ROTHAMSTED RESEARCH

The Brimstone Farm Experiment

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2: Hydrology and Soil Physics Studies

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2. HYDROLOGY AND SOIL PHYSICS STUDIES

2.1 BACKGROUND

Movement of water and transport of agrochemicals in clay soils is strongly influenced by the development of macropores such as root channels and seasonal desiccation cracks (Germann and Beven 1981). When the Brimstone Experiment was started in 1978 it was known that the cultivated layer of a ploughed soil is more porous and has a greater hydraulic conductivity than the soil to the same depth in direct drilled land. It was also known that in clay soils water moves laterally in the plough layer if no attempt has been made to modify the subsoil, but that untilled soils have continuous vertical channels which persist from year to year and can enhance infiltration of water. However, it was not known whether these differences affect the total runoff from clay soils or their drainage requirements.

In Phase I the effects of the different cultivation and drainage treatments on the flow paths by which excess water is removed, the timing of movement and the total volume removed provided key support for measuring leaching losses of nitrate. In Phase II the imposition of different drainage treatments and cropping sequences allowed more detailed investigation of the processes determining movement of agrochemicals. In Phase III these are being continued, and the influence of drainflow restrictors (rotatable U-bends in the pipework carrying drainwater from the mole drains to the flow meters and water samplers) on water tables and agrochemical leaching is being studied.

2.1.1 Objectives

In Phase I the main hydrological objectives were:

2.1.1.1 To compare the drainage requirements of ploughed and direct drilled land.

2.1.1.2 To compare surface flow, interflow and drainflow on ploughed and direct drilled land and their effect on total flood runoff.

2.1.1.3 To provide a detailed hydrological database to support nitrate leaching studies.

The hydrological objectives of the different soil drainage and crop management strategies in relation to leaching and surface layer flow of pesticides in Phase II are given in section 5.1.1.

2.1.2 Drainage design standards

The drainage for the site conformed to general recommendations for clay soils in the late 1970s. The diameter of plastic or clay pipe recommended for such soils was 75 mm, but because the total drain length on each plot was only 41 m, the capacity of each drain considerably exceeded the design standard for the site. However, this allowed the peak drainflows to be fully recorded under all weather conditions experienced.

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2.2 RAINFALL PATTERNS IN PHASE I

The weather over the 10 year period of Phase I was very variable. In most winters the rainfall totals were within 15% of the long-term average, but there were two very dry summers (1983 and 1984) each having < 50% of the average rainfall (Table 2). In several summers soil drying led to surface and subsurface cracking.

Table 2. Rainfall expressed as a percentage of the long term average, 1978-88.
(+) Oct-Nov, (*) Gauge suspended - end of Phase I.

	78/ 79	79/ 80	80/ 81	81/ 82	82/ 83	83/ 84	84/ 85	85/ 86	86/ 87	87/ 88
Sep-Nov		51	95	111	135	73	143	46	101	123
Dec-Mar	21^{+}	121	100	112	83	96	81	114	79	108
Jun-Aug	116	114	76	91	44	40	141	73	90	-*
	67									
Total		85	93	96	102	74	117	87	91	-
	-									
mm	456	578	632	653	694	503	796	593	619	789

Mea 63

The network of 10 check raingauges installed in the early years of Phase I showed up to 10% variability in rainfall across the site. Greater rainfall was recorded on north-western parts of the site, especially with prevailing westerly winds in winter. Values from the various gauges were averaged to produce agreed daily, weekly and monthly figures. Heavy snowfalls also resulted in different surface accumulations between plots, and 'rainfall' for each plot then had to be adjusted to correct the water-balances.

