COLLECTION AND EVALUATION OF LARGE SOIL MONOLITHS FOR SOIL AND CROP STUDIES

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(WITH FOUR PLATES)

Summary

A technique is described which allows collection and transportation of undisturbed soil monoliths in glass fibre casings 80 cm in diameter and 135 cm deep. The technique has been used to obtain 150 monoliths from a range of soil types in England and Wales, including soils with compact or chalky horizons.

Measurements from lysimeters containing a non-swelling sandy loam and a swelling clay showed that the hydraulic properties of both soils were not affected by encasement of the profiles, provided that supplementary drainage outlets at the depth of field mole drains were provided in the lysimeters containing the clay soil. Aeration of the clay monoliths was comparable with that of the same soil in the field.

When winter wheat plants growing on the lysimeters were surrounded by a similar guard crop, yields were equivalent to those obtained in the field. Edge effects were not significant; plants grown adjacent to the lysimeter wall yielded the same weight of grain per unit soil area as those in the central area of the monolith.

Introduction

FOR many soil and plant studies, traditional field experiments are inappropriate in that experimental variables cannot be adequately controlled or measured. In planning work at the Agricultural Research Council Letcombe Laboratory, these limitations were apparent for two areas of study:

(i) the response of field crops to short-term waterlogging (in collaboration with the Field Drainage Experimental Unit of the Ministry of Agriculture, Fisheries and Food); this work requires control of water-tables;

(ii) the fate of nitrogen fertilizer applied to crops and grass; here a knowledge of leaching losses of nitrogen is required.

For both projects it was considered that encased soil columns would enable the experimental requirements to be met.

The importance of using undisturbed soil profiles in lysimeter studies has long been recognised (Kohnke *et al.*, 1940). Lysimeters filled with disturbed soil are simple to install, but there is evidence that the physical and chemical properties (particularly water and solute movement) of a disturbed soil differ from the properties of the undisturbed profile (Flodquist, 1936; Cassel *et al.*, 1974; Shaykewich, 1970). Also a change in moisture regime will affect aeration, and thus the mineralization and denitrification of soil nitrogen, particularly in fine-textured soils. Extrapolation of results from infilled lysimeters to the field would be unreliable.

A technique was thus required to allow both the collection of soil monoliths from a range of soil types in sufficiently large numbers for replicated experimental

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work, and the subsequent transportation of these monoliths to a central location to simplify the management of experiments.

The lysimeters were required to have sufficient surface area (0.5 m^2 was judged to be a minimum size) to establish a good experimental plant population and to minimize edge effects; for this purpose a circular cross section provided a more favourable ratio of surface area to edge length than other shapes of container. It was desirable to use corrosion-free plastic rather than steel for the lysimeter casing, both for ease of maintenance, and the reduction of abnormal heat flux and temperature gradients in the lysimeter soil resulting from heat conduction in steel (Black *et al.*, 1968). The monoliths were required to be as deep as effective root penetration of common arable crops, i.e. 100–150 cm (Russell, 1973). Water movement in, and drainage from the monoliths was to be similar to that in the field sites from which they were collected.

Many techniques for collecting monolith lysimeters have been described. Those for the creation of large in-situ monoliths, with or without weighing facilities (Harrold and Dreibelbis, 1958; Armijo *et al.*, 1972) were inappropriate because of the problems of transportation. A procedure described by Brown *et al.*, (1974) allowed the collection and subsequent movement of monoliths up to 200 x 150 x 150 cm deep, but would be expensive if replicate samples were required, and also difficult to apply in areas with small moisture deficits because of the poor trafficability of field sites for heavy equipment. Similar problems would arise with other techniques (Tackett *et al.*, 1965; Hiler, 1969) in which steel tubes up to 100 cm diameter and 275 cm deep have been driven into soil profiles by heavy weights. Much simpler techniques have been described for obtaining small monoliths lysimeters in casings up to 50 cm diameter (0.2 m^2 surface area) using both steel (Low and Armitage, 1970; Hudson, 1974; Watson and Lees, 1975) and plastic casings (Overrein, 1968; Wijnsma, 1975). Monoliths of up to 40 cm have also been prepared by isolating soil columns which were then wrapped in glass fibre and impregnated with polyester resin (Homeyer *et al.*, 1973). This procedure is best applied in well structured soils and would not be suitable in weakly structured soils with high water tables which are prone to slumping and collapse.

