The impact of soil preparation method on water-table depth in Irish forest plantations on wet mineral soils

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Abstract
The impact of a range of soil preparation treatments on water-table depth in surface water gley soils was investigated. Although water-table levels were lowered for brief periods during the winter months, generally soil preparation did not have a big impact upon soil water levels in the types of wet mineral soils investigated at the study sites. Mound drains were found to lower the water-table during the winter for a distance of only 3 m from the drain. Mole drainage, however, when used on a suitable site, did lower the water-table uniformly. These results indicate that mole drainage may be more effective in lowering the water-table on these site types than mechanical mounding. However, continued evaluation of these experiments is required to assess the long-term effectiveness of the different soil preparation methods in lowering the water-table depth and improving tree stability.

Introduction
Roots are the below ground structures which supply water, minerals and support to the stem, leaves and flowers of a plant (Sutton 1969, Kozlowski 1971). Root growth is not completely random; each species possesses an internal mechanism to determine the structure of its root system. However, it is the external environment that creates the variability in rooting pattern (Henderson *et al.* 1983). Variations in water supply are frequently a cause of differences in the distribution of roots, particularly the depth they attain in the soil (Russell 1977). Gleys and peaty soils are particularly prone to waterlogging, as microaerophilic and anaerobic conditions can occur over prolonged periods (Smith 1976), inhibiting root growth (Sutton 1969).

Direct planting of trees into soils with a high water content and/or a high water-table has led to poor plant establishment in forest plantations in Ireland (Savill 1976). In addition, surviving trees usually experience check and poor early growth. Furthermore, stands of trees planted on such sites have frequently been found to have very shallow root systems (Horton 1958, Fayle 1965) and to lack stability (Ray and Nicoll 1998). The physical soil conditions necessary for tree survival, growth and stability can however be created on many poor sites by soil cultivation and drainage (Sanderson and Armstrong 1978). Establishment methods include deep drainage by ploughing or mounding, ripping or ploughing to disrupt iron pans, and moling to provide closed drainage systems (Ford and Deans 1977, Anon. 2000). Deep drainage has often been unsuccessful on fine textured soils, with the drainage effects restricted to areas immediately adjacent to drains (Armstrong *et al.* 1976). The ideal soil preparation technique should increase the degree of soil aeration by removing excess water, disrupt indurated soil layers/horizons (if present), provide an improved rooting medium for root proliferation, increase soil aeration and hence nutrient availability and reduce the impact of competing vegetation.

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Experimentation on soil preparation techniques for forest establishment has been carried out in Ireland for at least 70 years (OCarroll 1972). The most important techniques investigated and used, both in Ireland and abroad are spaced furrow ploughing (Savill 1976, Håkansson and Lindström 1994, Coutts and Philipson 1987), ripping (Chavasse 1978, Anon. 1980), mole drainage (Hendrick 1989) and mounding (Sutton 1993, Örlander *et al.* 1991). Most of the research work has been aimed at improving the establishment and early growth of tree crops planted on hard or wet soils. Assessments carried out in Ireland generally involved the measurement of survival and crop growth, with less attention given to the effect of soil preparation and drainage on water-table depth, root development or long-term crop stability. This article describes the impact of a range of soil cultivation practices upon water-table depth in surface water gley soils. The experiments and results presented here were part of a larger project examining the development of Sitka spruce crops on wet mineral soils (Wills 1999, Wills *et al.* 1999).

