discussed earlier), and this may necessitate daily renewal of soil cores for about 4 days after rain.

A Protocol for use of microlysimeters in sandy soils

The results presented above combined with our field experience of the method allow the following list of recommendations for use of microlysimeters on sandy soils to be drawn up.

The ideal renewal schedule would involve: (1) extraction of cores from the soil profile immediately after rain, and renewal of these cores within 12 h; (2) then daily renewal until root extraction of water from the soil to the lysimeter depth becomes insignificant (in the order of 4 days after rain); (3) thereafter, infrequent renewal (every 7 days) is all that is required. During a rainy season the next rain will most probably intervene and the schedule can begin again.

Lysimeters and liners should be constructed of PVC pipe with internal diameter ≥ 50 mm, and length ≥ 100 mm.

Waterproof tape and a metal base plate should be used to seal the base of the lysimeter which should fit tightly into a positioned liner tube and be seated directly on the soil at the bottom of the liner.

A portable balance that can determine weight loss to an accuracy better than the loss of 0.1 mm of water to evaporation, should be used.

A level pad should be installed at the field site for the balance with a box for protection against wind during measurement.

Conclusions

The microlysimeter method can provide a simple and accurate measurement of evaporation from sandy soils. In sandy soils the main sources of error that need to be considered when using microlysimeters are: (1) the root extraction of water from the lysimeter; (2) the impedance of drainage at the

base of the lysimeter following rain. However, the above protocol allows these problems to be largely overcome.

Accounting for variability in evaporation may become the most important consideration and this may be facilitated by using the smallest diameter lysimeters. Smaller diameters may allow soil cores to be renewed more quickly and easily with minimal disruption of the crop and plot. A soil core extraction device could perhaps be used, eliminating the need for lysimeter excavation. Small diameter lysimeters may necessitate more replication, but will allow more detailed studies of soil evaporation across crop rows.

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