The technique described below was therefore developed from that of Wijnsma (1975), to obtain lysimeters of intermediate size with simple equipment, and at reasonable cost.

Methods

Collection of the soil monoliths

The lysimeter casing (80 cm o.d., 78.8 cm i.d., 135 cm long) is made of glass-fibre reinforced polyester, with a coating of inert epoxy resin on the inner surface of the cylinder to prevent diffusion of hydrocarbons from the polyester into the enclosed soil column. A glass-fibre casing was preferred to PVC because of its greater strength and durability; costs were similar.

The casing is placed on the soil surface, standing in a steel cutting ring which has the same internal diameter as the casing. The ring has a chamfered cutting edge, so that compression of the soil occurs to the outside of the ring, away from the soil monolith. The casing is pushed into the soil by a hand-operated 10-tonne hydraulic ram, mounted on a pressure plate on top of the casing. The ram reacts against a beam which is pinned to vertical bars, sliding on horizontal steel tubes anchored to the ground at each end by 200 cm long augers (Plate 1). With the ram fully extended (15 cm), pressure is released and the beam repositioned 15 cm lower on the vertical bars. This process is repeated until the cylinder is fully inserted, with 4 cm of the casing protruding above the soil surface.

It is important that the casing remains vertical at all times, both to avoid causing unnatural fractures within the soil profile, and to simplify the subsequent removal of monolith and casing. The beam and bar assembly allows close control over the attitude of the casing. For the same purpose, it is important to hand-excavate soil from around the casing and the cutting ring. This operation also helps to reduce the force required to push the casing into the soil.

The monolith is removed by lowering a steel frame over the casing. This frame displaces the cutting ring from the lower edge of the casing and guides a square steel cutting plate which is pushed between the lower edge of the casing and the cutting ring by the hydraulic ram (see Plate 2). The cutting plate cuts off and prevents loss of soil from the monolith, and acts as a temporary base during transport. After fitting steel rods between the frame and a steel lifting ring on top of the lysimeter, the lysimeter can be lifted from the pit by a tractor fitted with hydraulic lifting equipment. The frame is unbolted from around the casing. The lysimeter can then be secured for handling and transport by first filling the space between the monolith soil surface and the top of the casing with wooden discs of similar internal diameter to the casing, and then bolting a top plate (fitted with lifting eyebolts) to the cutting plate with steel rods.

When collecting more than one lysimeter at the same site, one auger on each side of the lysimeter position is left in place, and the other two repositioned so that the next casing can be placed 120 cm from the first. Proceeding in this way, five people can collect between two and four monoliths per day whilst working along the collection 'trench'. The slower rates of collection occur on soils of heavy texture, or those containing compacted horizons or an appreciable quantity of stones. The weight of a filled lysimeter is approximately 1400 kg.

Preparation of lysimeters for experimental work

After transport to the required site, the complete lysimeter is inverted gently using the tractor. The steel cutting plate can then be unbolted.

Before fitting the permanent base, modification of the subsoil may be necessary to provide moisture tension and allow natural water movement at the base of the soil column; a sealed base would remove the tension normally exerted by the underlying soil (van Bavel, 1961). In deep, free-draining sandy, silty and chalky soils the required tension can be applied using ceramic candles, which are installed either directly into the subsoil, or in a matrix of silica sand (e.g. British Industrial sand HPF 5, 55–75 μm) in contact with the subsoil. In soils with very low hydraulic conductivity, or where a water table is maintained in the lower 20–30 cm of the profile, no tension drainage is required; it is necessary only to replace 5 cm of subsoil by a similar depth of 6 mm gravel. Drainage holes are cut in the lower edge of the casing. A permanent steel base, coated on the inside with epoxy resin to prevent rusting, and having a single drainage outlet, is bolted in place before re-inversion of the lysimeter. The annular space between the steel base and the glass-fibre casing is filled with gravel, and sealed by underwater grade epoxy resin putty (Quentsplass 600 20A/B).

For the insertion of instruments (e.g. thermistors, tensiometers and gas sampling probes) and provision of additional drainage outlets, holes are cut in the casing using an electric drill and hole saws. Later, the holes are either covered with aluminium plates, or filled with the original disc of glass-fibre; sealing is effected by epoxy resin.

The completed lysimeters are craned to their final positions, using a lifting plate which is hooked to the base by steel rods. Plate 3 shows details of the base, and the lifting operation.