Materials and methods

Site description

Two experimental sites, located in the mid-west of the country, at Ballygar in Co Galway and at Strokestown in Co Roscommon, were selected for study. The soils at Ballygar and Strokestown were surface water gleys (Gardiner and Radford 1980) and best match the FAO-UNESCO (1971-81) types: Ballygar – Stagno-eutric Gleysol with incipient fragipan; Strokestown – Stagno-dystric Gleysol. Prior to the establishment of the field trials (Hendrick 1990) in 1990, the Ballygar site was neglected farmland consisting of small fields, some overgrown with furze (*Ulex* spp.) and whitethorn (*Crataegus monogyna*). The predominant vegetation was grass/rush (*Poa* spp/*Juncus* spp). The Strokestown site was in agricultural use before planting and had been cultivated. The predominant vegetation was

Table 1. *Location of and topography at the experiment sites.*

Experiment site	*Location*	*Elevation m*	*Aspect*	*Exposure*
Ballygar	53° 33' N; 08° 21' W	65	Flat, with slope generally of 1° or less.	Sheltered
Strokestown	53° 44' N; 08° 05' W	100	South-west, with slope of 2° - 3°.	Exposed

Table 2. *Site and crop descriptions including geology, soil type and vegetation.*

Site	*Geology*	*Soil*	*Vegetation*	*Crop*
Ballygar	Old red sandstone and some glacial drift of mixed origin.	Uppermost layer of shallow medium loam with an abrupt change to a sandy/stony, impervious gley.	*Poa and Juncus* spp.	Sitka spruce planted in 1990 at 2 x 2 m spacing.
Strokestown	Mixed sandstone/ limestone drift and glacial lake deposits.	Upper layer of medium loam changing to a sandy/stony, impervious gley.	*Poa and Juncus* spp. with some *Rubus* spp.	Sitka spruce planted in 1990 at 2 x 2 m spacing.

grass/rush (*Poa* spp/*Juncus* spp) and some briar (*Rubus* spp). Additional information on each of the sites is provided in Tables 1 and 2.

Experiment design

The experiments at Ballygar and Strokestown were established in 1990. The experimental design employed at both sites was a randomised block design, with three replications (Table 3). The experiments were blocked according to variations in soil type and/or the positions of the plots on the slope. There were four treatments at both Ballygar and Strokestown: mechanical mounding (the creation of mounds of soil to provide a raised planting position and drains for the removal rainfall and soil water); mole drainage (installed using a tine with a bullet shaped expander); mole drains combined with mounds; and a no soil preparation control.

Table 3. *Experiment design and soil preparation treatments at each site.*

Site	*Experiment design*	*Treatment*	*Distance between drains*	*Depth of drains*
			m	*m*
Ballygar	Randomised block design (3 blocks)	Machine mounding	16.0	0.45
		Mole-and-mound	2.0	0.35-0.40
		Mole	2.0	0.35-0.40
		Control, no soil preparation	---	---
Strokestown	Randomised block design (3 blocks)	Machine mounding	12.0	0.45
		Mole-and-mound	2.0	0.35-0.40
		Mole	2.0	0.35-0.40
		Control, no soil preparation	---	---

Water-table measurement

Water-table measurements were carried out at Ballygar and Strokestown from April 1995 to April 1996 and from October 1996 to April 1997. Slotted drainage pipes, 70 mm diameter were installed, using a soil auger to a depth of 0.6-0.9 m in the centre of each plot, and at 0.5, 1.0, 2.0, 3.0 and 8.0 m from the edge of the drains in the machine mounded mound plots at Ballygar (drains 16.0 m apart). At Strokestown wells were installed in the same treatment at 0.5, 1.0, 2.0, 3.0 and 6.0 m from the mound drains (drains 12.0 m apart). At both sites the mole-drained plots had wells installed at 0.2, 0.5, and 1.0 m from the mole drain centres (2.0 m apart). In the control plots, three wells were placed in the centre of each plot at 1.0 m apart. Approximately 5 cm of drainage pipe was left protruding above ground level at each location. Above-ground pipe slots were sealed with soil. Each pipe was covered with a plastic cap.

Water-table readings were taken from a graduated measuring rod with a float attached to the bottom. The rod was calibrated to allow for the part-immersion of the float. When inserted in the well, the rod floated on the water and a reading was taken to the top of the pipe. Readings were taken to the nearest 0.5 cm and were adjusted to ground level.

