ROTHAMSTED RESEARCH

The Brimstone Farm Experiment

1: Introduction to the Site and the Experiment

Rothamsted Research

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1. INTRODUCTION TO THE SITE AND THE EXPERIMENT

Brimstone Farm was established as an experimental site in 1978 and has become one of the UK's best facilities for field leaching studies. Based on a series of hydrologically isolated plot lysimeters, which are large enough for normal agricultural operations to be undertaken, it has achieved international acclaim for its work on water transport, nitrate and pesticide residue leaching.

The first phase of the experiment (1978-88) investigated the effects of drainage on crops established by direct drilling or after ploughing; losses of nitrogen in the field drainage system and the effects of ploughing and direct drilling on water losses and catchment hydrology were also studied.

In Phase II (1988-93) various crop management strategies for minimising losses of nitrate and pesticide residues were studied, and the data used to validate models of water, nitrate and pesticide movement in clay soils; the effects of different drainage systems on removal of water and losses of agrochemicals were also investigated.

In the current phase (Phase III, 1993-97) the effects of drainflow restrictors on the leaching of nitrate, nitrite, phosphate and pesticides are being assessed.

1.1 BACKGROUND TO PHASE I

Clay soils provide some 45% of the cereal-growing land in England and Wales, but they are slowly permeable (< 0.1 m/day) and require artificial drainage. On ploughed clay land the preferred drainage treatment has been mole drains at 2 m spacing to maintain the water table at about 0.5 m depth within 24 hr of the cessation of rainfall (Trafford and Oliphant 1977).

During the early 1970s farmers were encouraged to adopt direct drilling and other minimal tillage systems on clay soils, because they decreased input costs and helped avoid soil structural damage (compaction in wet seasons and cloddy seedbeds in dry autumns) resulting from ill-timed seedbed preparation by conventional methods. Work at the ARC Letcombe Laboratory and elsewhere had shown that, with good management, similar crop yields could be achieved on clayey arable soils whatever the cultivation regime. However, the effect of minimal tillage on drainage was unknown. Goss *et al*. (1984) reported that the water table is often closer to the surface of direct drilled than ploughed soils, and that the mole drains deteriorate more rapidly, so it seemed that direct drilled soils needed a more intensive drainage system.

Despite the absence of direct supporting evidence, improved field drainage was often cited as the cause of frequent flooding and of increasing nitrate concentrations in surface waters. The Brimstone Farm Experiment was designed to examine these allegations.

1.1.2 Principal objectives

1.1.2.1 To investigate the effects of drainage in a clay soil on crops established by direct drilling and after ploughing.

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1.1.2.2 To measure the loss of nitrogen by a field drainage system.

1.1.2.3 To investigate the relative amounts of rainfall lost by surface flow, interflow (movement in the cultivated layer of the soil) and drainflow (through a mole and pipe drainage system), and the effects on catchment hydrology.

1.1.3 Site characteristics

To examine these aspects the experimental site needed to be uniform, representative of UK clay lowland in terms of climate, soil and topography and gently sloping for reliability of hydrological monitoring. After an 18 month search for a suitable site, which involved uniformity trials at four possible locations, the experimental facility at Brimstone Farm (National Grid Reference SU 248946) on the National Trust's Coleshill Estate near Faringdon, Oxfordshire, was established jointly by ADAS Field Drainage Experimental Unit and the then ARC Letcombe Laboratory. With the closure of Letcombe Laboratory in 1985, their responsibility was transferred to Rothamsted Experimental Station.

Throughout the experiment the responsibilities have been:
ADAS: Supervision and installation of all drainage and hydrological equipment; collection of hydrological data.
Letcombe and Rothamsted: Agronomy; measurement of plant growth and soil physical conditions; nitrate concentrations in the drainage water.

In Phase III the emphasis is on work on pesticide leaching and nutrient losses.

The experimental site is on a heavy clay of the Denchworth series derived from Upper Jurassic Oxford Clay. In the top 0.2 m of the profile the soil contains 54% clay (< 2 μm), 39% silt (2-60 μm) and 7% sand (> 60 μm). An initial auger survey, soil cores collected on a grid pattern between the proposed plot areas and five soil pits (Cannell *et al*. 1984) all demonstrated good soil uniformity across the site. The altitude is 100-106 m O.D. and the slope is approximately 2% (Fig. 1). Relief was surveyed on a 20 m x 10 m grid in 1979. The mean annual rainfall is 680 mm.