Equipment and materials used in the lysimeter collection operation are summarized in Appendix 1.

Results and discussion

Collection of monoliths from a non-swelling soil

Thirty-two monoliths of a Gley podzol (Skipwith series sandy loam) were collected in 1973 for the waterlogging studies. This stone-free soil was chosen as it is typical of those affected by groundwater, but has a moderate hydraulic conductivity above impermeable clay at 120–150 cm.

Collection of monoliths was straightforward. Some problems were experienced whilst pushing the base plate under the monolith, as water seepage above the clay caused partial collapse of the walls of the trench and made working conditions difficult. Also, lifting and handling operations were difficult after rain; the structural weakness of the profile, particularly at the edge of the pit, made manoeuvering of the laden tractor hazardous. There was no measurable compression of the 135 cm profile in any of the lysimeters.

Infiltration of water into the monoliths in the lysimeters (using the lysimeter casing as an infiltrometer ring) compared well with field measurements of hydraulic conductivity obtained by an auger hole method (van Beers, 1970). The equilibrium infiltration rate (assumed equivalent to the limiting vertical hydraulic conductivity in the monolith) was 2.9 ± 0.4 metres/day; the lateral conductivity from field measurements was 2.4 ± 0.5 metres/day at 100 cm depth. Comparison of these figures is reasonable as the permeability of some similar weakly structured sandy soils in Romney Marsh has been shown as isotropic (Childs, *et al.*, 1957). Thus the hydraulic properties of the profile were not measurably affected by the collection operation.

Collection of monoliths from a swelling soil with a high clay content

The importance of drainage to facilitate water movement in heavy textured soils in the U.K. (Field Drainage Experimental Unit, 1973; Field Drainage Experimental Unit, 1974) led to the selection of a calcareous pelosol (Evesham series clay) for the waterlogging studies. Thirty-two monoliths of this soil were also required.

It is known from work on small diameter cores that lateral confinement of a swelling clay can reduce the percentage of large pores in the surface layers of the soil, and thus the infiltration capacity of the soil (Bridge *et al.*, 1970; Lal *et al.*, 1970). To avoid the possibility of this occurring in lysimeters it was intended to obtain monoliths when the soil was fully swollen. However, the poor trafficability of clay soils when wet would have precluded the use of heavy equipment. It was therefore decided to work during the summer months when site trafficability was good; the monoliths were collected from a strip of land 2 m wide which was wetted to above field capacity by trickle irrigation.

Application of the collection technique was largely trouble-free, as the mechanical strength of the clay prevented occurrence of the problems of profile instability which were experienced in the sandy loam. Difficulty was experienced with frequent fossil shells (10–15 cm in diameter) at depths greater than 90 cm, which had to be broken cleanly below the cutting ring to avoid disturbance of the soil profile. Trafficability of the site was reasonable except after rain, when even slow progress was only possible by using steel tracking for the tractor to run on.

Vertical compression of the clay profile inside the casings was observed in only 2 of the 32 monoliths, and in these was of the order of 2 cm in 135. There was no obvious compaction of the soil adjacent to the casing; this experience is similar to that reported by Tackett *et al.*, (1965) when collecting monoliths of a clay soil.

Drainage of the clay soil in lysimeters

The drainage of the free water under gravity in clay soils takes place through cracks, channels and large pores between soil peds, the distribution of such cracks causing high point-to-point variability in water movement (Talsma and van der Lelij, 1976). However, in massive clayey subsoils where there are few such cracks, the lateral movement of water within the cultivated layer (where the hydraulic conductivity is comparatively high) is of considerable importance in the drainage of the soil (Trafford and Rycroft, 1973). The impermeable casing of a lysimeter will inevitably modify such water movement. Ritchie *et al.* (1972) found an 8-fold reduction in the conductivity of water through a 73 cm diameter clay monolith lysimeter by comparison with field sites. They attributed this difference to the effect of the lysimeter wall in cutting off cracks through which much of the water movement would have taken place.

Thus, the rate of infiltration of water into the profile was determined in four of the monoliths, and also in the field adjacent to the lysimeter collection position. Using a 50 cm diameter single ring infiltrometer in the field, infiltration rates were very high (3.2 metres/day) and declined only slightly with time over a long period. Soil surrounding the ring gradually became wetter during this period, providing a clear demonstration of lateral water movement in the top soil. A double ring infiltrometer, consisting of two concentric steel rings of 60 cm and 90 cm diameters, was also used in the field (Massey, 1970). Five replicate tests showed a high initial infiltration rate, which declined exponentially; the infiltration rate after 6 hours was equivalent to 0.07 metres/day.