Readings were taken at monthly intervals from April 1995 to April 1996, and twice monthly from October 1996 to April 1997. During the months of May to September 1995 almost all of the wells were dry at both sites. Hence, in the second measuring period (1996/1997) measurements were not taken during those months but were increased to twice monthly readings for the remainder of the year. Water-table depths were measured from October 1996 to April 1997. Daily rainfall values were obtained from weather stations at Ballygar and Carrowclogher (both within 5 km of the experiment sites). The cumulative periodic rainfall from one measurement to the next is presented in the Results section, along with the water-table depths.

Data analysis

The data set from each site was analysed as a randomised block design, using the SAS (SAS 1990) General Linear Models (GLM) procedure. Water-table depth was treated as the dependent variable with experiment treatment (machine mounding, mole-and-mound, mole, and no soil preparation) and block as the independent variables. Within treatments, the impact of the distance from the drains on water-table depth was analysed. As the depth to the water-table was greater than the depth of the wells during the summer months, and therefore the true depth to the water-table was not known, the data from Ballygar for the months of May 1995 to September 1995 and the data from Strokestown for the months of May 1995 to October 1995 were omitted from the data sets used in the statistical analysis. These data sets are referred to as the 'complete data sets'. Data sets, using only readings taken on dates when the average depth to the water-table in the control plots was less than 25 cm, were also compiled. These data sets are referred to as the 'reduced data sets'.

Results

The effect of machine mounding on the depth of the water-table

The effect of the machine mounding treatment on the depth of the water-table was different at the two sites. At Ballygar, the depth to the water-table at any distance from the mound drain was similar to the water-table depth in the control plots (Figure 1). Analysis showed that the depth of the water-table did not change with increasing distance from the mound drain (Table 4).

Statistical analysis showed that the depths to the water-table in machine mounding plots did not differ significantly from those in the control, mole or mole-and-mound plots (Table 5).

At Strokestown, however, during periods of high rainfall the depth to the water-table was greater in wells within 3 m of the mound drain than those at greater distances from the drain (Figure 2). When the complete data set was analysed no significant differences were found between the wells with increasing distance from the mound drain (Table 6), nor were there significant differences among the average depths to the water-table in the different soil preparation treatments (Table 7). However, on dates when the average water-table depth in the control plots was less than 25 cm (using the reduced data set), depths were significantly lower at distances of less than 3 m from the mound drain compared to the depths at distances greater than 3 m from the drain (Table 6). In addition, when using the reduced data set, the average water-table depth level in the control plots was significantly less than in the plots with mole drains (Table 7).

Table 4. *The effect of distance from the machine mounding drain on the depth of the water-table at Ballygar from October 1995 to April 1997. (Results in the same column with different letters alongside indicate a significant difference at the p ≤ 0.05 level.)*

Distance from mound drain	*Mean water-table depth and pairwise t-test*	
	Complete data set	*Reduced data set*
m	*cm*	
0.5	23.22 A	16.90 A
1.0	22.48 A	15.07 A
2.0	22.76 A	15.47 A
4.0	23.83 A	16.33 A
8.0	21.11 A	12.83 A
Standard error of difference between two means	5.076	6.007

Table 5. *The effect of soil preparation treatment on the water-table depth at Ballygar from October 1995 to April 1997. (Results in the same column with different letters alongside indicate a significant difference at the p ≤ 0.05 level.)*

Treatment	*Mean water-table depth and pairwise t-test*	
	Complete data set	*Reduced data set*
	cm	
Machine mounding	23.69 A	15.32 AB
Mole-and-mound	23.18 A	12.80 A
Mole	31.32 A	23.13 B
Control	22.72 A	13.00 A
Standard error of difference between two means	4.602	4.244