2.3 COMPONENTS OF FLOW IN PHASE I

2.3.1 Surface flow

On all plots surface flow depends on rainfall; on the drained plots it also depends on the effectiveness of the mole drainage system. In Phase I there was no difference in surface flow between tine cultivated (1978/79 and 1979/80) and ploughed (1980/81 onwards) plots, but the change to direct drilling (1980/81 onwards) led to peaky hydrographs (Figs 7 and 8) and an increase in surface flow on both drained and undrained plots (Table 3). On direct drilled plots surface flow often occurred after 3-4 mm rainfall in winter, and the lag time between peak rainfall and peak flow was on 15-30 mins. In contrast on the ploughed plots, surface flow occurred less in response to low rainfall amounts, and the lag time between peak rainfall and peak flow was usually 30 mins (Figs 7 and 8).

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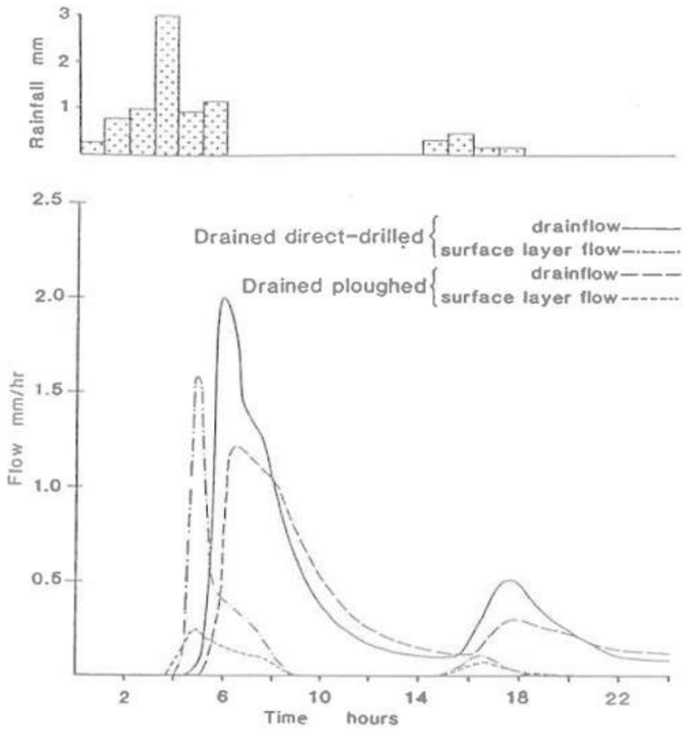

Fig. 7. Typical surface flow and interflow response to a winter rainfall event on a drained plot for direct drilled and ploughed treatments (after Arrowsmith et al. 1989).

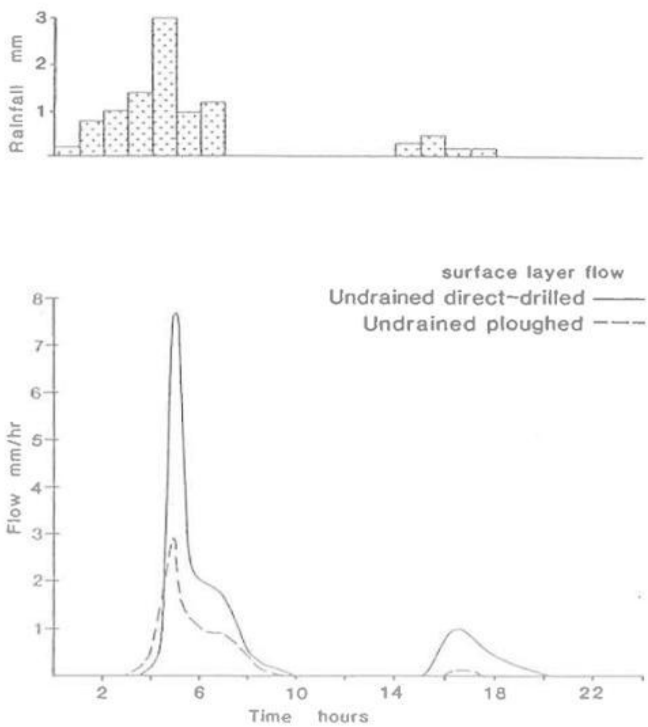

Fig. 8. Typical surface flow and interflow response to a winter rainfall event on an undrained plot for direct drilled and ploughed treatments (after Arrowsmith et al. 1989).