The records of earlier drainage systems were not found before deciding the plot layout. Exploratory trenching identified numerous clay pipe drains of different layouts and careful recording later established the existence of three systems within the experimental area and five within the whole field (Cannell *et al*. 1984). Initial recording in spring 1978 indicated reasonable uniformity in the depth to the water table.

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1.1.4 Experimental design

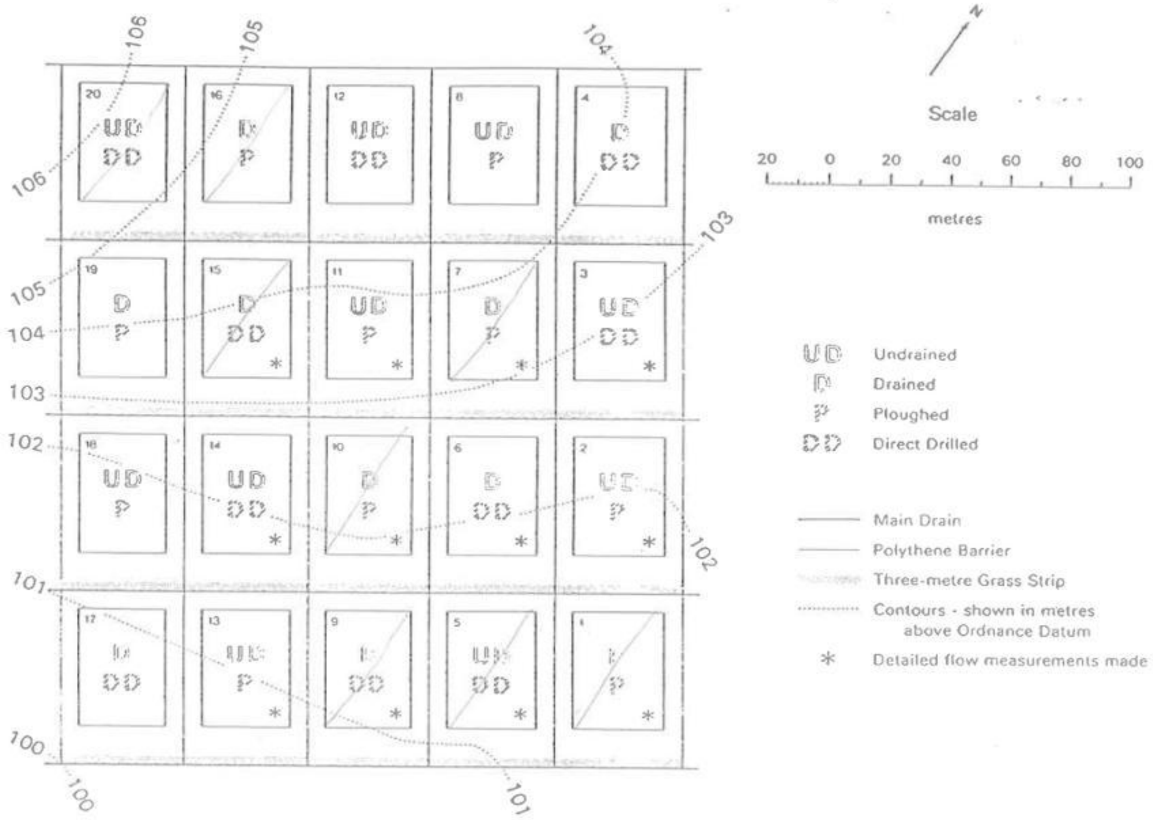

Fig. 1 Layout of plots, site topography, treatments and facilities for hydrological separation.

In Phase I there were four treatments, each replicated five times (Fig. 1), established in a 4 x 4 latin square (Plots 1-16) with a fifth block (Plots 17-20). The treatments were:

undrained, direct drilled (UD/DD)
undrained, ploughed to 0.2 m (UD/P)
drained, direct drilled (D/DD)
drained, ploughed (D/P).

There were thus ten drained and ten undrained plots. Direct drilling was a simplified system in which seeds were planted with minimum soil disturbance.

Each year crop residues were burnt and the ash incorporated with the least possible soil disturbance using the same discs or tines on all plots. From autumn 1984 the ash was incorporated within 36 hr.