Table 6. *The effect of distance from the machine mounding drain on water-table depth at Strokestown from November 1995 to April 1997. (Results in the same column with different letters alongside indicate a significant difference at the p ≤ 0.05 level.)*

Distance from the mound drain	*Mean water-table depth and pairwise t-test*	
	Complete data set	*Reduced data set*
m	*cm*	
0.5	38.37 A	32.65 A
1.0	42.64 A	36.06 A
2.0	44.56 A	38.94 A
3.0	31.17 A B	25.04 AB
6.0	19.63 B	9.30 B
Standard error of difference between two means	6.687	9.036

Table 7. *The effect of soil preparation treatment on water-table depth at Strokestown. (Results in the same column with different letters alongside indicate a significant difference at the p ≤ 0.05 level.)*

Treatment	*Mean water-table depth and pairwise t-test*	
	Complete data set	*Reduced data set*
	cm	
Machine mounding	36.59 A	29.99 AB
Mole-and-mound	40.26 A	34.51 B
Mole	39.89 A	34.75 B
Control	29.04 A	17.65 A
Standard error of difference between two means	7.072	7.072

The effect of moling and of moling combined with mounding on the depth to the water-table

In the mole treatment, the water-table depth at 0.2 m from the mole drain at Ballygar was deeper than the water level at 0.5 or 1.0 m from the mole (Table 8). This was especially the case during periods when the water-table was high. However, statistical analysis showed no significant differences ($p \leq 0.05$) in water-table depth with increasing distance from the mole, even when the reduced data set was used (i.e. only those readings when the depth to the water-table in the control plots was less than 25 cm). In contrast, in the mole-and-

