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The impact of broadleaved woodland on water resources in lowland UK:
III. The results from Black Wood and Bridgets Farm compared with those from other woodland and grassland sites

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Abstract

In the United Kingdom the planting of broadleaved woodland has led to concerns about the impact on water resources. Comparative studies, typically using soil water measurements, have been established to compare water use of broadleaved woodland and grassland. The diversity of outcomes from these studies makes it difficult to make any consistent prediction of the hydrological impact of afforestation. Most studies have shown greater drying of soils under broadleaved woodland than under grass. However, two studies in a beech wood growing on shallow soils above chalk at Black Wood, Micheldever, Hampshire showed little overall difference between broadleaved woodland and grass, either in soil water abstraction or in evaporation. Two factors are thought to contribute to the different results from Black Wood. It is known that evaporation can be considerably enhanced at the edges of woodlands or in small areas of woodlands. The studies at Black Wood were made well within a large area of fairly uniform woodland. Other studies in which a difference occurred in soil drying between broadleaved woodland and grass used measurements made in small areas of woodlands or at woodland edges. Another important difference between comparison of woodland at Black Wood and grassland growing nearby, also on shallow soils above Chalk, compared to other broadleaved woodland/grass comparisons, growing on other geologies, is the influence of the Chalk. Although vegetation such as grass (and woodland) does not populate the chalk profusely with roots, water can be removed from the Chalk by the roots which proliferate at the soil/chalk interface and which can generate upward water movement within the Chalk. Published work showed that only in a very dry summer did the evaporation from grass growing on shallow soils above chalk fall below potential. In broadleaved woodland/grass comparisons on non-chalky soils it is possible that moisture deficits in the soil below the grass may reach critical levels and reduce evaporation below that of the woodland with which it is being compared.

Keywords: land use, water resources, broadleaved woodland, grass, literature review, edge effects, woodland size, geology

Introduction

The increase in the area of broadleaved woodland in lowland UK (Forestry Commission, 2001) in response to various incentives has raised concerns about the impacts of afforestation on water resources (HMSO, 1996). Results from existing comparative studies of the water use of woodland versus grass are inconsistent; in some, water use by woodland was substantially greater whilst in others, the difference was negligible. It is essential to be able to predict, with confidence, the likely impact on water resources of woodland planting in diverse environmental situations.

Harding *et al*. (1992) found that the water use by broadleaved woodland at Black Wood in southern England did not exceed that of grassland. This outcome was re-interpreted by Calder *et al*., (1997; 2000) on the assumption that drainage does not occur in chalk below soils with a significant moisture deficit and suggested that a substantial fraction of the soil moisture drainage measured by Harding *et al.* (1992) was, in fact, additional woodland evaporation.

However, Roberts and Rosier (2005) and Roberts *et al.* (2005), using different approaches, have shown that, despite seasonal differences, on an annual basis the drainage below broadleaved woodland at Black Wood was essentially the same as from adjoining pasture at Bridgets Farm, thus confirming the original findings of Harding *et al*., (1992).

To rationalise the different results from comparisons in lowland UK of evaporation from broadleaved woodland and grassland on soils, all relevant studies have been re-examined and their results compared with rather more intensive investigations at Black Wood and Bridgets Farm. It has been shown that the alternative hypothesis of Calder *et al*. (1997) for the Black Wood 'anomaly' is untenable, so a rational physical explanation has been sought for the near equality of water use by broadleaved woodland and pasture.

Methods

Except for the study of Bending and Moffat (1997) at the Straits Inclosure, Surrey, aimed to emulate the exposed conditions experienced by woodland planted on landfill, the justification for comparative studies of soil water changes and evaporation from broadleaved woodland and grassland has been to determine the impacts of land use on water resources. To compare soil water changes below broadleaved woodland and grass, for each study an occasion has been chosen when the soil under each land use was wet during the winter months. The soil water content at this point was then used as a datum and any subsequent reductions in the water content of the soil profile are referenced to this point. In another study, reported by Williams (1971), McGowan and Williams (1980a and b) and McGowan *et al*., (1980), evaporation estimates from broadleaved woodland and grass are compared using soil water changes and a soil water balance approach.

SITES

Table 1 summarises environmental information on the woodland sites used in the various comparisons. In all cases, soil profile water content changes were derived only from frequent measurements of soil profile water contents made using neutron probes.

Black Wood and Bridgets Farm, Hampshire

Both sites are on shallow soils of the Andover series above chalk (Jarvis, 1973). Measurements in the extensive forest were made well away from any edges in a large block of even-aged beech woodland. Full details of the experimental set up at Black Wood and Bridgets Farm are given in Roberts and Rosier (2005).

Straits Inclosure, Surrey

Soil moisture content changes at the edge of a 0.8 km^2, 35-year old oak woodland with an understorey of hazel and holly were compared with those under permanent grassland, adjacent to the woodland, on clay soils at the Straits Inclosure, Alice Holt, Surrey by Bending and Moffat (1997). The soil, of the Wickham series (Jarvis *et al*., 1984), had loamy upper layers over clay.