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1.1.5 Plot isolation

Each plot is 59 m x 41 m (0.24 ha), but with discard margins around a central agronomic area of 40 m x 28 m (0.112 ha). In 1978 the whole experimental area was hydrologically isolated to 1.3 m depth around the site perimeter, and plots were isolated to 1.1 m depth using continuous polythene membrane placed in trenches extending up and down the slope in the discard areas between plots. The trenches were then refilled with soil. Experience on other clay sites had shown that water movement in clay soils is almost entirely in the top 1.0 m. Water moving downslope is prevented from reaching the next plot by pipe drains located at 1.0 m depth in trenches 0.1 m wide and filled to the surface with coarse gravel (Fig. 2). These interceptor trenches are separated from the marginal plot discard areas by 3 m wide grass strips. The polythene barriers and interceptor trenches together create what are in effect field plot lysimeters.

1.1.6 Plot drainage

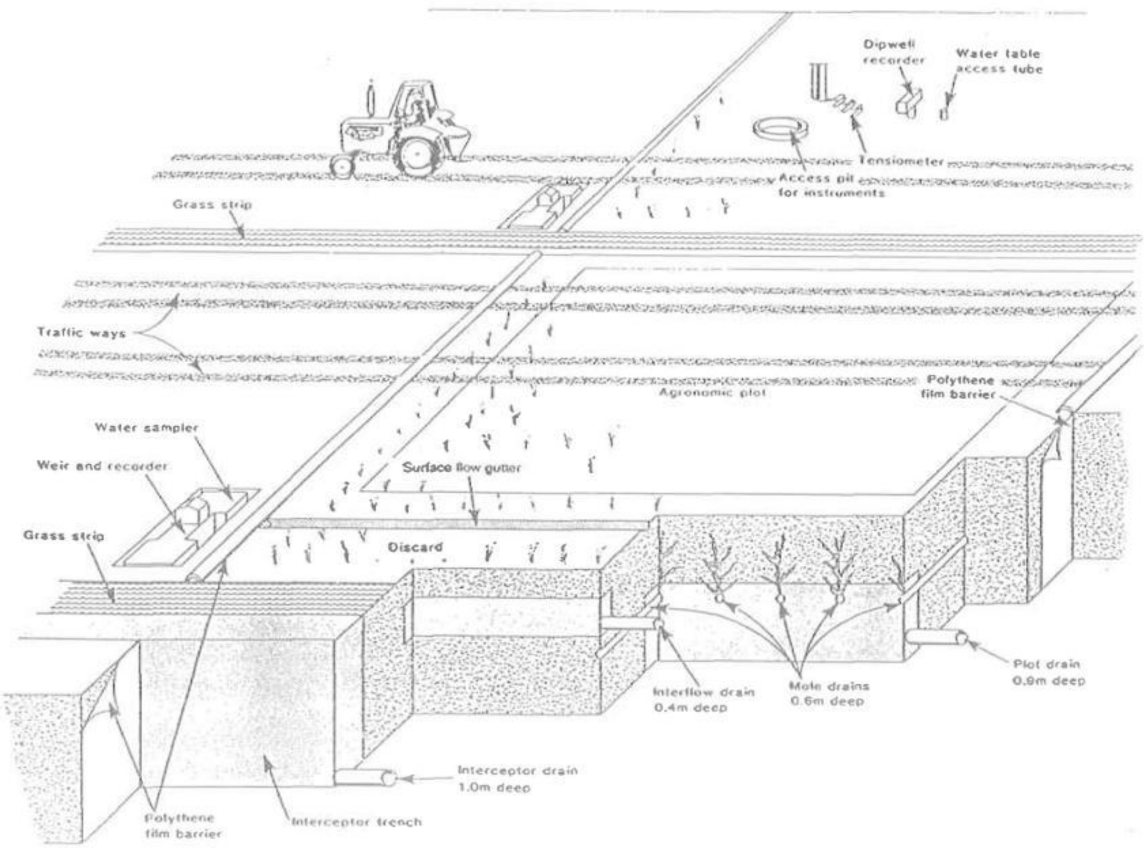

Fig. 2 Plot layout showing location of drainage and hydrological flow monitoring equipment.

