SOIL WATER REGIMES

END OF PROJECT REPORT

ARMIS 4479

Authors

J. Diamond, P. Sills

Teagasc,
Johnstown Castle Research Centre,
Wexford.

June 2001

ISBN No. 1 84170 223 4

Teagasc acknowledges with gratitude the support of European Union Structural Funding (EAGGF) in financing this research project.

teagasc
Agriculture and Food Development Authority

EUROPEAN UNION

European Agricultural Guidance
and Guarantee Fund

Teagasc, 19 Sandymount Avenue, Ballsbridge, Dublin 4.

TABLE OF CONTENTS

SUMMARY

Soil moisture tension was monitored, for three years, at three sites representing different natural soil drainage classes that were defined morphologically.

The soils comprised:

- Gley, poorly drained, loam
- Brown Earth, well drained, loam
- Brown Earth, somewhat excessively drained, sandy loam.

The main features of the moisture regime were:

- Average annual soil water tension was analogous to the natural drainage classification and followed the sequence: somewhat excessively drained > well drained > poorly drained.
- Some horizons that lacked visible evidence of reduction, in the subsoil of the Brown Earths, were saturated for long periods.
- The Brown Earths were unsaturated, at 15 cm depth, throughout the three-year period.
- The Gley was saturated at 15 cm depth for up to nearly four months per year.

This implies that the risk of overland flow, due to saturation excess, differs among soil types. The risk is probably significant on Gleys, which occupy 25 percent of the land area; it is probably small or negligible on Brown Earths and analogous soils, which comprise over forty percent and account for virtually all of the intensive agriculture in the country.

INTRODUCTION

Under Irish conditions, the soil water regime is one of the most important physical factors that determine the use and productivity of soils. In recent times there is an added interest because of the need to assess and manage the risks of off-site contamination. A study of infiltration rates on some major well drained soils indicated little or no risk of overland flow in summer due to infiltration excess (Diamond and Shanley, 1998). This implies that overland flow is more likely to result from saturation excess, which is determined by the soil water regime. The concept of natural drainage class, which refers to the frequency and duration of wet periods under conditions similar to those under which the soil developed, has been used widely in soil classification and mapping (Soil Survey Division Staff, 1993). However, this is a qualitative method based on inferences drawn from morphological features. There is a need to calibrate the existing drainage classes to provide a more precise and quantitative basis for describing soil water regimes and predicting risk of off-site contamination through overland flow. The drainage class forms a link with an existing data set so that areal values can be derived from point measurements. The main aims of the project were to compare the water regimes of soils representing different drainage classes and assess the implications for overland flow and soil classification.

SITES

Measurements were performed on a site at each of the following locations (Fig.1):

- Ballintemple Nursery, Coillte, Co. Carlow
- Clonroche Research Station, Co. Wexford
- Johnstown Castle Research Centre, Co. Wexford.

As shown in Fig. 1 the sites were located near the 1000 mm isohyet. The sites at Clonroche and Johnstown Castle were between the 1000 mm and 1125 mm isohyets and the Ballintemple site was between the 875 mm and 1000 mm isohyets. Thus, slightly lower rainfall would be expected, in the long term, at Ballintemple than at Clonroche and Johnstown Castle.

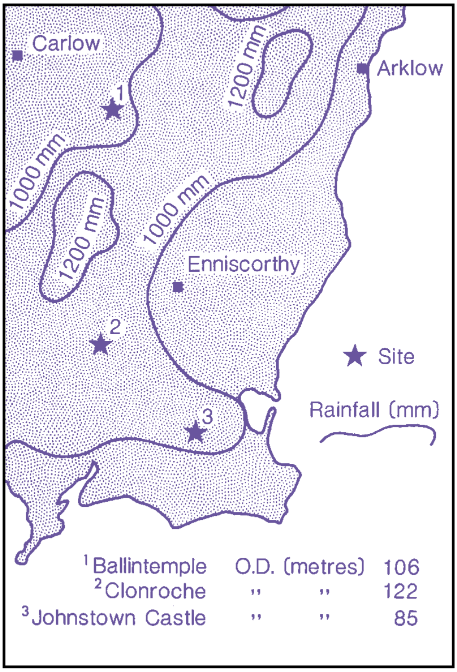


Fig1: Location of sites and rainfall contours

At Clonroche the soil is a Brown Earth, Clonroche Series, loam, derived from predominantly shale till (Gardiner and Ryan, 1964). The Ballintemple soil is a Brown Earth, Borris Series, sandy loam, derived from granite till (Conry and Ryan, 1967). The absence of redoximorphic features indicates relatively free drainage in both soils. The particle size distribution, based on material obtained from each hole at Clonroche and Johnstown Castle and on bulked samples at Ballintemple, is shown in Table 1. The content of coarse sand at Ballintemple (> 40 percent) is about twice that at Clonroche while the clay content (13 percent) is less than half that at Clonroche. The Clonroche and Ballintemple sites, because of their textural differences, could be expected to span most of the range in drainage conditions in 'freely drained' soils in Ireland. In the USDA system, the Clonroche soil is assigned to the well-drained class; the Ballintemple soil, because of its coarse texture, is somewhat excessively drained. At Johnstown Castle, yellowish-brown mottles occur in the surface (0-25 cm), and, below this depth, grey mottles occur throughout the profile. In the subsoil, the exteriors of peds are paler than the matrix, indicating that the soil material is saturated, at least temporarily, with surface water

(FAO, 1998). The soil is classified as a poorly drained member of the Crosstown Complex derived from sandy deposits and fine Irish Sea till (Gardiner and Ryan, 1964). The fineness of the texture is between that of the Clonroche and Ballintemple sites; clay content is about 18 percent to 90 cm depth and then decreases to 13 percent. Silt content is much higher (47 percent) at 60 - 90 cm depth than in the overlying and underlying material.

Table 1: Particle Size

Site (Elevation)	Depth cm	Coarse sand %	Fine Sand %	Silt %	Clay %
Ballintemple	0-25	43	21	23	13
	25-60	44	21	23	13
(127 m O.D.)	60-90	44	20	23	13
Clonroche	0-25	19	10	39	32
	25-60	21	10	40	29
(146 m O.D.)	60-90	23	12	38	26
	90-120	18	11	42	29
Johnstown Castle	0-25	21	28	32	19
	25-60	19	30	33	18
(102 m O.D.)	60-90	10	26	47	17
	90-120	14	38	36	13

As shown in Fig. 1, the sites were located near the 1000 mm isohyet. The sites at Clonroche and Johnstown Castle were between the 1000 mm and 1125 mm isohyets and the Ballintemple site was between the 875 mm and 1000 mm isohyets. Thus, in the long term, slightly lower rainfall would be expected at Ballintemple than at Clonroche and Johnstown Castle. Table 1 shows the annual rainfall for each site for the duration of the observations 1998-2000. As weather records at Ballintemple were incomplete, the data shown are for Hacketstown, the nearest analogue station. This is about 50 metres elevation above Ballintemple, which probably results in a slight overestimation. The annual rainfall, on average, follows the sequence Clonroche > Ballintemple > Johnstown Castle (Table 1). However, it is likely that there is little difference between Ballintemple and Johnstown Castle as the Ballintemple data are probably overestimates.

Table 2: Annual rainfall (mm)

Year	**Johnstown Castle**	**Clonroche**	**Ballintemple**
1998	1181	1270	1163
1999	856	1074	1002
2000	1110	1285	1153
Mean	**1049**	**1209**	**1106**
Ratio	**1.00**	**1.15**	**1.05**

Figure 2 shows the monthly distribution of rainfall for the 36 month period 1998-2000. The greatest monthly rainfall was most frequent at Clonroche (22 months), followed by Ballintemple (9) and Johnstown Castle (5).

METHODOLOGY

A system comprising tensiometers, pressure transducers and a logger was set up at each site to measure soil moisture tension. Tensiometers were placed 50 cm apart in rows that were 70 to 90 cm apart. At Ballintemple and Clonroche four tensiometers were inserted at 15 cm and 30 cm depth and three tensiometers at 45 cm, 60 cm, 90 cm and 120 cm depth. This amounted to 20 tensiometers at each site corresponding to the capacity of the loggers. At Johnstown Castle a 24-channel logger was used and four tensiometers were inserted at each of the six depths. However, overpressure, caused by freezing temperatures in the preliminary phase, reduced the number of operational units at Ballintemple and Clonroche to 14 and 16 respectively. A 25% aqueous solution of Methanol, added during November - March period, prevented any further damage to the transducers. Over the three years, no tensiometer body or cup was damaged by frost.

Pressure transducers were fixed directly on the body of the tensiometers. At Clonroche, the transducers were four-wire solid-state, differential silicon shear stress/strain gauge, operating range 0 to -1 bar, operating temperature range 0-60^{o}C, linearity, 25% full scale and hysteresis less than 1%. The output was 4 - 20 mA and the power supply 12 VDC batteries. At Ballintemple and Johnstown Castle different pressure transducers with a stated compensated temperature range of -20 to + 80 ^{o}C. Data were downloaded to a laptop at least once a month at each site. The tensiometers were refilled with water twice weekly. To allow for the head of water in the tensiometer tube, between the soil surface and the cup, the readings were corrected by subtracting the pressure equivalent of the column of water in the tube. This can give rise to negative values, which indicate a water table in the soil profile (Richards, 1965)

Piezometers were driven to 45, 90 and 135 cm depths at Clonroche and to 45, 90 and 120 cm at the other sites. All were read twice weekly.