Clipstone Forest, Nottinghamshire

A comparison of oak, pine, heather and grass was made at Clipstone, Notts. (Calder *et al*., 2000; Calder, 1999). The sites are on sandy soils over Triassic Sandstone and the woodland extended to more than 5 km^2 but the experimental plot was within 50 m of the edge of the woodland.

Wellhouse Farm, Berkshire

A mixed woodland of oak, larch and chestnut was compared with adjacent grassland near Hermitage, Berkshire by Finch (2000). The site is on loamy sand alluvial soils and the woodland area was 1ha.

Kingston Brook catchment, Leicestershire

Studies reported by Williams (1971), McGowan and Williams (1980a and b) and McGowan *et al*., (1980) were based on measurements made in the Kingston Brook catchment, Leicestershire. Measurements of rainfall and soil

Table 1. Details of woodlands referred to in the comparisons

Woodland	*National Grid Ref.*	*Soil type*	*Location of study in woodland*
Black Wood	SU 542432	Shallow clay (0.6m) over chalk	Within 35 ha compartment surrounded by similar woodland of total area 2.5 km^2
Straits Inclosure	SU802398	Loam over clay	10-15 m from woodland edge
Clipstone	SK622612	Sandy soil over Triassic sandstone	Within 50 m of edge of woodland of >5 km^2
Wellhouse	SU522724	Loamy sand, alluvial soil	Within a woodland of 1 ha
Kingston Brook	SK570245	Coarse loamy soil	10-20 m from edge of 12.5 ha woodland

water content were used to calculate evaporation from a water balance in a range of land use types, i.e. cereals, grass and mixed woodland consisting of beech, sweet chestnut and sycamore. The woodland, subsequently referred to here as Rempstone Hall, is in a narrow belt (250 × 500m) about 12.5 ha in area and is located west of the village of Rempstone. Five soil moisture access tubes were located about 10 to 20 m from the north edge of the woodland (Dr Jim Williams, *pers. comm.*, 2004). There were four neutron probe access tubes in permanent pasture close to Rempstone. The soils were coarse loamy soils of the freely drained Newport and the imperfectly drained Arrow series (Thomasson, 1971).

Results

The soil water content changes below beech woodland at Black Wood and grassland at Bridgets Farm referenced to the values on 21 January 1999 are shown in Fig. 1. Although the soil begins to dry out at Bridgets Farm earlier in both 1999 and 2000 by the middle of summer, in both years, the difference in profile soil water content from the winter datum values are very similar. Note that soil wetting occurs more rapidly below the grassland than the beech woodland. Further details of this work can be found in Roberts and Rosier (2005).

The soil water content changes below the oak woodland at the Straits Inclosure and the adjacent grassland referenced to the wettest period are shown in Fig. 2. In all three years of the study (1993, 1994 and 1995) greater drying occurs below the woodland compared to the grassland. The degree of drying below both woodland and grass increases from 1993 to 1994 and drying is most evident in 1995, the year with the least rainfall. In 1993 and 1995, but not in 1994, the soil below the grass begins to dry before the woodland but later the woodland dries out more rapidly and eventually exceeds that of the grassland. In 1994 there was a significant period when the drying below woodland and grass appeared to proceed at similar rates. However, in 1993 and 1995, there was only a short period when rates of water abstraction below woodland and grass were the same; higher water demand by the grass in the spring was exceeded by that by the woodland later in the year and the cross-over between grass and woodland occurred rather sharply. It would appear that in 1993 and 1994 the wetting up of the profile is more protracted below the woodland compared to the grass. It is not possible to say what happened in 1995 as the data record is incomplete.

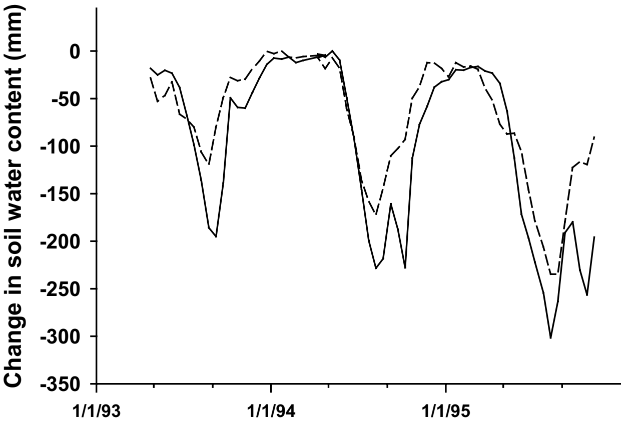

Fig. 2. Seasonal changes in soil water content below oak (—) and grassland (----) at Straits Inclosure relative to the soil water content in the Spring of 1993 (after Bending and Moffat, 1997).