Infiltration on the lysimeters was tested by ponding water on top of the monoliths and measuring the quantity of water required to maintain a constant head. By contrast with the field site, a high initial infiltration rate declined very rapidly to 0.004 metres/day, presumably equivalent to the saturated hydraulic conductivity of the subsoil.

Effective drainage of clay soils in the field has been shown to depend mainly on closely spaced shallow drainage channels (usually created by mole ploughs or subsoilers working at about 50 cm depth) which transmit water to deeper and wider spaced permanent drains covered by permeable backfill, usually gravel (Trafford, 1975). Such a drainage system had been installed in the field from which the Evesham clay lysimeters were obtained. Additional drainage outlets to permit lateral water movement in the lysimeter soil were therefore provided in 9 lysimeters at 20 cm depth, and in 16 lysimeters at both 20 and 50 cm. The outlets consisted of 15 cm x 5 cm cavities lined with porous samplers through which water could

TABLE 1

Rate of fall of water table in an Evesham series clay soil, in lysimeters and in the field from which the lysimeters were collected

	Lysimeters			*Field*		
Depth (cm)	*No. of observations*	*Mean rate of fall cm/day*	*Range*	*No. of observations*	*Mean rate of fall cm/day*	*Range*
0–20	9	3.31	1.40–5.30	4	1.33	0.40–1.85
20–50	16	2.91	0.53–5.80	33	1.51	0.16–5.14

drain; they were evaluated by comparing the rate of fall of the water-table in the lysimeters (as measured by small dipwells in the centre of the lysimeter) with similar data derived from dipwell readings in the artificially drained field during rain-free periods. Results are summarized in Table 1, and demonstrate that the drainage rate in lysimeters using these secondary outlets was at least as good as that in the field.

All lysimeters were subsequently provided with five radial outlets at 50 cm depth, the cavities being lined by flexible perforated pipe (Wavincoil 50 mm PVC drainage pipe). In the winter and spring of the first experimental year following this work the mean total leachate from the lysimeters was 179 mm, of which 65 per cent drained from the outlets at 50 cm depth.

Aeration of the soils in lysimeters

The oxygen content of the soils used in the lysimeters has been studied over several years. Samples for analysis are withdrawn through porous bronze containers similar to those described by Dowdell *et al.* (1972), the containers being installed horizontally through the lysimeter casing at depths of 20, 50 and 80 cm. Oxygen concentrations of the samples are determined by gas chromatography (Smith and Dowdell, 1973).

It is generally recognized that the rate of gaseous diffusion within a soil is largely dependent on the air-filled porosity of the soil (Russell, 1973). Thus in the non-swelling soil, in which porosity was high and the pores dimensionally stable, oxygen concentrations were little affected during the winter months (Fig. 1). In the clay soil, however, the decline in oxygen concentration during the winter (Fig. 1) reflects a reduction in air-filled porosity because of the slow swelling of the clay profile, and consequently, a lower rate of gaseous diffusion of atmospheric oxygen into the wet soil. Oxygen concentrations increased to near atmospheric levels after the end of April as moisture extraction by the wheat crop caused the clay to shrink. The pattern of oxygen depletion and subsequent increase in these Evesham clay monoliths closely follows that observed under wheat in the field from which the lysimeters were collected (Dowdell *et al.*, 1979).

Crop growth in lysimeters

Plant growth in lysimeters may not be typical of growth in comparable field sites for several reasons. Normal root proliferation may be restricted by the lysimeter