Hydraulic conductivity (Ksat) was determined in three holes, at successive depths, at each site. At least three measurements were performed at each depth in each hole. The inverse-auger-hole method was used at Ballintemple, Clonroche and above 60 cm at Johnstown Castle. The auger-hole method was used at Johnstown Castle at 60 cm and greater depths because a water table was present at these depths for most of the year.

RESULTS

Hydraulic conductivity

Analysis of Variance showed significant differences in hydraulic conductivity (Ksat) among sites and among depths ($p < .05$). Overall, the geomean of Ksat decreased with depth. However, at Clonroche 30 cm depth and Ballintemple 45 cm depth, the average Ksat was much greater than in the next layer above (Table 1). In general the hydraulic conductivity followed the sequence Ballintemple > Clonroche = Johnstown Castle. Below 60 cm, Ksat was slower at Clonroche than at Johnstown Castle. This probably reflected the much higher clay content at Clonroche but may also have been influenced by the different method that was used below the water table at Johnstown Castle.

Table 3: Hydraulic conductivity (Ksat)

Depth cm	Ballintemple	Clonroche	Johnstown Castle	Geomean
		m day^{-1}		
15	0.672	0.118	0.332	0.298
30	0.530	0.219	0.102	0.228
45	1.334	0.130	0.021	0.155
60	0.342	0.051	0.046	0.093
90	0.250	0.023	0.038	0.060
120	0.068	0.014	0.064	0.040
Geomean	**0.374**	**0.062**	**0.066**	

The results of a variable selection procedure to estimate hydraulic conductivity (Ksat) from various soil properties are presented in Table 4. Bulk density is not included because compression of the soil occurred within the split-tube sampler. The best single predictor of Ksat was the amount of coarse sand; the best pair was coarse sand and depth (r^2 =0.720). It is likely that depth is partly a proxy for bulk density, which has been used in a model developed from statistical analysis of several thousand measurements (Rawls and Brakensiek, 1983). The best three-variable model includes clay content and an almost equal r^2 was obtained by including fine sand, which is easier to measure, instead of clay content. Only a marginal increase in r^2 results from increasing the model size above three. Thus, in the sample studied, a fairly good estimate of hydraulic conductivity could be derived from the simple properties of sand content and depth.

Table 4: Variable selection for best model of Ksat

Code	Variable	Model size	R-Squared	R-Squared change	Coded variables
	Ksat	1	0.575838	0.575838	B
A	Depth	2	0.719966	0.144128	AB
B	Coarse sand	3	0.758333	0.038367	ACE
C	Fine sand	4	0.768393	0.010061	ABCE
D	Silt	5	0.768523	0.00013	ABCDE
E	Clay	3	0.743404		ABC

Influence of soil properties on tension and saturation

The relationship between hydraulic conductivity, particle size, depth and average annual tension or duration of saturation are shown in Table 5. In each of the three years the log-transformed Ksat was the best single predictor of both tension and duration of saturation ($r > 0.7$). The next best predictor was either depth or coarse sand. In each year, the regression model accounted for a large proportion ($r^2 > 0.9$) of the variation in tension and saturation. However, these have to be interpreted with caution as the model varied somewhat from year to year and multicollinearity occurred in the data e.g. Ksat and coarse sand. However, the relationship between saturation /tension and the easily measured sand fractions should be worthy of experimentation over a larger sample of soil profiles.

Table 5: Influence of soil properties on average annual soil water tension and on duration of saturation

	1998	1999	2000
		Tension	
Depth	-0.7044	-0.6686	-0.7570
Ksat (Ln)	0.7358	0.7469	0.7347
Coarse sand	0.6557	0.7074	0.6256
Fine sand	-0.5086	-0.4567	-0.2705
Silt	-0.5146	-0.5781	-0.6089
Clay	0.1765	0.1011	0.0139
Regression R^2	0.9875	0.9689	0.9057
		Saturation	
Depth	0.6403	0.7122	0.7120
Ksat (Ln)	-0.7752	-0.7486	-0.7694
Coarse sand	-0.6459	-0.6095	-0.6160
Fine sand	0.5282	0.4763	0.4561
Silt	0.4785	0.4867	0.4828
Clay	-0.1847	-0.1801	-0.1409
Regression R^2	0.9603	0.9383	0.9268

Values are Pearson correlation coefficients (r) and regression model coefficient of determination (R^2)

Soil water tension and duration of saturation

In 1998 the seasonal pattern of soil water tensions was very similar at all sites and was characterised by three periods with increased tension, in late May, early July and throughout August (Fig. 3). These peaks reflect the low rainfall in May, July and August (Fig. 2), and, except for these periods, tensions seldom reached 60 hPa at Clonroche and Johnstown Castle or 100 hPa at Ballintemple. There were consistent differences in soil water tension among sites. At each depth the average annual tension followed the sequence Ballintemple > Clonroche > Johnstown Castle (Table 6). The maximum tensions were well within the operable range of tensiometers (> 850 hPa) and followed the same sequence: Ballintemple (512 hPa) > Clonroche (297 hPa) > Johnstown Castle (109 hPa). Thus, the sequence of average and maximum tensions was analogous to the predefined drainage classification based on soil morphology.

Table 6: Average soil water tension (hPa) 1998

Depth (cm)	**15**	**30**	**45**	**60**	**90**	**120**
Ballintemple	88	70	66	53	50	1
Clonroche	61	54	29	13	0	-36
Johnstown Castle	29	16	-15	-24	-59	-85

In general, wetness increased gradually with depth but, at Ballintemple and Clonroche, the rate of change increased between 90 cm and 120 cm depth.