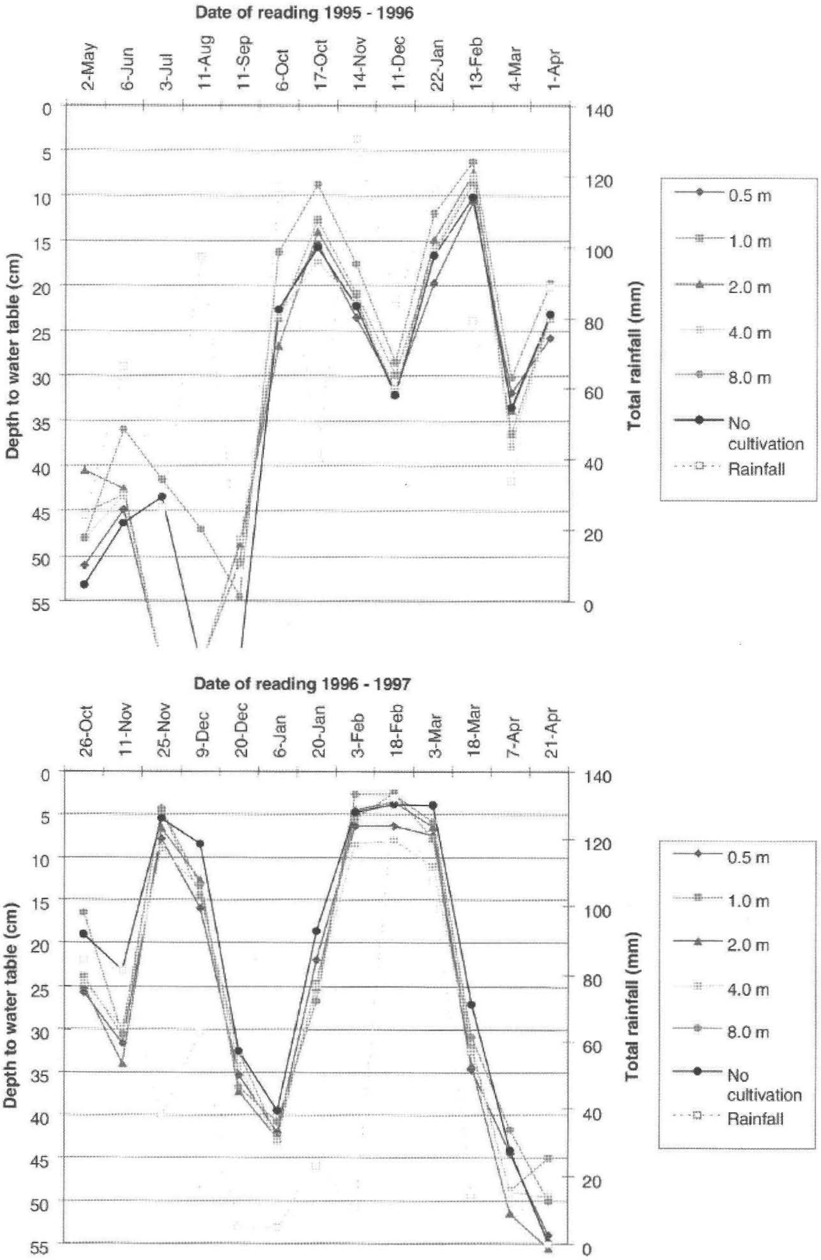

Figure 1. *Cumulative periodic rainfall and the fluctuation of water-table depth with respect to distance from the mound drains (16 m apart), from May 1995 to April 1997 in the machine mounding plots at Ballygar.*