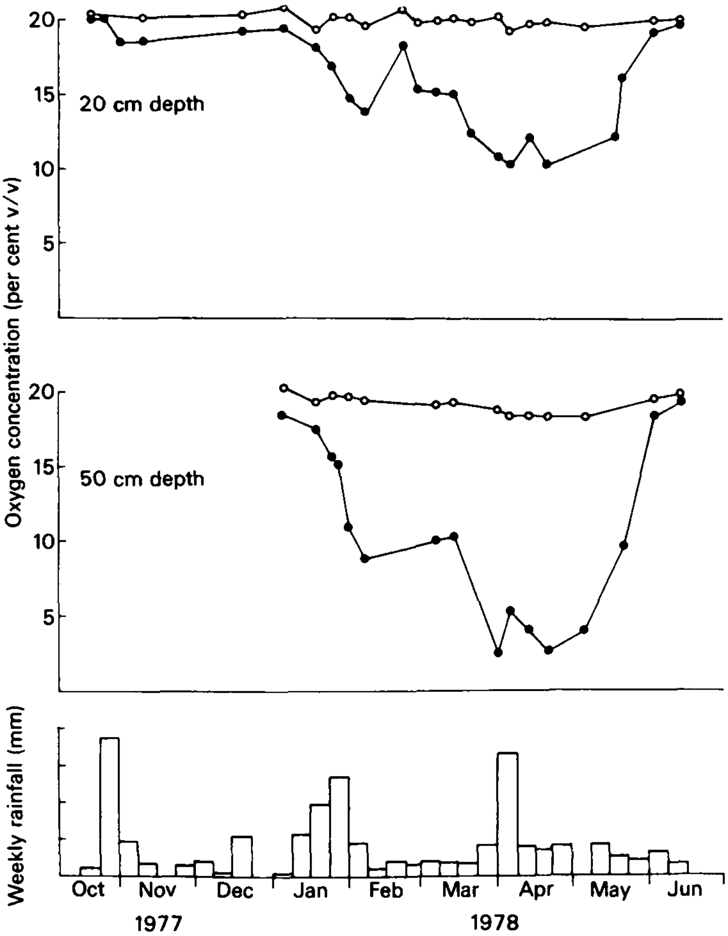

FIG. 1. Concentrations of oxygen in the soil atmosphere in lysimeters containing Skipwith series sandy loam (o–o) and Evesham series clay (●–●). Each point is the mean of 4 replicate values.

wall; abnormal aeration, temperature and moisture conditions may develop adjacent to the casing; and the transpiration of the outermost plants may be higher than normal if the lysimeter is isolated from cropped areas (van Bavel, 1961; Hudson, 1967). These effects are difficult to quantify. They were minimized as far as possible by using the largest diameter lysimeters that were practicable, by burying the lysimeters (see Plate 3) to ensure that soil temperatures were comparable with those in field situations, and by surrounding the lysimeter crop with a similar guard crop.

Winter wheat (cv. Cappelle Desprez) was sown in the Skipwith series lysimeters in 1974. Seeds were sown in 5 concentric rows, 8 cm apart, using an aluminium template (Plate 4). Seed spacing in all rows was 3.1 cm, giving potential plant populations which were slightly higher on inner and outer rows than in the central rows. Each row was harvested separately; results appear in Table 2.

TABLE 2

Yield components of winter wheat cv Cappelle Desprez grown in lysimeters containing a Skipwith series sandy loam soil. The seeds were sown in five concentric rows

	Plant populations			*Harvest data*		
	Seeds sown					
	Per row	*Per m²*	*Plants emerged %*	*Fertile shoots per m²*	*Grain yield per m²*	*Straw yield per m²*
Outer row[1]	72	433	80	467	641	827
Central rows[2]	40	398	80	442	644	813
Inner row[3]	8	424	87	434	634	794
Mean		411	81	454	641	812
LSD $P < 0.05$				38.6	70.9	68.3

[1] Adjacent to lysimeter casing.

[2] Mean of 3 central rows, in which 56, 40 and 24 seeds are sown. There were no significant differences between the 3 rows for fertile shoot populations, grain and straw yields per m².

[3] Adjacent to aluminium access tube for neutron probe.