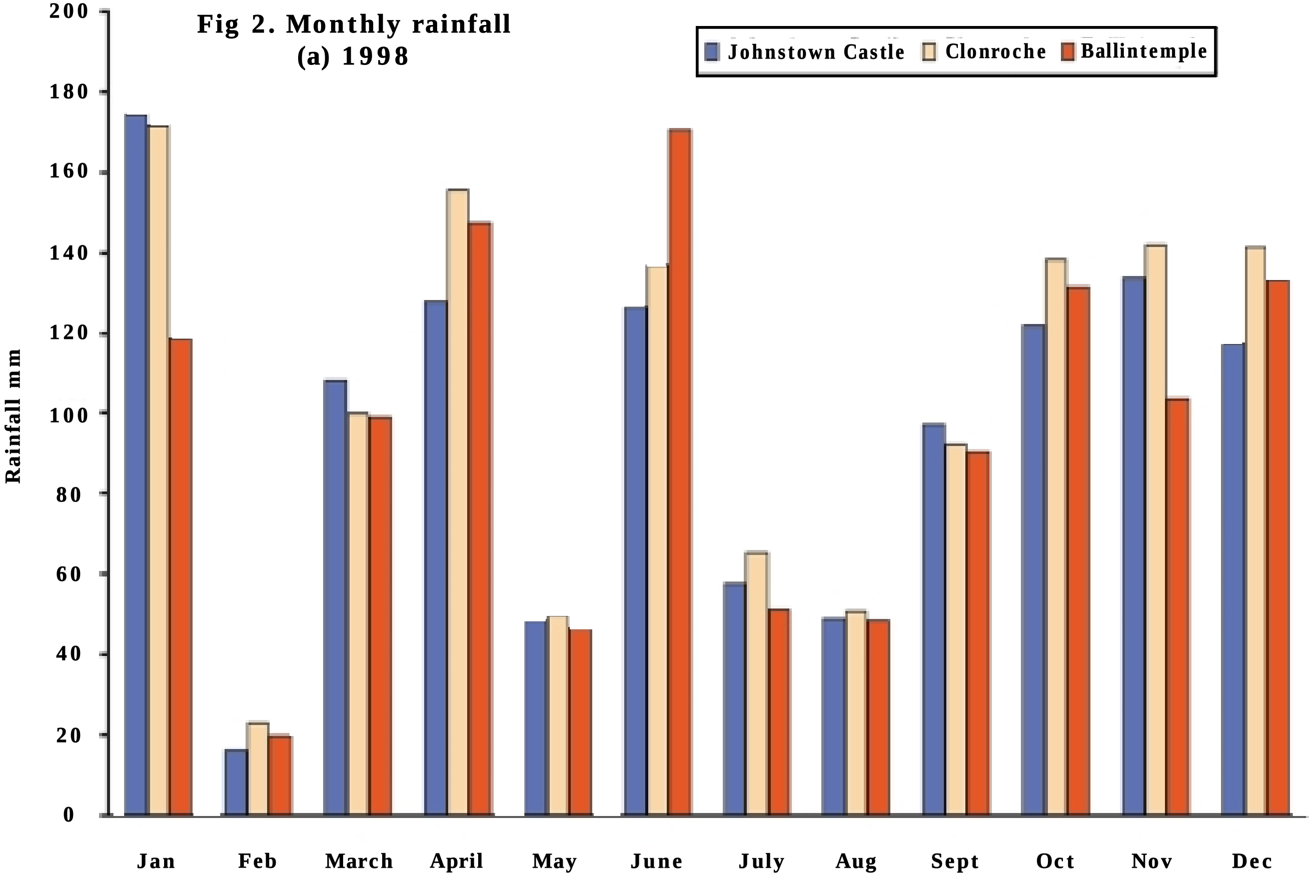


Fig 2. Monthly rainfall
(a) 1998

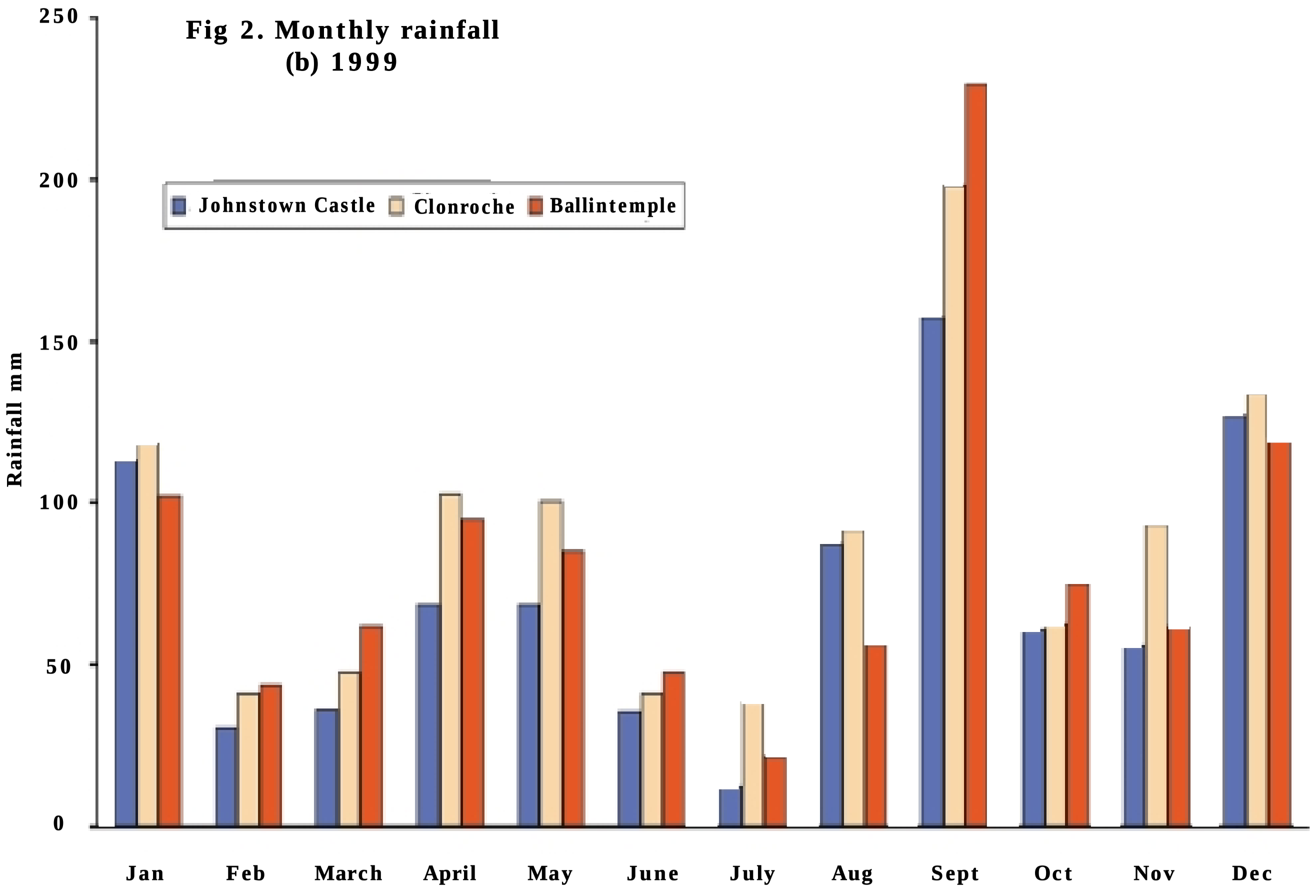


Fig 2. Monthly rainfall
(b) 1999

Fig 2. Monthly rainfall (c) 2000

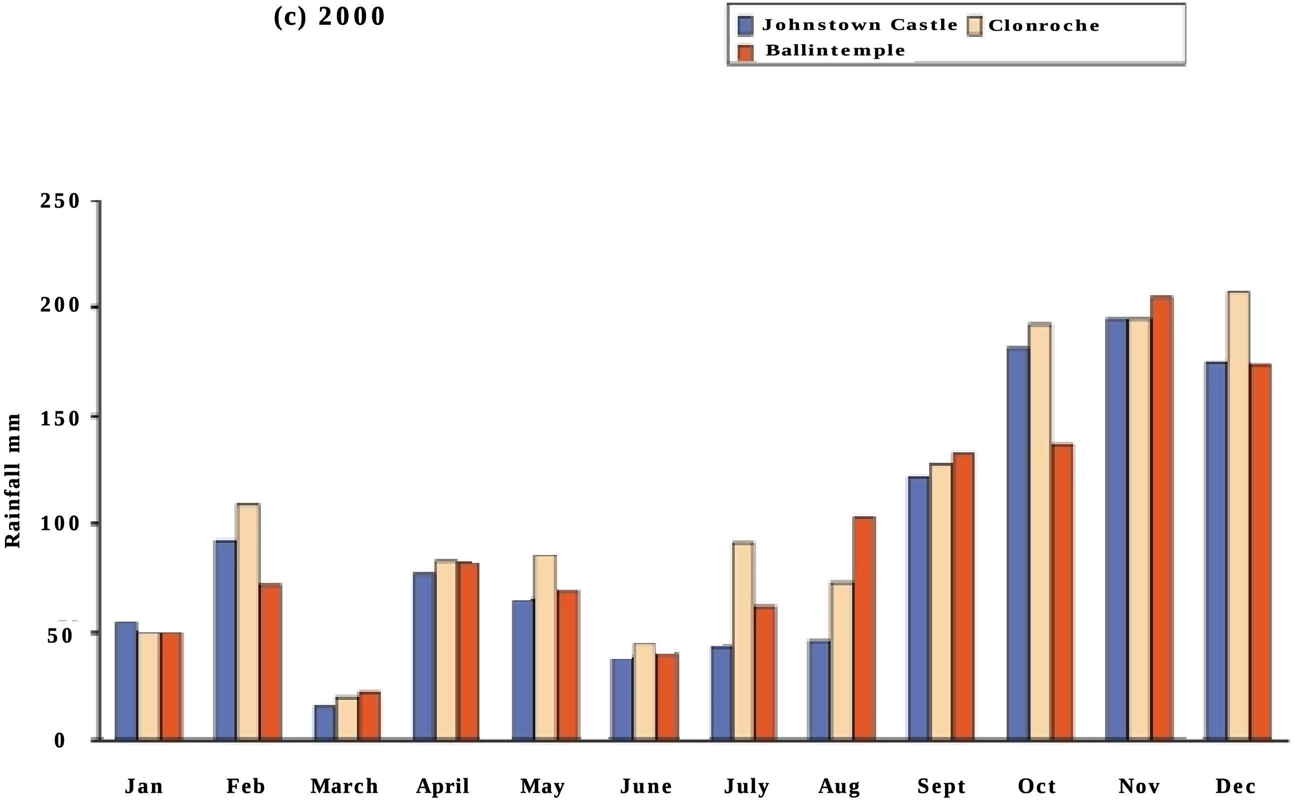


Fig. 3: Soil water tension 1998
(a) Ballintemple

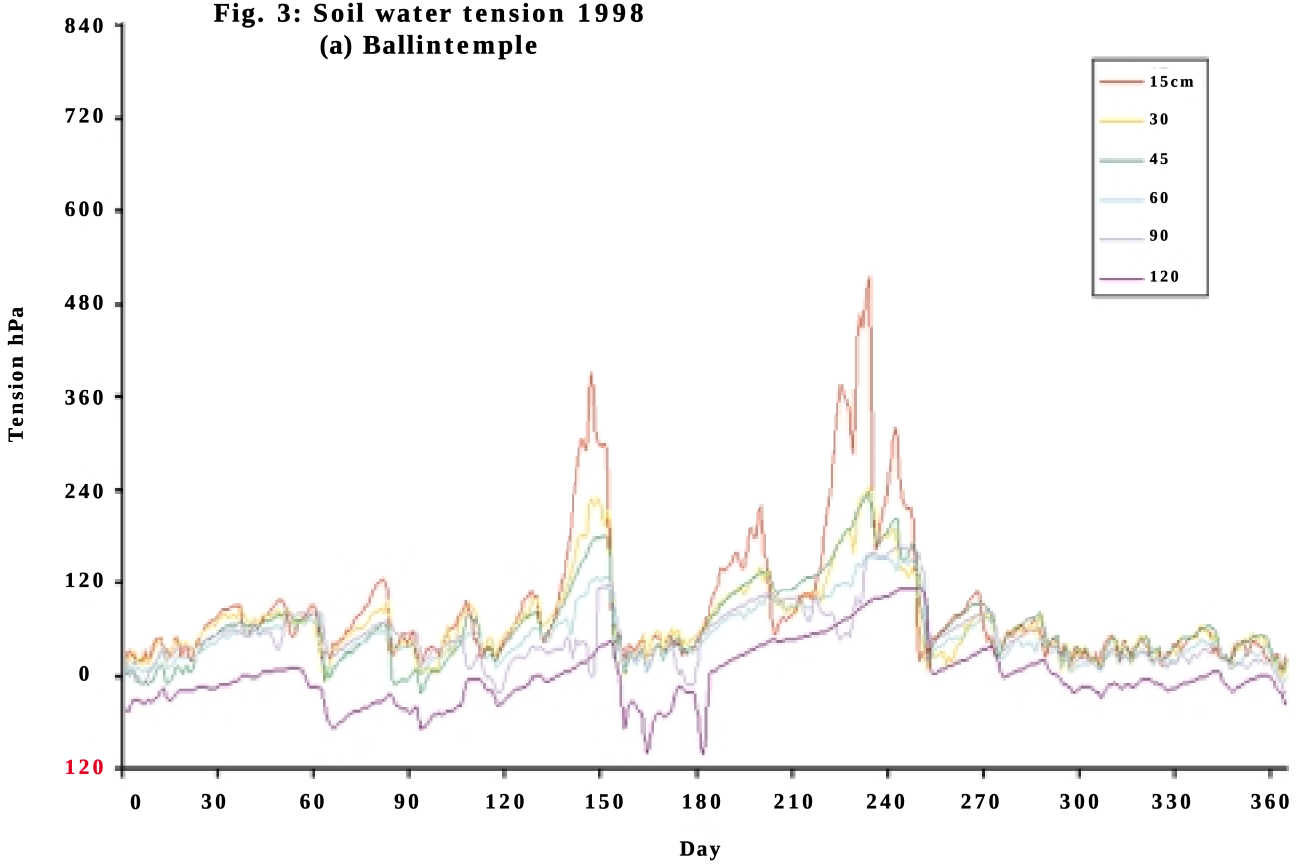


Fig. 3: Soil water tension 1998
(b) Clonroche

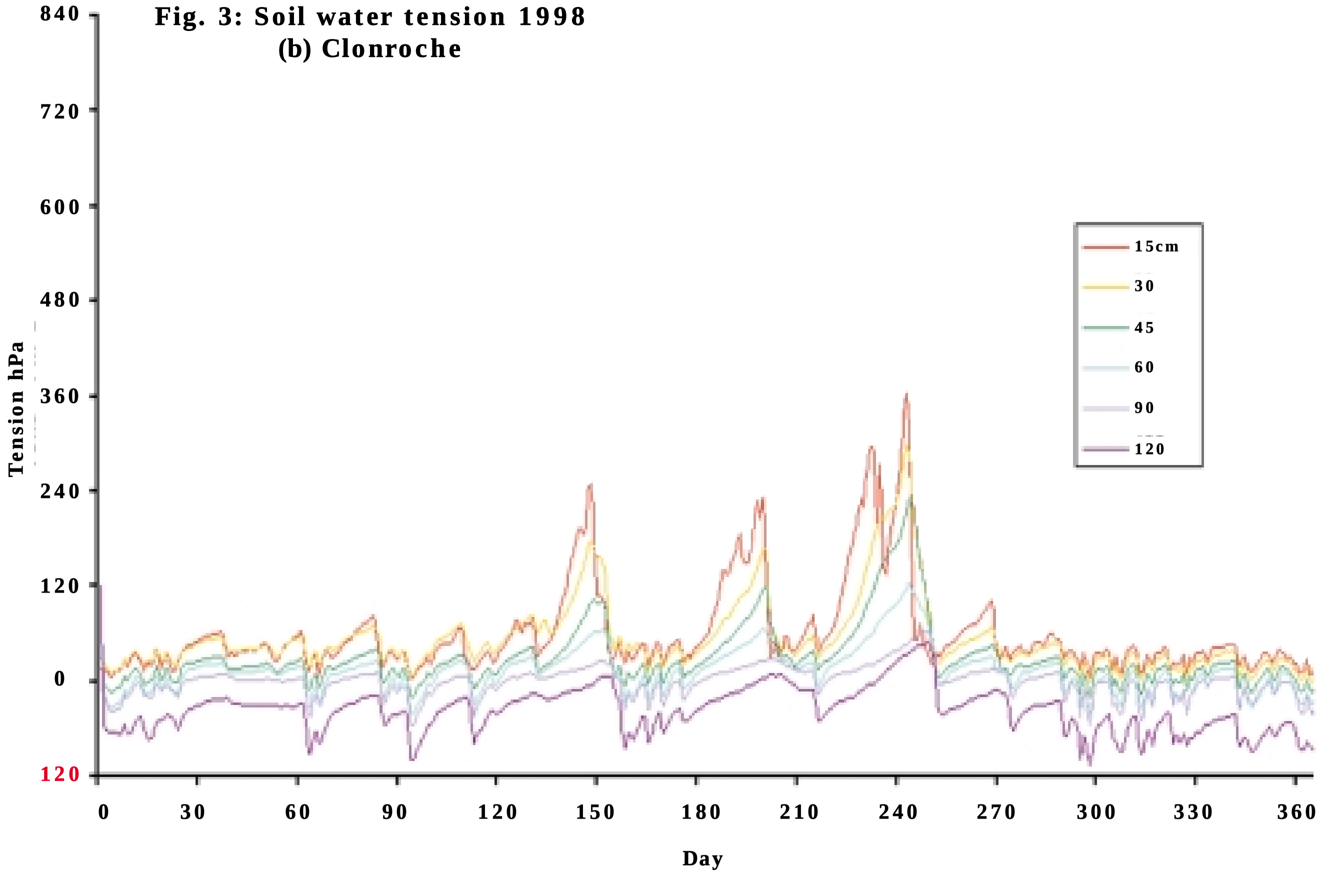
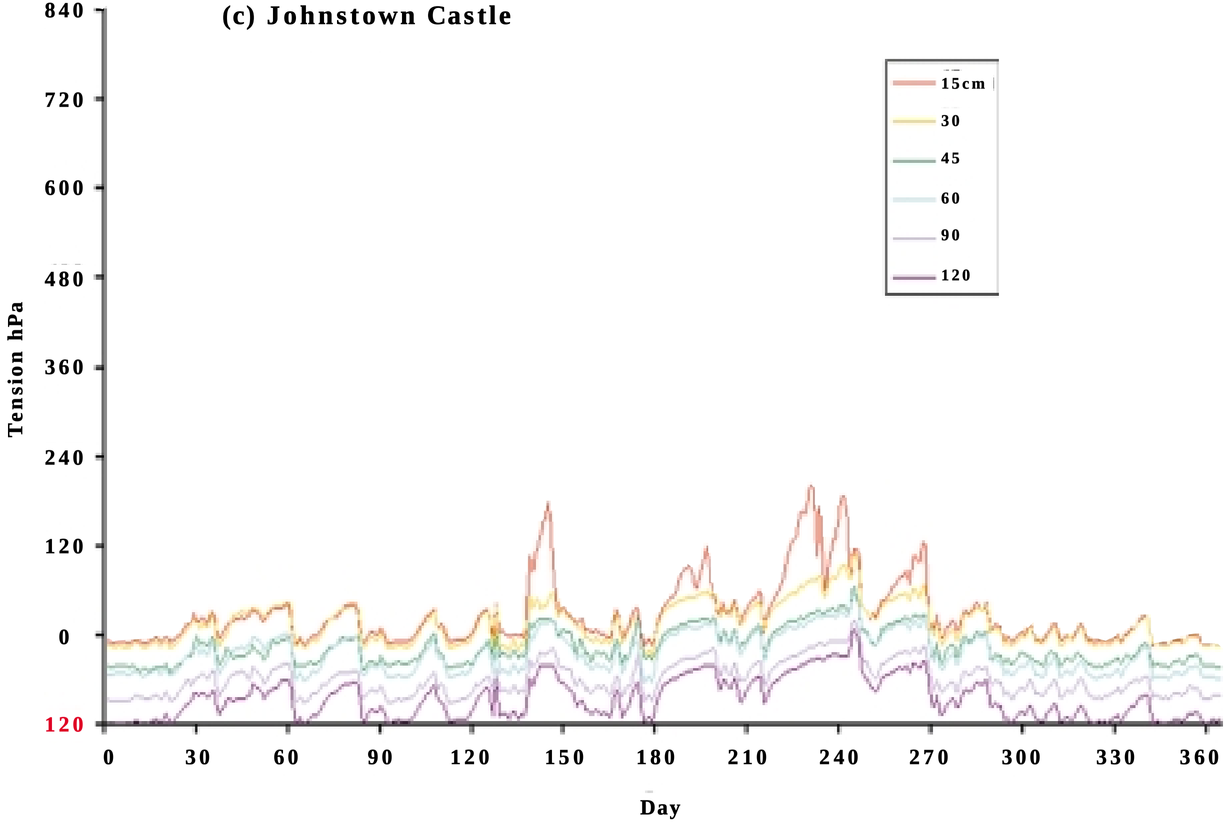


Fig. 3: Soil water tension 1998
(c) Johnstown Castle



The Ballintemple and Clonroche sites were unsaturated throughout the year at 15 cm depth (Table 7). The duration of saturation increased with depth at both sites and was greater at Clonroche where it lasted for 332 days at 120 cm depth. The Johnstown Castle site was saturated for a substantial period at 15 cm depth (111 days); the duration of saturation increased with depth and lasted for virtually the whole year (359 days) at 90 cm and 120 cm depths.