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In several years peak surface flow on direct drilled plots exceeded drainflow, and resulted in shallow erosion rills.

2.3.2 Interflow

Amounts of interflow were small in all years, especially on drained plots. Except during very intense rainfall, hydrographs were much less peaky than those of the surface flow, with peak flow occurring 1-1½ hrs after peak rainfall.

2.3.3 Drainflow

Drainflow was continuous through most of each winter, with trickle flows lasting for several weeks after cessation of rainfall. Peak flow rates in direct drilled soils were often greater than those in tilled (tine or ploughed) plots, particularly with newly drawn mole channels (1978, 1982, 1985). The difference was greatest in early autumn and late spring when soil cracking was most evident. For the drainflow events that exceeded 0.85 mm/hr (the UK design rate for sub-surface drainage at Brimstone) the peak drainflows from direct drilled plots were on average 30% greater than those from ploughed plots. The lag time between peak rainfall and peak drainflow was typically 2-3 hrs for ploughed plots but only 1½-2 hrs for direct drilled plots; the latter also exhibited a faster hydrograph recession (Fig. 9).

Table 3. Mean flow for each cultivation treatment as a percentage of total runoff for December to March inclusive, each year, 1978-88.

Year	Undrained Surface Flow		Drained Surface Flow		Drained Mole + Pipe Drainflow	
	Ploughed	Direct Drilled	Ploughed	Direct Drilled	Ploughed	Direct Drilled
1978/79	47*	-	1*	-	91*	-
1979/80	55*	-	5*	-	90*	-
1980/81	68	5	14	74	80	-
1981/82	77	81	8	23	83	64
1982/83	76	89	5	17	93	82
1983/84	19	57	10	3	82	95
1984/85	30	69	7	3	91	94
1985/86	54	81	3	11	96	81
1986/87	77	79	3	3	94	93
1987/88	83	93	3	20	91	78

* all plots tine cultivated.

Means 52.6 69.3 5.9 19.3

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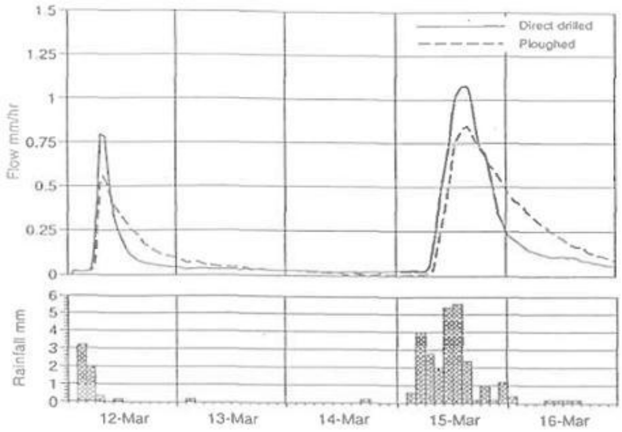

Fig. 9. Comparison of typical drainflow response, direct drilled and ploughed treatments, March 1982

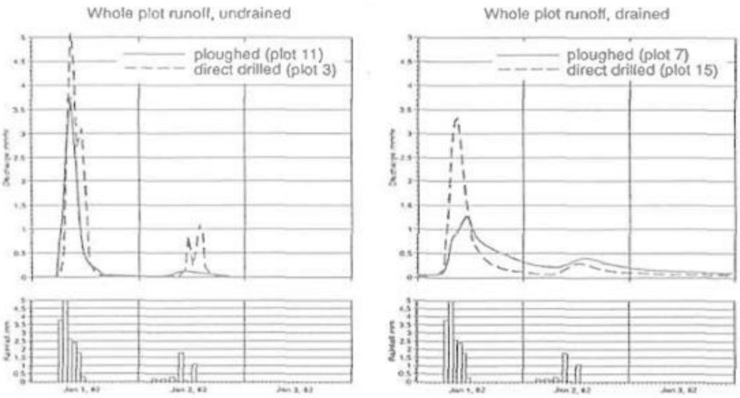

Fig. 10. Total runoff response from drained and undrained land showing effect of drainage on overall flood risk for a typical winter event.