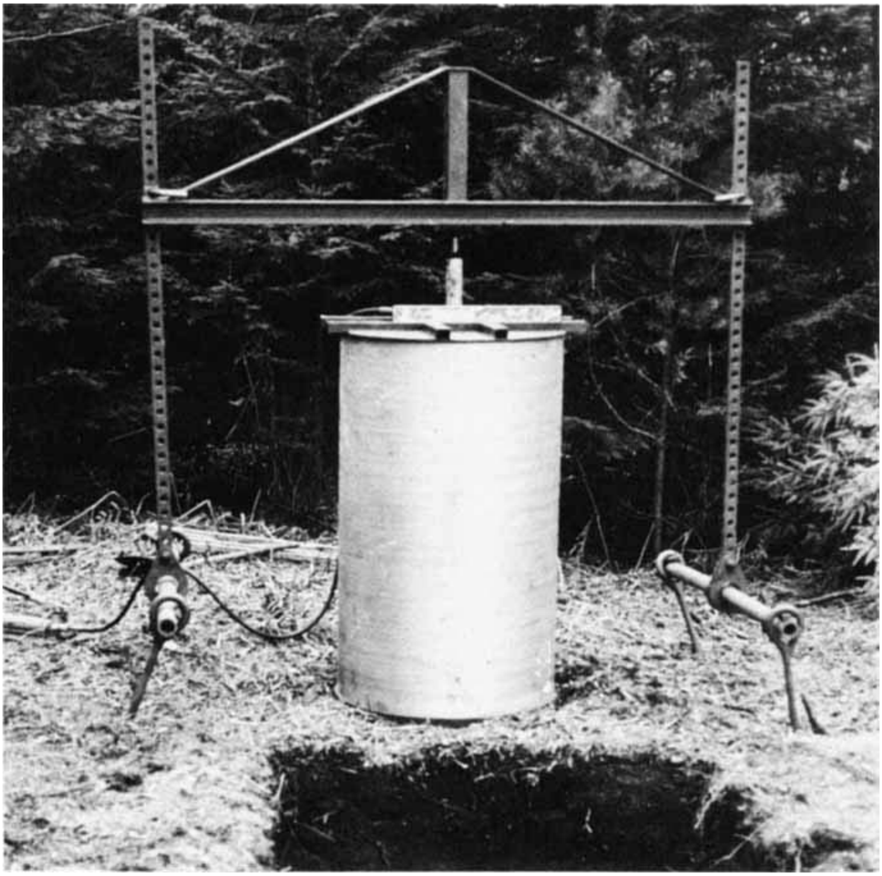

PLATE 1. *Monolith cutting equipment at start of operation.* The attitude of the cylinder is checked by a spirit level on top of the pressure plate. The hand pump to operate the hydraulic ram can be seen on the left of the picture.

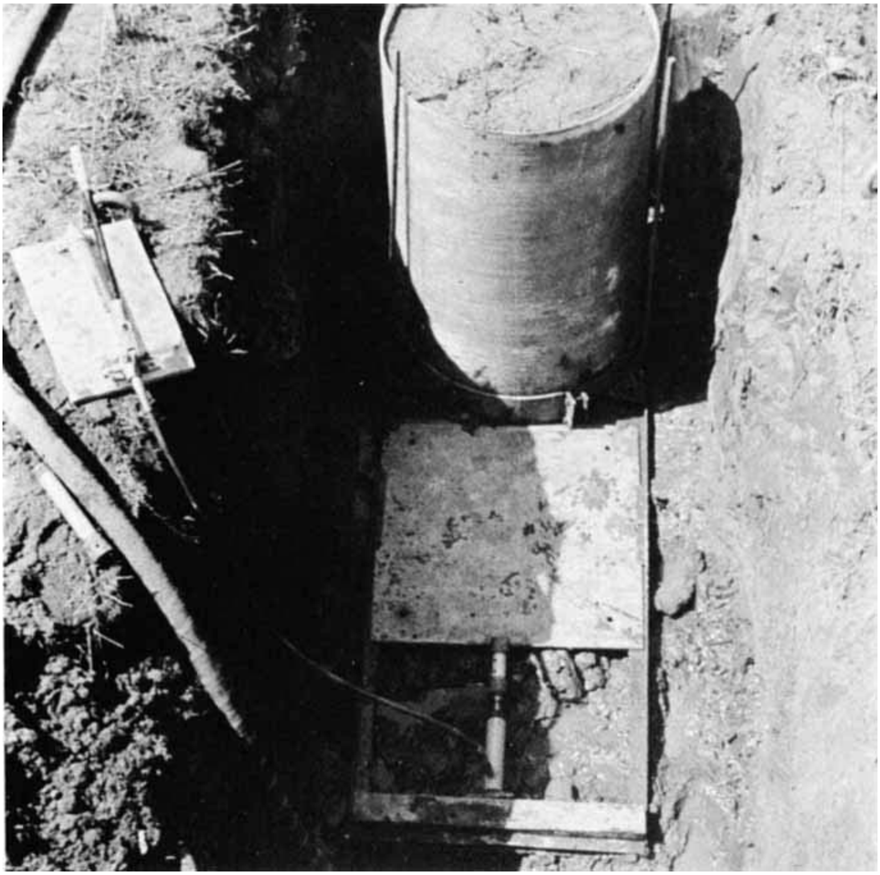

PLATE 2. *Insertion of the steel cutting plate under the lysimeter casing.*

PLATE 3. *Installation of a complete lysimeter.* The permanent steel base, with a drainage outlet and the hooks for lifting, can be seen. The pipes at 50 cm depth are connected to supplementary drainage outlets in the clay monoliths (see text).