Table 7: Duration of saturation* (days) 1998

Depth(cm)	Ballintemple	Clonroche	Johnstown Castle
15	0	0	111
30	1	1	148
45	18	44	268
60	2	112	282
90	18	166	359
120	208	332	361

* Tension ≤ 0 hPa

In 1999, soil water tension followed a similar pattern at all sites (Fig. 4); for example, two minor peaks, prior to day 150, were evident at all sites. Tensions were within the operable range of tensiometers throughout the year at all sites except for a 13-day period (day 209-221) at 15 cm depth at Ballintemple. Maximum tensions followed the sequence Ballintemple (> 850 hPa) > Clonroche (617 hPa) Johnstown Castle (505 hPa). Except during the three-month summer period (day 160-250), tensions seldom reached 60 hPa at Clonroche and Johnstown Castle or 100 hPa at Ballintemple. Average annual soil water tension at each depth followed the sequence: Ballintemple > Clonroche > Johnstown Castle (Table 8). The average moisture tension generally decreased with depth at each site except at Ballintemple, 90-cm depth, where the tension was greater than at 60-cm depth.

Table 8: Average soil water tension (hPa) 1999

Depth(cm)	Ballintemple	Clonroche	Johnstown Castle
15	115	73	60
30	109	61	45
45	111	48	1
60	68	35	-13
90	83	21	-49
120	41	-13	-70