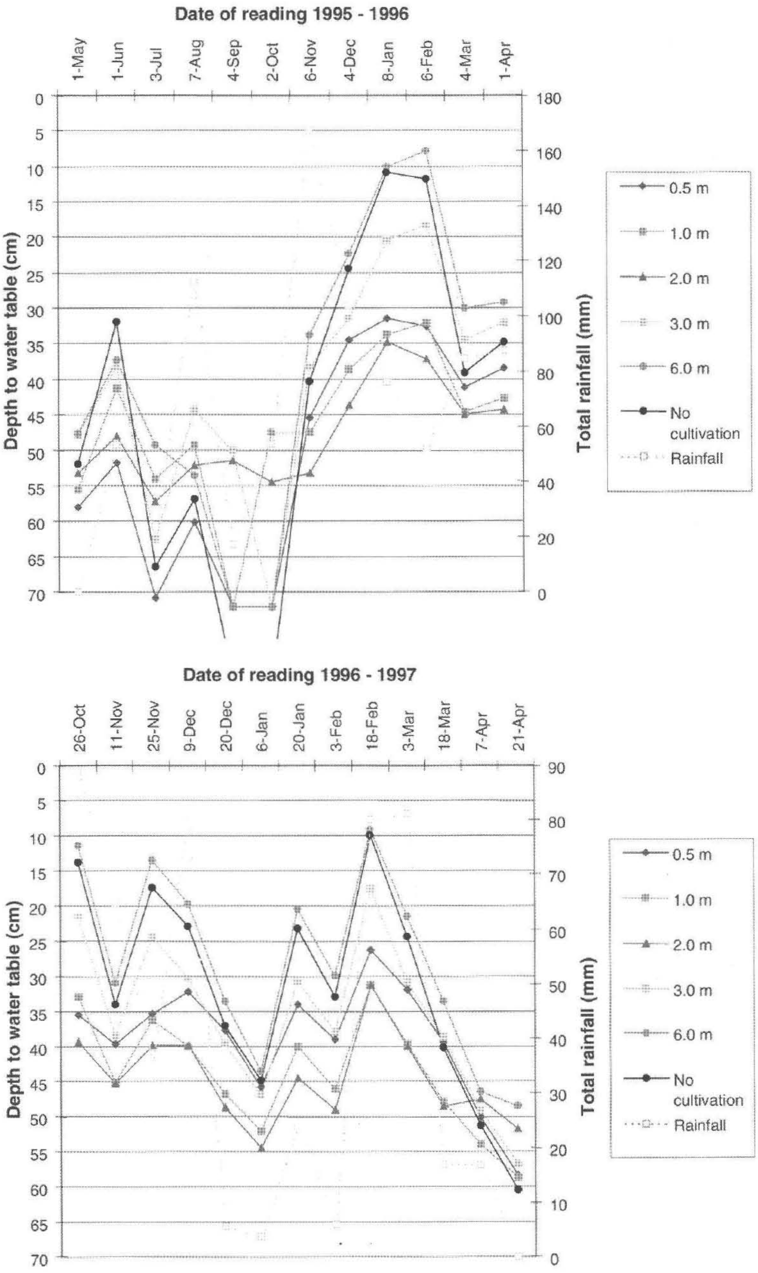

Figure 2. *Cumulative periodic rainfall and the fluctuation of water-table depth with respect to distance from the mound drains (12 m apart), from May 1995 to April 1997 in the machine mounding plots at Strokestown.*

mound treatment at Ballygar, there was very little difference between the water-table at distances of 0.2 and 0.5 m from the mole, and the water-table depth at 1.0 m from the mole was lower than in the two sets of wells nearer the mole (Table 8). However, no significant difference in water level was found between wells with increasing distance from the mole drain.

On average, the depth to the water-table in the mole plots at Ballygar was lower than that in the other soil preparation treatments or in the control (Table 5). The average water-table depth in the mole plots was 8.6 cm (complete data set), and 10.1 cm lower (reduced data set) than in the control plots. However, the water-table depth in the mole plots was only statistically different with the depth in the mole-and-mound and control plots, and only when the reduced data set was used. The mole-and-mound treatment had no effect on lowering the depth to the water-table, even during periods of high rainfall (Table 5).

Table 8. *The depth to the water-table at different distances from the drains in the mole and mole-and-mound plots at Ballygar. (Results in the same column with different letters alongside indicate a significant difference at the p ≤ 0.05 level.)*

Distance from the mole drain	*Mean water-table depth and pairwise t-test*			
	Mole		*Mole-and-mound*	
	Complete data set	*Reduced data set*	*Complete data set*	*Reduced data set*
m	*cm*			
0.2	33.12 A	28.97 A	18.57 A	10.07 A
0.5	29.12 A	20.77 A	19.44 A	11.50 A
1.0	27.95 A	19.53 A	23.58 A	16.83 A
Standard error of difference between two means	5.289	4.317	3.689	3.036

As at Ballygar, the water-table depth at 0.2 m from the mole drain as at Strokestown was slightly deeper at 0.5 or 1.0 m from the drain (Table 9). This was especially the case during periods when the water-table was high. However, as at Ballygar, the differences were not statistically significant ($p \leq 0.05$), even for the reduced data set. In the mole-and-mound treatment there was very little difference in water-table depth at 0.2, 0.5 or 1.0 m from the mole (Table 9). In contrast to Ballygar however, the average water-table depth at Strokestown in both the mole and mole-and-mounded plots was deeper than in the control plots (by 10.9 and 11.2 cm respectively) when the complete data set was used (Table 7). These differences increased to 17.1 cm and 16.9 cm respectively when the reduced data set was used. Although these were not significant for the complete data set, the average water depth in the mole and mole-and-mound plots was significantly deeper when compared to the control plots in the reduced data set (Table 7).

Table 9. *The depth to the water-table at different distances from the drains in the mole and mole-and-mound plots at Strokestown. (Results in the same column with different letters alongside indicate a significant difference at the $p \leq 0.05$ level.)*

Distance from the mole drain	*Mean water-table depth and pairwise t-test*			
	Mole		*Mole-and-mound*	
	Complete data set	*Reduced data set*	*Complete data set*	*Reduced data set*
m	*cm*			
0.2	46.15 A	40.70 A	40.55 A	33.93 A
0.5	36.35 A	31.63 A	42.86 A	38.37 A
1.0	38.52 A	33.77 A	40.00 A	34.70 A
Standard error of difference between two means	8.369	11.135	4.090	5.023