The hydrologically monitored area covers the full plot width of 41 m, and extends 46 m downslope from the interceptor drain at the top of each plot. The remaining 13 m of each plot has no subsurface drainage (Fig. 3). The effective drainage on each of the ten

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drained plots was therefore a pipe drain 46 m downslope from the interceptor drain and at 0.9 m depth, covered with permeable backfill to connect with 19 mole channels 2 m apart and at 0.6 m depth. To intercept plough layer flow (interflow) a pipe drain was also installed at 0.35 depth in a polythene-lined trench and covered with permeable backfill. This was located 3 m downslope of the plot drain to allow for pull-out of the mole drains.

Originally a 0.1 m wide PVC gutter was laid across the plot 1.5 m downslope of the agronomic plot boundary to collect surface flow. However, difficulties with distortion of the PVC by frost heave, achieving a uniform level across the plot and movement of soil into the gutter prevented accurate measurement of flow. A second system of rectangular gutters in either galvanized metal or reinforced glass fibre with polythene sheeting laid under the soil upslope was more successful, but had to be removed for autumn cultivations. Eventually only 8 plots retained surface flow collectors across one third of the plot width.

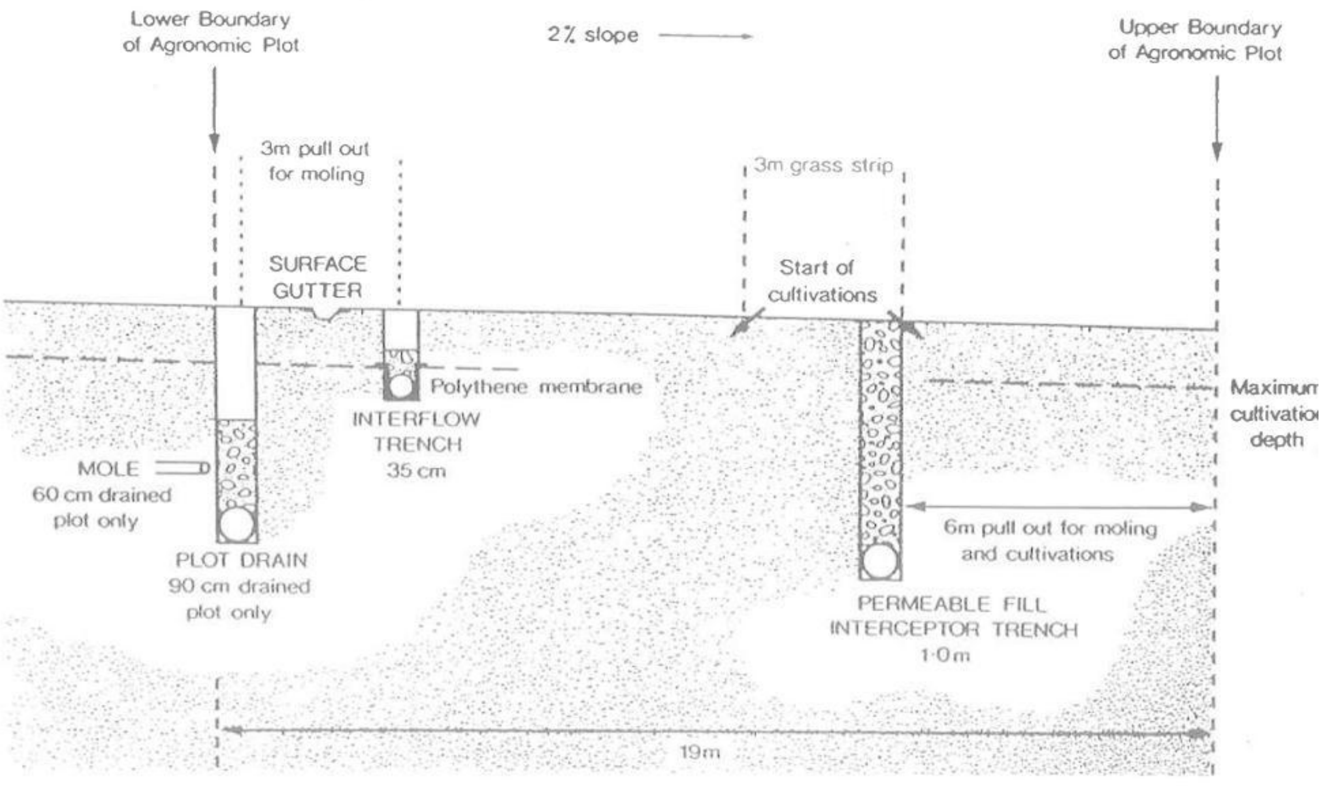

Fig. 3 Cross-section across plots showing collector systems and discard for machinery operations between drained Plots 6 and 7 (after Cannell et al. 1984).