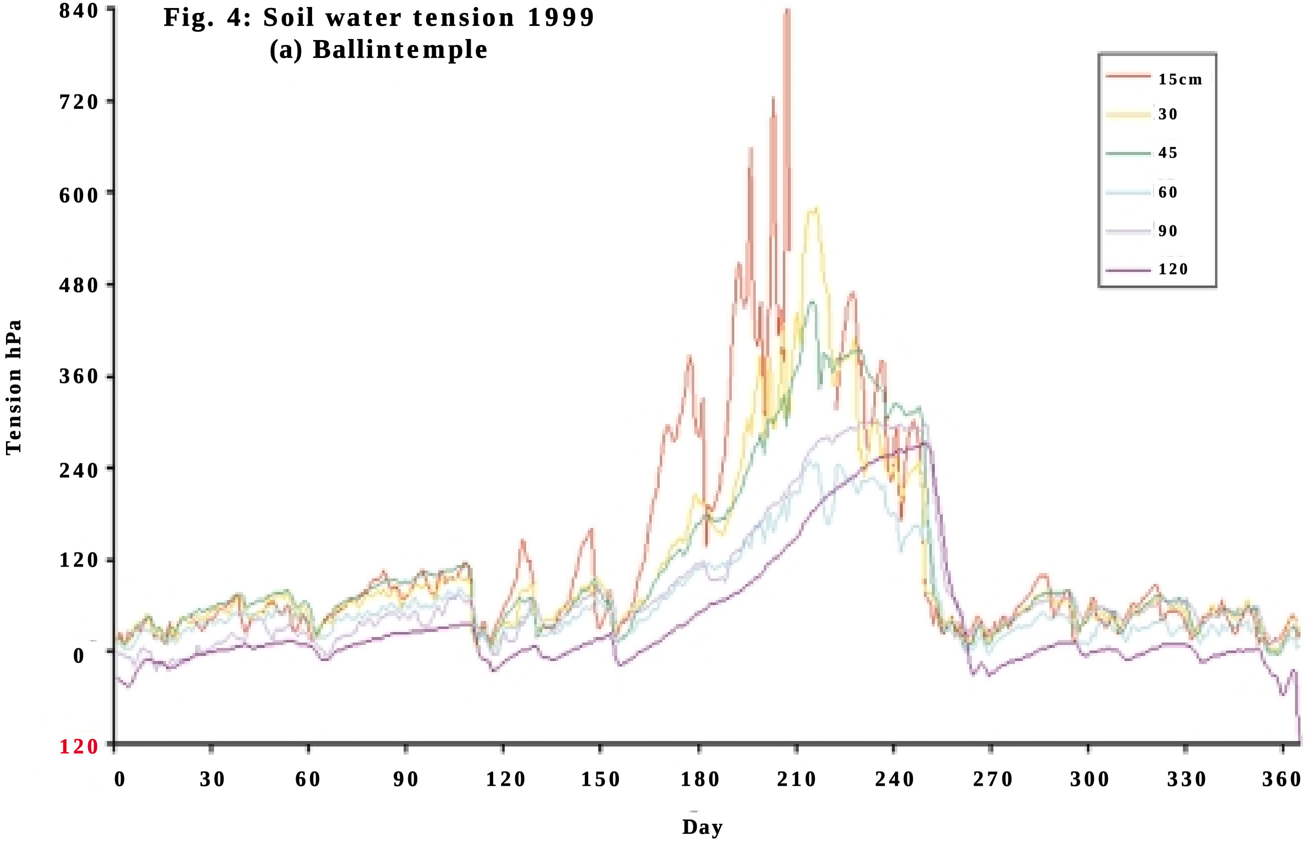


Fig. 4: Soil water tension 1999
(a) Ballintemple

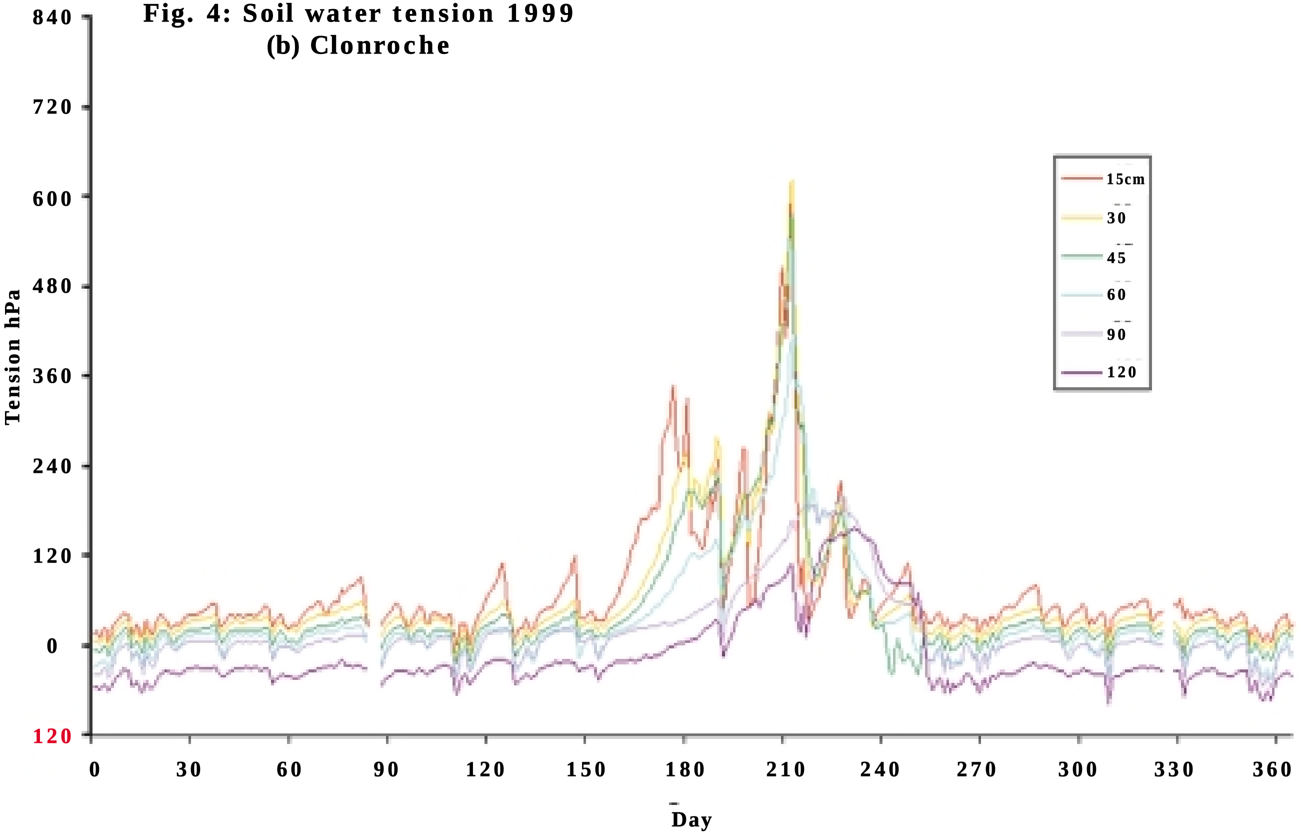
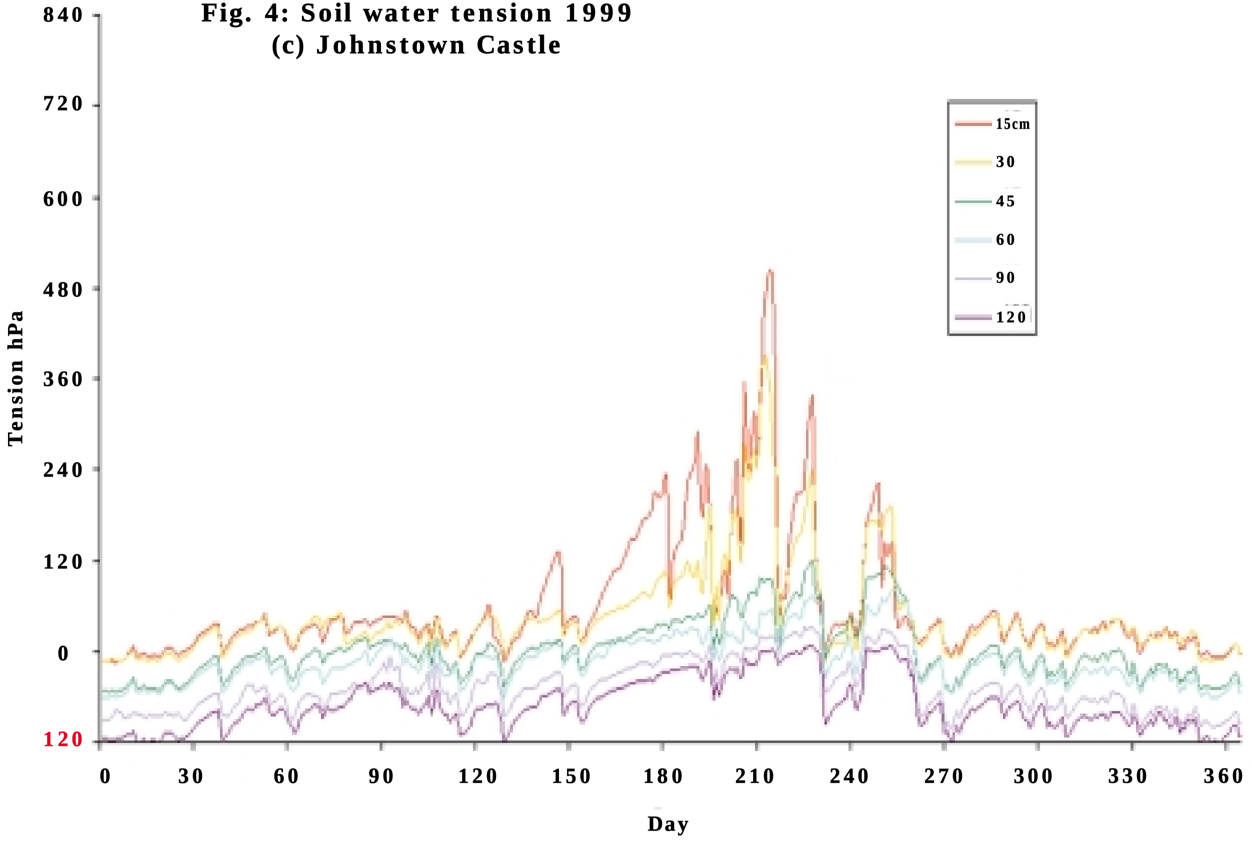


Fig. 4: Soil water tension 1999
(b) Clonroche

Fig. 4: Soil water tension 1999
(c) Johnstown Castle



The soils were unsaturated throughout the year down to 30-cm depth at Ballintemple and down to 15-cm depth at Clonroche (Table 9). The Gley soil at Johnstown Castle was saturated (Tension ≤ 0 hPa) at 15 cm depth for 45 days, which was less than in 1998. At all sites the duration of saturation increased regularly with depth and at 120-cm depth ranged from118 days at Ballintemple to 349 days at Johnstown Castle. Measurements of pressure heads made with piezometers from September to the end of the year indicated the presence of a water table for about one week at 120-cm at Ballintemple, for three months at 90-cm at Clonroche and continuously at Johnstown Castle at 90-cm. and 120-cm depths.

Table 9: Duration of saturation* (days) 1999

Depth(cm)	Ballintemple	Clonroche	Johnstown Castle
15	0	0	45
30	0	10	54
45	1	41	208
60	4	104	265
90	26	125	325
120	118	286	349

* Tension ≤ 0 hPa

Unlike previous years there were differences among sites in the pattern of soil water tensions in 2000. The pattern was similar at Johnstown Castle and Ballintemple up to the end of July (day 213) when tensions dropped sharply at both sites (Fig. 5). Tensions remained low at Ballintemple but a peak formed in Johnstown Castle from mid-August to mid-September (day 232-262). A much greater rainfall at Ballintemple that was 2.2 times the rainfall at Johnstown Castle during August (Fig. 2), could account for the difference. The pattern at Clonroche was unusual. The peak normally expected in July did not develop. Instead, a gradual uptrend continued until October when tensions dropped sharply. This pattern reflected the unusually high rainfall in July at Clonroche that was 2.1 times the rainfall at Johnstown Castle.