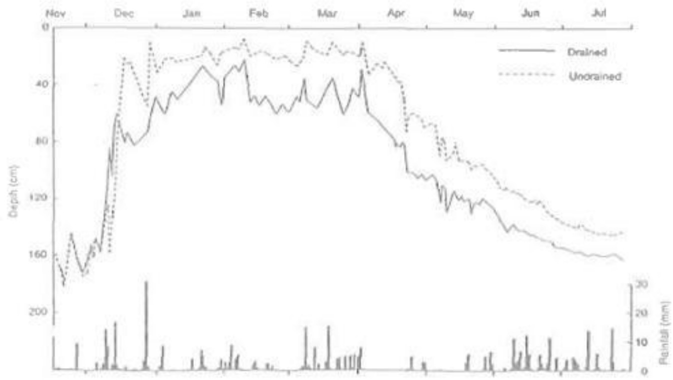

Fig. 11. Mean depth to the water table, for drained and undrained central eight plots, 1979-80 (after Harris et al. 1984). Data from tensiometers.

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Whereas direct drilling resulted in greater runoff at peak flow than ploughing, and therefore increased the risk of flooding downstream, drainage decreased peak total runoff (Fig. 10). This is because it increased the depth to water table (Fig. 11) and provided opportunities for excess water to be temporarily stored in upper soil horizons. A computer model developed to examine the implication of the increased peak drainflows under direct drilling showed that surcharging of systems designed to current standards could occur, with water backing up in pipes and mole channels, and that flood problems could result nationally.

2.4 WATER BALANCES

Daily, monthly and winter water balances were produced from rainfall, evapotranspiration and total runoff values. Poor balances were obtained in early years, but improved plot separation and settlement of drainage trenches gave better balances in later years. Winter water balances were then almost 100% on the drained plots and up to 70% on undrained plots.

2.5 MOLE CHANNEL DETERIORATION AND SOIL STRUCTURE

In most years mole channel deterioration occurred equally under ploughing and direct drilling. The roof and walls gradually collapsed over 3-4 years, so the channels were redrawn in 1982 and 1985. However, after dry periods in 1983 and 1986 deep cracking allowed topsoil to infill the channels, especially on the direct drilled plots. In the dry summer of 1984 extensive roof collapse occurred on all plots, but on the direct drilled plots a continuous void up to 100 mm in diameter developed along the old roof; this later provided effective drainage, though the water table control was less than that offered by the original mole channel.

The soil structure around mole channels was better developed under direct drilling, with more continuous vertical cracks likely to encourage downward water movement. This increased the effectiveness of the channels and extended the life of the system by at least 25% compared with that on ploughed plots. Earthworm populations were small on both ploughed and direct drilled plots and few were found deep in the soil, so it is unlikely that they account for the structural and drainage differences.

2.6 WATER TABLE CONTROL

In 1978/79 drainage gave no water table or crop yield benefit because of the cultivation pan. Once this had been removed the drainage system increased the depth to the water table by 0.25 m in 1979/80 (Fig. 11) and by 0.15 - 0.20 m in subsequent winters, as indicated by both water table meters and tensiometers (Thackeray *et al.* 1987). On the drained, direct drilled plots the improved soil structure lowered the water table more rapidly and for longer periods than on ploughed plots. On undrained direct drilled plots the dense cultivated soil resulted in a shallower aerated zone, with water held nearer to the surface and the crop, than on undrained ploughed land.

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