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As lateral movement below the depth of the interflow collectors could not be measured on undrained plots without draining them, it was estimated from piezometers on undrained land outside the experimental area. Because of deep seepage observed below some of the plot isolation trenches, Plots 3, 7, 11 and 15 were further isolated to 1.8 m depth in 1984.

1.2 UNIFORMITY TRIALS

After installation of the mole drainage system on the drained plots in autumn 1978, all 20 plots were tine cultivated and sown to winter wheat to assess uniformity of the treatments. Over the winter no difference was observed in mean depth to the water table between the drainage treatments, and in 1979 crop growth and yield were similar on all plots.

Examination of soil profiles in summer 1979 showed the presence of a discontinuous cultivation pan. This limited soil water movement and caused a perched water table during rain. However, water movement to the drains was possible through the leg slot crack produced by mole draining. The pan was removed by shallow subsoiling across the plots in autumn 1979 and the uniformity trial repeated, all plots again being tine cultivated. Subsequent measurements showed that the pan had been successfully removed; the depth to the water table was increased by typically 0.2 m and crop yields reflected the improved soil aeration.

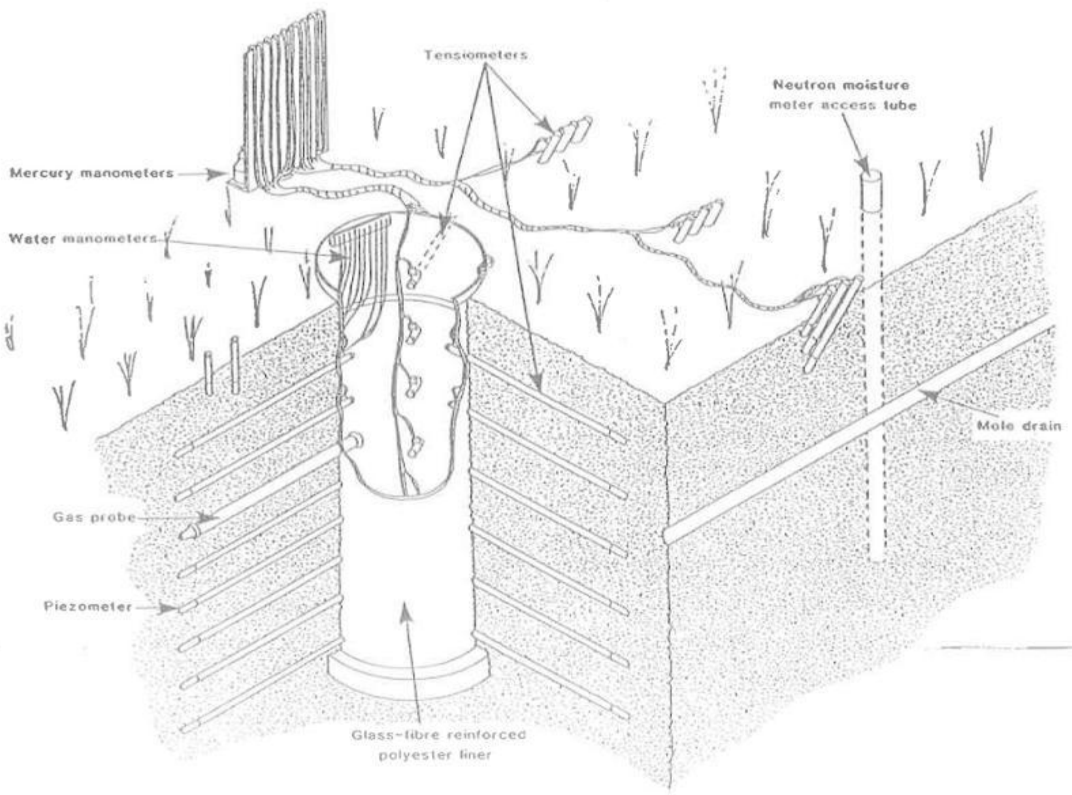

Fig. 4 Cut-away section showing soil properties instrumentation.

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1.3 MONITORING IN PHASE I

1.3.1 Crop growth

Combined yield and components of yield (grain and straw) were recorded every year from 1979 to 1988. In some years crop growth (roots and shoots) and uptake of nutrients were also measured.