PLATE 4. *Aluminium template used to sow 5 concentric rows of cereal seeds on a lysimeter.* This plate can be adapted for a range of seed sizes and spacings.

There was no significant differences between the rows for fertile shoot numbers, grain and straw yields when expressed per unit area of soil surface. This reflects both the lack of any appreciable edge effects due to the lysimeter casing, and also the stability of winter wheat grain yields over the narrow range of plant populations which existed. Grain yields for the whole lysimeter were comparable to those in good commercial practice, being equivalent to a mean of 6.5 tonnes/ha for the 32 lysimeters.

In 1975/76, winter wheat (cv. Maris Huntsman) was sown on both the Skipwith series sandy loam and Evesham series clay lysimeters. Sowing rate was the same as in the previous year. The outer row of plants was harvested separately. Shrinkage of the clay soil away from the lysimeter wall in summer had no effect on subsequent plant development or yield; the outer row of plants which occupied 33 per cent of the lysimeter surface area produced 33 per cent of the yield of fertile shoots, grain and straw.

Use of the monolith collection technique on other soil types

Since the collection of the initial lysimeters on sandy loam and clay soils as described above, the equipment has been used satisfactorily by this Laboratory and other Institutes. Soil groups (after Avery, 1973) from which lysimeters have been collected in England and Wales include a stagnohumic gley soil (Ynys series, peat over silt loam); stagnogley soil (Salop series, silty clay loam); podzol (Southampton series, loamy sand over sand); browth earth (Frilsham series, sandy loam over chalk); and rendzina (Andover series, silt loam over chalk).

In the absence of a water-table, the main problem was usually that of interference by stones, particularly flints. Where these were small, and occurred within cultivation depth (as in the Andover series), the flints could normally be re-orientated so that movement of the cutting ring was unobstructed. Larger and deeper flints (Frilsham series) caused long delays, when breaking, trimming and sometimes replacement of these flints was necessary. Similar problems arose on the Southampton series profile where discontinuous bands of iron-cemented sand were encountered at varying depths.

The fragile structure of the Upper chalk in the Andover series soil also dictated slow and careful progress. It was important to carry out minimal excavation in front of the cutting ring to avoid creating unnatural fractures within the monolith.

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Appendix

The major items of equipment needed to collect 80 cm diameter and up to 135 cm deep soil monoliths are listed. Most of the equipment can be made up from mild steel by engineering firms. Specialized items are indicated by an asterisk. Further details and drawings of the equipment are available from the author.

Items shown in Plate 1.
*Lysimeter casing (from Redland Pipes Ltd., Poole, Dorset, England).
Cutting ring
Pressure Plate (above casing)
*Hydraulic equipment (Enerpac 10-tonne ram, pump and attachments, from Smail, Sons & Co., Ltd., London SE 24, England).
Beam (above ram)
Vertical bars, pins and locating assemblies (2 sets).
Horizontal steel tubes (2)
Ground augers, 2 m long (4)
Also required: Long-handled spades (from Eijkelkamp B. V., Lathum, Holland).
Items shown in Plate 2.
Cutting frame
4 steel rods to tie cutting frame to a lifting ring
Square cutting plate
Also required, but not shown:
Top plate with eyebolts
Steel rods to tie cutting plate to top plate for handling and transport (4)
Items shown in Plate 3.
*Lifting ring (for U.K. use, this component requires a lifting equipment test certificate – Factories Act 1961)
*Lifting chain sling (also requires a lifting certificate, and is available from Holt Williams, Reading, England)
Hooked steel rods (4)
Lysimeter base, with a drainage outlet, and hooks to receive rods.

If lysimeters are required to be of greater diameter or deeper than those described, hydraulic equipment with a higher capacity than 10 tonnes would be necessary to push the casing into the soil. As many of the steel components listed in this appendix are suitable only for 10-tonnes loading, the collection of larger lysimeters would be possible only with redesigned and heavier equipment.