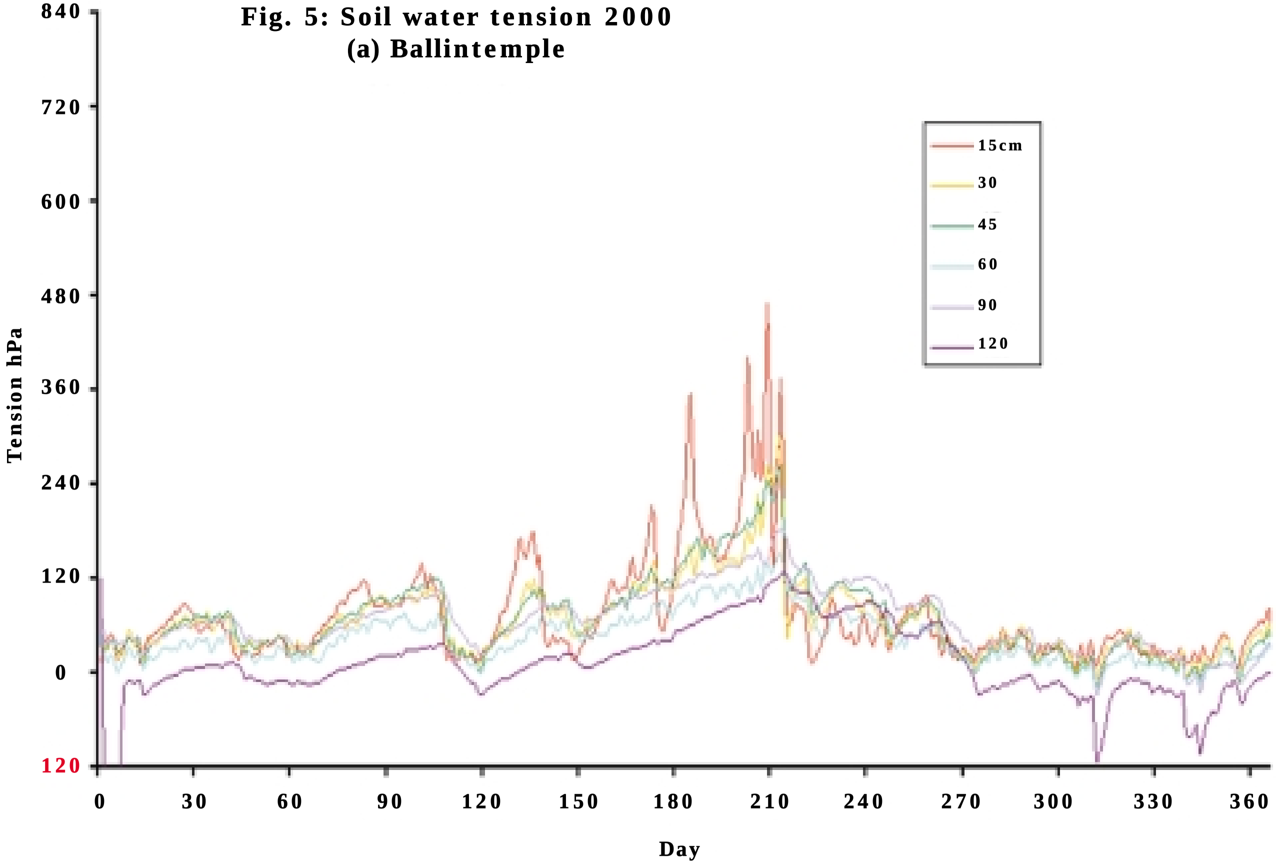


Fig. 5: Soil water tension 2000
(a) Ballintemple

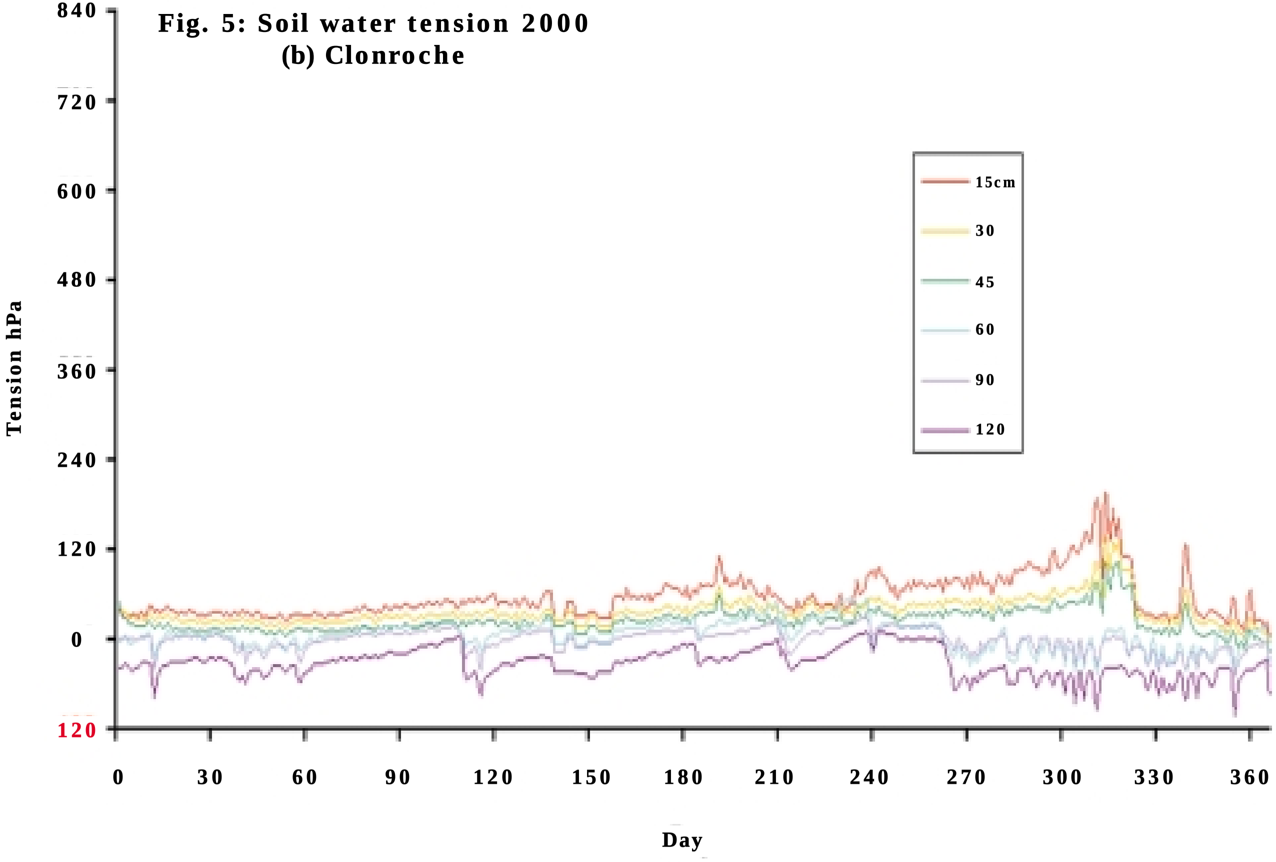


Fig. 5: Soil water tension 2000
(b) Clonroche

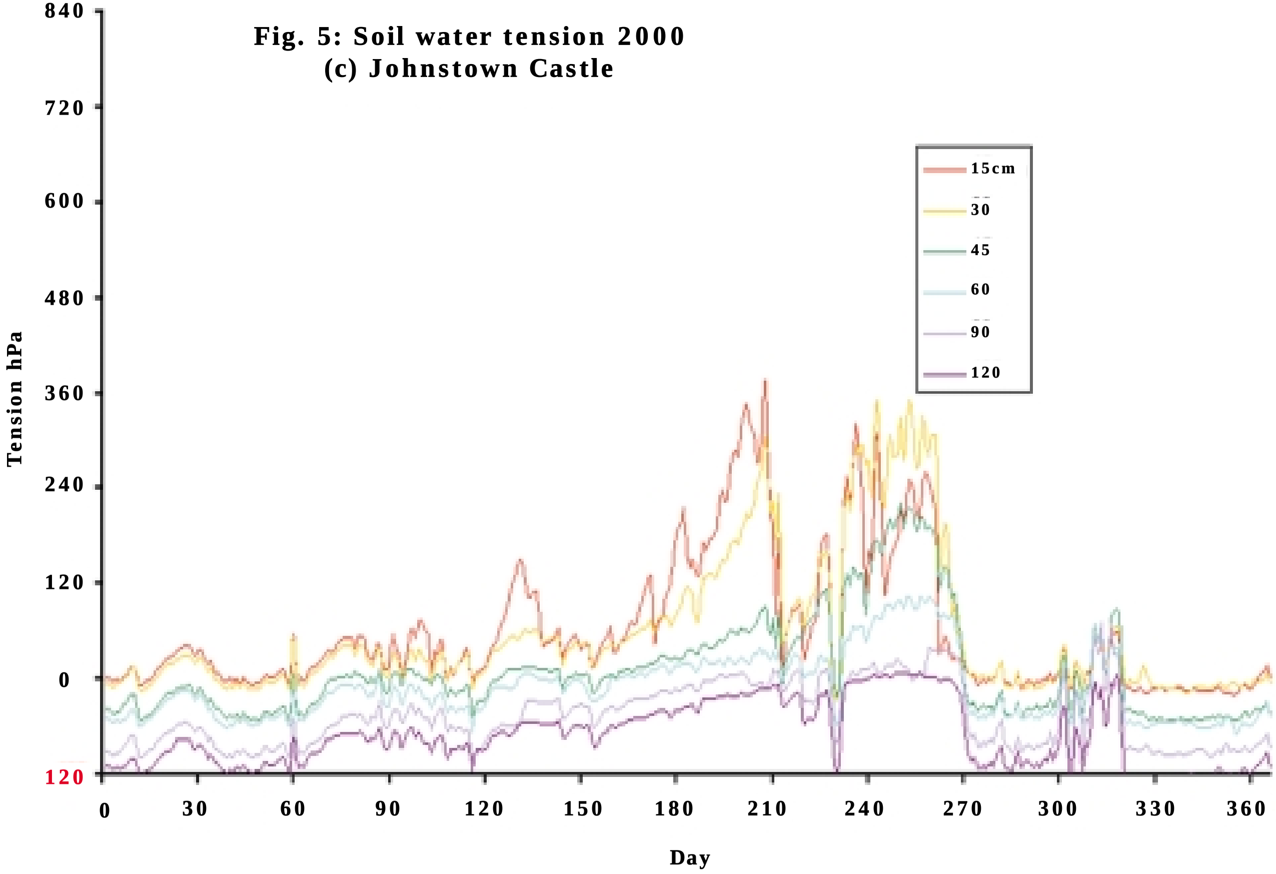


Fig. 5: Soil water tension 2000
(c) Johnstown Castle

At all depths, average annual tension was greater, (i.e. drier), at Ballintemple than at Clonroche or Johnstown Castle. In the subsoil, at depths ≤ 45 cm, the average annual soil moisture tension at each depth followed the sequence defined by soil morphology: Ballintemple > Clonroche > Johnstown Castle (Table 10). At 15 cm depth, average tension was the same at Clonroche and Johnstown Castle but at 30 cm depth, average tension was greater at Johnstown Castle. This probably reflected the difference in summer rainfall, which was 35 percent lower at Johnstown Castle. As in previous years, the largest maximum tension occurred at Ballintemple (471 hPa), but the maximum tension at Johnstown Castle (372 hPa) was greater than that at Clonroche (196 hPa). The average tension generally decreased with depth at each site except at Ballintemple, 90-cm depth, where the tension was greater than at 60-cm depth.

Table 10: Average soil water tension (hPa) 2000

Depth(cm)	Ballintemple	Clonroche	Johnstown Castle
15	73	58	61
30	68	39	58
45	70	25	11
60	45	6	-11
90	68	-0.5	-46
120	17	-31	-70

The soils were unsaturated (Tension > 0 hPa) throughout the year at 15-cm depth at Ballintemple and Clonroche (Table 11). The Gley soil at Johnstown Castle was saturated (Tension $\leq$ 0 hPa) at 15 cm depth for 89 days, which was more than in 1999. At all sites, the duration of saturation increased regularly with depth and at 120-cm depth ranged from 165 days at Ballintemple to 342 days at Johnstown Castle. Pressure head was measured twice weekly with piezometers at three depths at each site. In general, the duration of saturation derived from measurements with piezometers was slightly lower (Tensiometer = 1.009*Piezometer; r^2=0.82) but there were some large differences between the two methods e.g. Ballintemple, 120 cm depth (Table 11).