1.3.2 Soil physical measurements

The intention was to measure short- and long-term changes in soil conditions associated with both the drainage and cultivation treatments and their influence on crop growth. The water balance of crops is determined from meteorological measurements, drainage losses, soil water content measured by calibrated neutron moisture meter and soil water potential measured by tensiometers. To avoid repeated disturbance of the plots, tensiometers and piezometers were permanently installed at 0.2 m intervals to a depth of 2 m through the walls of lined access pits (Fig. 4), which can be temporarily covered to permit soil cultivations (Howse and Goss 1982). Water table depth is measured by dipwells and autographic water table meters. Soil structure was assessed with particular reference to root growth by measurements of soil water characteristics and hydraulic conductivity. Soil strength was assessed in relation to slaking and trafficability by measurements of aggregate stability and cone penetrometer resistance.

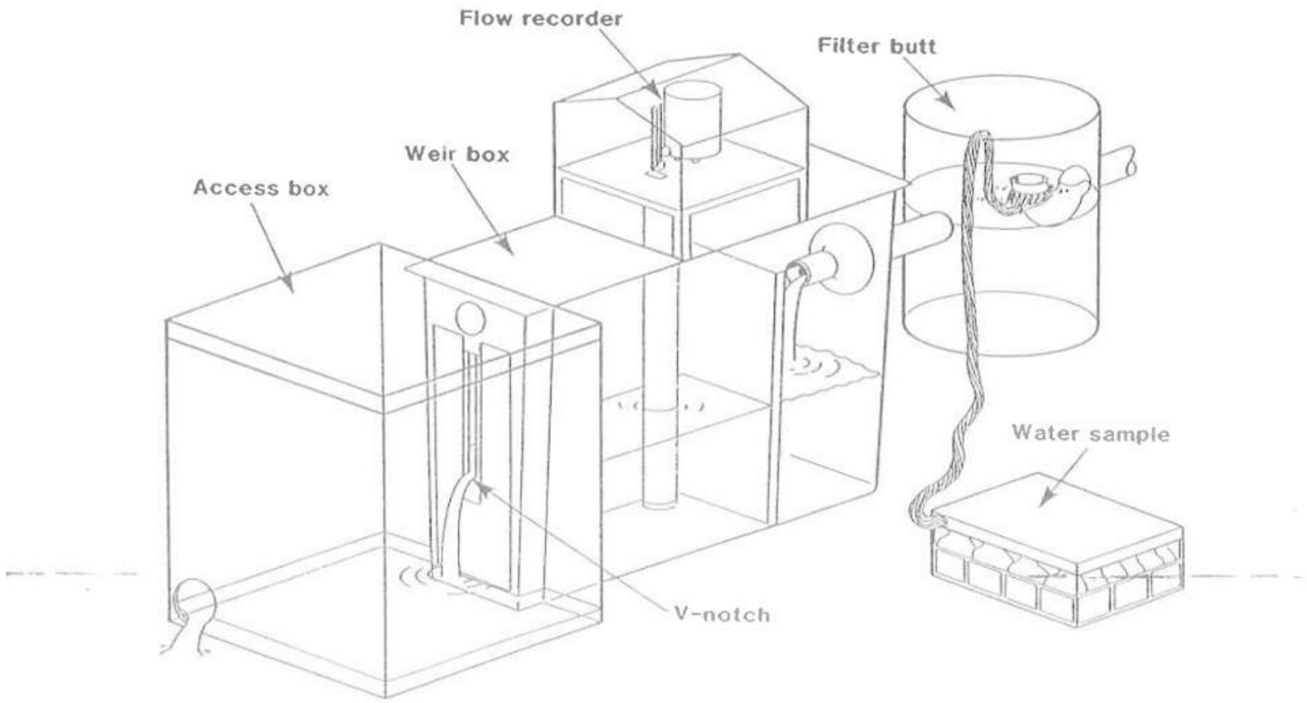

Fig. 5 Drainflow metering and water sampling equipment (after Harris et al. 1984).

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1.3.3 Meteorological measurements

A fully automatic weather station (AWS) was installed in 1979. Additional logged and autographic rainfall recorders at various positions in the field showed up to a 10% variation in rainfall, and so a second AWS was installed in 1983.