Discussion

The effect of soil preparation method

The impact of soil preparation method upon water-table depth was quite different at Ballygar and Strokestown. However, at both sites the positive soil drainage effects, if any, were restricted to the soil immediately adjacent to the drains. Similar results have been found in other drainage studies on gley and peat soils, such as by Savill (1976), Schaible and Dickson (1990) and Armstrong *et al.* (1976). At Ballygar machine mounding did not lower the water-table compared to the control treatment. At Strokestown however, machine mounding lowered the water-table during the winter period, by 12 cm on average, although the effect was only significant at distances within 3 m of the mound drains (Table 6). At both sites, mole draining showed a slight lowering of the water-table at 20 cm from the mole drain. This effect, however, was not statistically significant. A similar trend was not observed in mole-and-mound plots. At the Strokestown site, moling and mole and-mound lowered the water-table level by 17 cm on average during the winter months. At Ballygar, moling also lowered the level of the water-table (by 10 cm on average), although the effect was much less noticeable than at Strokestown. The mole-and-mound treatment at Ballygar had no effect on the depth of the soil water-table.

Water-table and rainfall

Generally an increase in cumulative rainfall was reflected in a decrease in water-table depth at Ballygar and Strokestown; likewise a decrease in cumulative rainfall led to an increase in water-table depth. Even where no soil preparation took place, the water-table level fell rapidly once heavy rain events were over. Thus, for example, while the water-table depth in the undrained plot at Strokestown in early 1997 came within 10 cm of the soil surface (Figure 2), this was maintained for one observation period only. Thereafter, the water-table fell rapidly in response to decreasing rainfall amounts. There were some occasions, however, when the cumulative rainfall amount increased but the depth to the water-table decreased, or vice versa. These anomalies may be explained by the distribution of the rainfall in the preceding month or fortnight, relative to the time of water-table measurement.

During the summer months, the water-table at both sites was deep; most of the time the wells (varying in depth between 50 and 80 cm) were dry. During the winter months, the drainage impact was most apparent when the water-table was at its highest, or at least not lower than 25 cm in the control plots. On average, in the control plots the winter water-table was at a depth of 13 and 17.7 cm at Ballygar and Strokestown respectively.

Rooting depth at Ballygar was not affected by the depth to the water-table, as maximum rooting depth had not yet reached the mean winter water-table in any of the soil preparation treatments (Wills 1999). At Strokestown, mean winter water-table depth did not appear to have a restricting effect on rooting depth of the trees, with roots found at a maximum depth of 50 cm. This was probably due to the rapid fluctuation of the water-table with changes in rainfall amounts (Wills 1999), leaving the top layer of the soil below the water-table sufficiently oxygenated (Nisbet *et al.* 1989).

Site differences

The soil preparation treatments were more effective at increasing water depth at Strokestown. This may have been due to a number of factors: slightly greater slope at Strokestown may have improved the effectiveness of the mole drains compared to Ballygar. At Ballygar, most of the site was flat, with only a very small slope in parts. In addition, the soil at Strokestown was slightly more clayey in texture. Mole drainage is generally more effective on clayey gleys, as moles tend to collapse if the proportion of sand in the soil is high (Savill 1976, Hendrick 1989).

Conclusion

Although water-table levels were lowered for brief periods during the winter months at Strokestown, soil preparation generally did not have a big impact on water-table depth in the types of soil found at Ballygar and Strokestown. At Strokestown mound drains were found to lower the water-table during the winter within a distance of 3 m from the drain. Mole drainage, when used on a suitable site (Strokestown), did lower the water-table during the winter months. These results indicate that mole drainage may be more effective in lowering the water-table on these site types than mechanical mounding. However, continued evaluation of these experiments is required to assess the long-term effectiveness of the different drainage and cultivation methods in lowering the water-table depth and improving stability.

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