Table 11: Duration of saturation (days) 2000

Depth (cm)	Ballintemple Tensiometer[1]	Ballintemple Piezometer[2]	Clonroche Tensiometer	Clonroche Piezometer	Johnstown Castle Tensiometer	Johnstown Castle Piezometer
15	0		0		89	
30	3		1		106	
45	7	0	7	45	189	197
60	11		129		236	
90	11	23	153	71	303	287
120	165	33	336		342	366
135				122		

[1] Tension ≤ 0 hPa

[2] Head > 0 cm

DISCUSSIONS AND CONCLUSIONS

Systems comprising tensiometers and pressure transducers measured soil water tension satisfactorily for three years at remote sites. Methanol, added to the water in the tensiometers, prevented frost damage to the transducers. A theoretical limitation of tensiometers is that the operable range is restricted to moist conditions; they do not function at moisture tensions greater than 850 hPa, due to air entry. Traditionally, gypsum blocks have supplemented tensiometers to extend the range. However, over a three-year period, soil water tensions exceeded the limits of tensiometers only at the surface (15 cm) of the driest site for two weeks in one year. Thus the extension in range attained with other methods, under the prevailing moist conditions, would have been marginal. An alternative method consists of using TDR probes (Time Domain Reflectance), which can span both wet and dry conditions; but there are some indications that the precision is low at the wet end of the range, which is the part of the moisture spectrum that is most significant for evaluating the risk of overland flow. TDR and gypsum blocks measure water content and the soil moisture retention curve is needed to translate the data into pressure head. As it is not feasible to measure tension and water content at the same point, due to compression of the sample extracted by soil corers, errors are introduced due to the large spatial variation in soil water retention. Hence a direct measurement of tension is preferable. Tensiometric and piezometric data are comparable as both measure pressure. The water tables (positive pressure heads) detected by tensiometers were confirmed by piezometers at all sites. In general, there was good agreement between both methods although large discrepancies occurred at particular points. Tensiometers are preferable to piezometers as both negative and positive pressure heads are measurable. The disadvantage is that they must be serviced twice-weekly in summer and weekly in winter.

Although the sites were located near the 1000 mm long term isohyet to minimise climatic differences, rainfall at the well drained site was 25 percent greater than at the poorly drained site. Over the first two years, (1998, 1999) the seasonal and short-term fluctuations in soil water tension followed a similar pattern on a well drained clay loam (Clonroche), on a somewhat excessively drained sandy loam (Ballintemple) and on a poorly drained loam (Johnstown Castle). However, the pattern differed between all sites in the third year (2000) and appeared to reflect differences in seasonal rainfall.

The degree and duration of wetness differed consistently, over a three-year period. among soils differentiated according to natural soil drainage class. These classes are derived using redoximorphic features and soil texture; they provide a means of linking point measurements to the field and to soil maps thus giving areal expression to point measurements. Duration of saturation is important in the assessment of overland flow and potential recharge. Duration of saturation was consistently in the order poorly drained > well drained = somewhat excessively drained. The topsoil (15 cm) of the poorly drained soil was saturated each year for 45 to 111days whereas the well and excessively drained soils remained unsaturated, at the same depth, for the entire three-year period. This implies that there is a substantial risk of overland flow due to saturation excess on the poorly drained soil and a zero or, at most, slight risk on the well and excessively drained soils.

Gley soils occupy about 25 percent of the country. They comprise, in about equal proportions:

- very slowly permeable soils ("impermeable soils") on drumlins and Upper Carboniferous shales
- slowly permeable soils on limestone, sandstone and shale

The Johnstown Castle site represents the latter group and as the surface horizon is saturated for long periods, and for even longer periods in the subsoil, there is a substantial risk of overland flow due to saturation excess. The "impermeable" Gleys were not represented and are most likely saturated for longer periods than the Gley at Johnstown Castle. The infiltration study (Diamond and Shanley, 1998) showed that there was a substantial risk of overland flow in both winter and summer on a site at Castlecomer representing the "impermeable" Gleys.

Based on the general soil map (Gardiner, 1980) it is estimated that moderate, well and excessively drained soils ('free draining soils') occupy 42 percent of the country. The fine-textured Clonroche and coarse-textured Ballintemple soils span the textural and drainage range of the free draining soils. The persistence of unsaturated conditions throughout the year at 15 cm in these sites implies an equally low or negligible risk of overland flow on a large area of the country that contains virtually all of the intensively farmed areas. Fine textured soils, analogous to Clonroche, form about half of the free draining areas. Periodic saturation occurred in the Clonroche subsoil. Whether this presents a risk of overland flow needs to be tested by direct measurement of overland flow, if any, in the field.

On a plot that consisted predominantly of Gley soil, beside the Johnstown Castle site, overland flow comprised 35 percent of total rainfall (Kurtz, 2000). Based on data published by Burke et al. (1974), the average amount of overland flow, on an 'impermeable' Gley at Ballinamore, was 32 percent of total rainfall over a six year period. The amount was related to rainfall (r^2=0.86 **) and ranged from 17 percent at 906 mm rainfall to 46 percent at 1393 mm. The latter figure (46 percent) probably represents the upper limit for lowland mineral soils in Ireland. Combining this limit with inferences drawn from the current study it seems that overland flow ranges from zero to nearly half of rainfall and most (approx. two thirds) of the mineral soils are at or near the lower end of the range. The balance of effective rainfall and overland flow on specific soil types can form an input into the assessment of potential interflow and recharge.

The moisture regime is an essential criterion in soil classification (FAO, 1998). Two of the six moisture regimes defined in Soil Taxonomy (Soil Survey Staff, 1999) occur in Ireland. Aquic moisture regimes occur in soils that are saturated long enough to create anaerobic conditions. The duration of saturation or anaerobic conditions is not specified. The udic regime is drier than the aquic regime but it is not dry in any part for more than 90 days cumulative. The common method of identifying an aquic regime is to infer saturation and reduction from the presence of low ($\leq$ 2) chroma. The soil water tension measurements confirmed the inferred saturation of the aquic soil (Johnstown Castle) for long periods ranging from 72 days per year (cumulative average) in the A horizon to 351 days in the C horizon. The udic soils had a clearly shorter period of saturation; they could however remain saturated in certain horizons for a significant period. This was evident especially in the fine-textured Brown Earth (Clonroche) where the average duration of saturation increased regularly from zero in the A horizon to 318 days in the C horizon. This is evidently a zone of episaturation; a piezometer at greater depth did not record positive pressure head. Periods of saturation and reduction do not necessarily coincide; Vepraskas and Wilding (1983) found that a soil horizon was saturated for four months before the horizon's redox potential indicated that iron reduction was occurring. The relationship between saturation and reduction is influenced by the mode of recharge. Where soils are recharged by rainfall, as was obviously the case at Clonroche, saturation must occur for sufficient time to chemically reduce repeated influxes of aerated water.

ACKNOWLEDGEMENTS

We thank Mr. T. Shanley for performing the hydraulic conductivity measurements.

REFERENCES

Burke, W., Mulqueen, J. & Butler, P. (1974). Aspects of the hydrology of a gley on a drumlin. Ir. J. agric. Res. 13:215-228.

Conry M.J. & Ryan, P. (1967). Soils of Co. Carlow. Soil Survey Bulletin No. 17, An Foras Taluntais, Dublin.

Diamond, J. & Shanley, T. (1998). Infiltration rate assessment of some major soils. End of Project Report, Armis 4102, Teagasc, Dublin.

FAO. (1998). World reference base for soil resources. World Soil Resource Report 84. FAO, Rome.

Gardiner, M & Ryan, P. (1964). Soils of Co. Wexford. Soil Survey Bulletin No. 1, An Foras Taluntais, Dublin.

Gardiner, M. & Radford, T. (1980). General Soil Map of Ireland, An Foras Taluntais, Dublin.

Kurtz, I. (2000). Phosphorus exports from agricultural grassland with overland flow and drainage water (Johnstown Castle). In: 'Quantification of phosphorus loss from soil to water' (ed. H. Tunney), Environmental Protection Agency, PO Box 3000, Johnstown Castle, Co. Wexford, pages 9-56.

Rawls, W.J. & Brakensiek, D.L. (1983). A procedure to predict Green and Ampt infiltration parameters. In Advances in infiltration. Proc. of the Nat'l Conference on Advances in Infiltration. Dec. 12-13. Chicago, IL.

Richards, S.J. (1965). Soil suction measurements with tensiometers. In: Methods of Soil Analysis, Part 1 (ed. C.A. Black). American Society of Agronomy, Madison, USA, pages 153-163.

Soil Survey Division Staff. (1993). Soil survey manual. USDA Handbook No. 18, U.S. Government Printing Office, Washington.

Soil Survey Staff. (1999). Soil Taxonomy. Agriculture Handbook No. 436, Government Printing Office, Washington.

Vepraskas, M.J. & Wilding, L.P. (1983). Albic neoskeletans in argillic horizons as indices of seasonal saturation and iron reduction. Soil Sci. Soc. Am. J. 47:1202-1208.