1.3.4 Drainflow rates

Water movement in surface flow and interflow (later combined into cultivated layer flow) and drainflow is measured using V-notch weirs (Fig. 5) with a flow range of 0 - 7.0 litre/sec (Talman 1980). The head level is recorded autographically using a float system linked to chart recorders and later also to potentiometers connected by buried cabling to a data logger housed in the site hut. In addition, in several years flow from paired mole channels was measured by tipping bucket recorders also linked to the site logger.

1.3.5 Losses of nutrients

Water samples are taken from a U-bend located in a filter bin immediately upstream of the V-notch weir (Fig. 5). In Phase I evacuated sample bottles were connected individually by rubber and polythene tubing to the U-bend, and a variable timer triggered sampling by releasing the vacuum at preset intervals. Since 1990 this sampling system has been progressively replaced by EPIC programmable samplers. In 1979-84 the usual sampling frequency was once every 24 hr, but it was increased to once every 3 hr from 1985 onwards. The water samples were originally analysed for nitrate, nitrite and ammonium, but nitrite and ammonium occurred in very small amounts and were later abandoned as they contributed little to the nitrogen balance. Nitrite measurements were resumed at the start of Phase III in autumn 1993.

Loss of nitrogen by denitrification was also measured in certain years by determining amounts of nitrous oxide after blocking further reduction to nitrogen gas with acetylene.

1.4 SITE CHANGES FOR PHASE II

As the Phase I experiment progressed it was evident that Brimstone Farm provided a valuable facility for further studies, so a new experiment was designed for the period 1988-93.

1.4.1 Principal objectives

1.4.1.1 To investigate alternative drainage systems, such as modifications to existing mole plough design to produce mole channels with different longevities, and to compare their effectiveness for removing excess water and the leaching of agrochemicals.

1.4.1.2 To develop soil and crop management strategies for minimising runoff of nitrate and pesticides.

1.4.1.3 To provide data to validate models of water, nitrate and pesticide movement.

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Table 1. Phase II, drainage and crop rotations for harvest years 1989-1991.

Secondary treatment Plot no.	1989	1990	1991
Moled conventional (4,18)	Winter oats	Winter wheat	Winter beans
Moled frequent (5,16)	Bare fallow/ Spring wheat	Winter barley	Forage rape/ Spring beans
Moled, large exp. (6,19)	Winter oats	Winter wheat	Winter wheat
Moled, no-expander (10,20)	Winter oats	Winter wheat	Winter wheat
Moled, wide space (17)	Winter oats	Winter barley	Winter wheat
Gravel moles (1,15)	Grass ley	Grass ley	Grass ley
Pipes (35 mm) (7,9)	White mustard/ Spring Wheat	Winter barley	Bare fallow/ Spring beans
Undrained control (14)	Spring oats	Winter wheat	Winter wheat

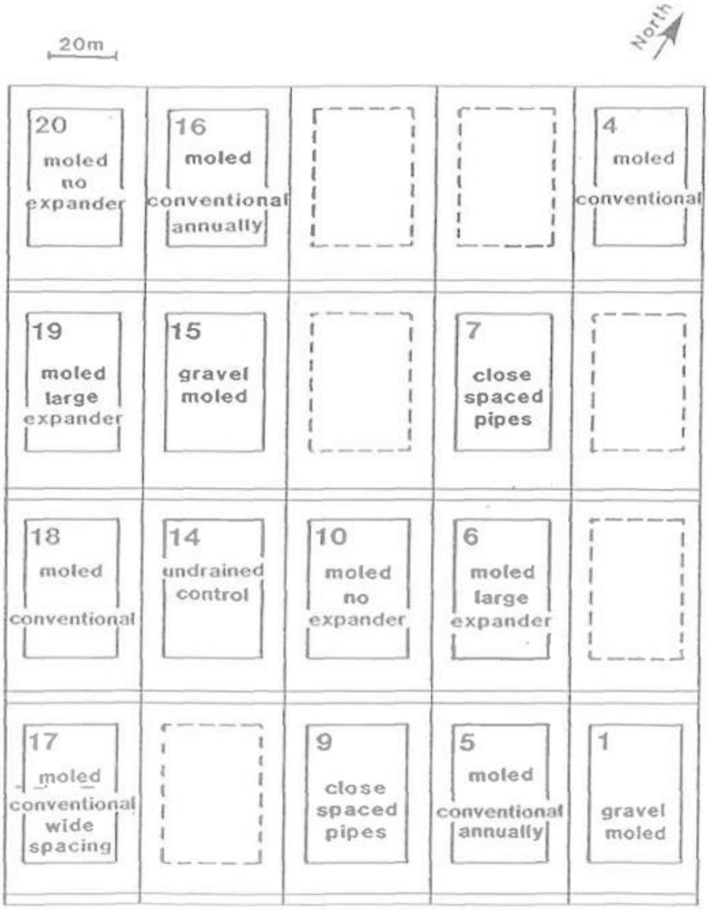

Fig. 6. Drainage treatments, Phase II, 1988-93. Plots shown with pecked borders are undrained cropped plots, not incorporated into the experiment, but available for soil physical monitoring.

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1.4.1.4 To measure soluble phosphate and total phosphorus losses in individual flow events.

1.4.2 Revised plot layout

Six pairs of plots had different drainage treatments and cropping systems (Table 1 and Fig. 6). An additional plot (14) was retained as an undrained control, and another (17) measured the effect of mole drains at 4 m spacing (twice that of the other secondary treatments on the site). As in Phase I, each of the 14 experimental plots was managed individually.

1.4.3 Collection of field data

The instrumentation remained similar except that surface flow and interflow were combined as surface layer flow collected in a deep plough furrow. Improvements to data capture include an upgraded data logger to record flow rates and a telemetry system for remote interrogation of data from ADAS, Cambridge. The physical state of mole channels, siltation in gravel-filled mole drains and any slot blockage in closely spaced plastic pipes have been assessed periodically. The nitrogen balance in the crop and soil was studied by determinations of soil organic matter, total and mineral nitrogen and the total dry matter and nitrogen content of the crop.

Water samples for analysis of pesticide residues were originally bulked from the small (300 ml) samples collected for determination of nitrate. This meant that few data were available on variations within individual flow events. To improve the sampling over storm periods, the programmable samplers were added to the site facilities in 1990 and 1991. The pesticides studied (isoproturon, mecoprop, triadimenol, prochloraz, propiconazole, simazine) are those commonly reported in surface watercourses. With respect to modelling, emphasis has been placed on isoproturon.

1.5 COLLABORATIVE STUDIES

Throughout its life the Brimstone Farm site has been used by many researchers working in collaboration with RES and ADAS.

1.5.1 Phase I projects

Rothamsted Experimental Station, Department of Soil Science (Dr D.S. Powlson). Use of ^{15}N-labelled fertilizer to study uptake and leaching losses of nitrogen in spring.

Birkbeck College, London, Department of Geography (Mr A.W. Warren). Effects of seasonal drying on soil structure and self-mulching properties.

Reading University, Department of Soil Science (Dr D. Payne). Changes in soil surface relief by shrinking and swelling.

Silsoe College, Department of Applied Soil Physics (Prof G. Spoor). Stability of mole drains.

Soil Survey and Land Research Centre (Prof A. Thomasson). Land management and water depletion studies.

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1.5.2 Phase II projects

Rothamsted Experiment Station, Department of Insecticides and Fungicides (Dr R.H. Bromilow). Pesticide degradation and movement in the soil.

Institute of Aerosol Sciences, Essex University and Department of Biological Sciences, Birmingham University (Mr A.B. Turnbull). Atmospheric deposition of pesticides.

Lancaster University, Institute of Biological and Environmental Sciences (Mr A.J. Beck). Column and lysimeter studies of pesticide movement.

MAFF CSL Application Hazards Unit, Harpenden (Mr G. Bell). Appraisal of pesticide application equipment and arable spraying mass-balance studies.

MAFF CSL Pesticides Analysis Group, Cambridge (Mr D.J. Mason). Analysis of pesticide residues in water samples.

Reading University, Department of Soil Science (Prof R. Swift). Transport of pesticides by association with mobile soil organic constituents.

NERC Institute of Hydrology (Dr P. Whitehead). Modelling nitrate leaching to surface waters.

1.5.3 Phase III projects

Rothamsted Experimental Station, Department of Biological and Environmental Chemistry (Dr R.H. Bromilow). Pesticide degradation, sorption and modelling.

Reading University, Department of Soil Science (Dr S. Nortcliff). Assessment of soil structure and water movement.

Silsoe College, Water Research Centre (Medmenham), Soil Survey and Land Research Centre, Horticulture Research International. Modelling of pesticide and nitrate leaching.

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