The soil water content changes below the oak woodland at Clipstone and adjacent grassland referenced to the wettest

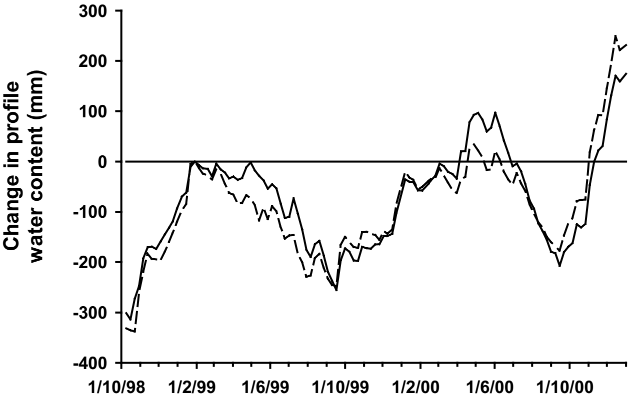

Fig. 1. *Fluctuations in profile soil water contents from 9 October 1998 to 22 December 2000 for the upper 7.8 m of soil at Black Wood (—) and Bridgets Farm (----).*

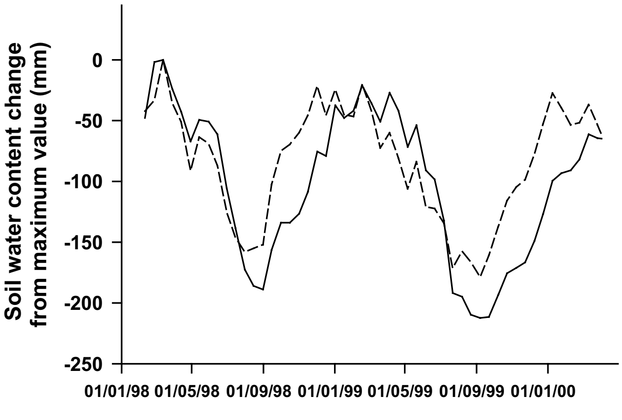

Fig. 3. *Seasonal changes in soil water content below oak (—) and grassland (----) at Clipstone relative to the soil water content in the spring of 1998 (after Calder* et al.*, 2000).*

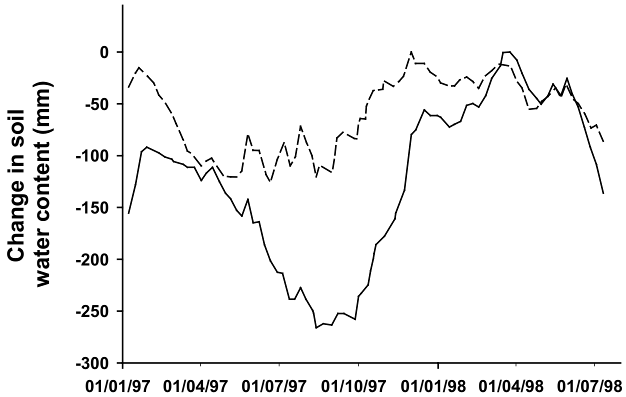

Fig. 4. *Seasonal changes in soil water content below oak (—) and grassland (----) at Well House Farm relative to the soil water content in the spring of 1998 (after Finch 2000).*

period are shown in Fig. 3. There are important similarities between the data from Clipstone and that from the Straits Inclosure (Fig. 2). Drying of the soil under the woodland is greater but drying occurs first under the grassland. In both years of the study, rewetting is slower under the woodland than under the grass.

The soil water content changes in woodland and adjacent grassland referenced to the wettest period at Wellhouse Farm for 1997 are shown in Fig. 4. The drying below the woodland is substantially more than that below the grassland than was observed at either the Straits Inclosure or Clipstone. The results from Wellhouse Farm also differ in that any initial drying below the grass does not exceed that from the woodland but, as in the case of the Straits Inclosure and Clipstone studies, the wetting up of the soil below the woodland is slower than under the grassland.

Figure 5 shows the cumulative evaporation for woodland and grass in 1969 and 1970 presented by McGowan and Williams (1980b). By the end of October, in both years, there has been substantially more evaporation from the woodland than from the grassland. In 1970 there was a full season of measurements that included the leafed period of the trees. In that year cumulative evaporation from the grass exceeded that from the woodland up until around mid- June.

Discussion

Explanations are possible for the different patterns of soil water behaviour or evaporation observed at four broadleaved woodland sites (Straits Inclosure, Clipstone, Wellhouse Farm and Rempstone Hall) and adjacent grassland sites and the similar behaviour observed in the comparison between Black Wood and Bridgets Farm. At Black Wood and Bridgets Farm, as well as similar soil moisture changes (Roberts and Rosier, 2005), eddy flux studies also indicated that evaporation from the woodland was similar to that from grassland (Roberts *et al*., 2005).

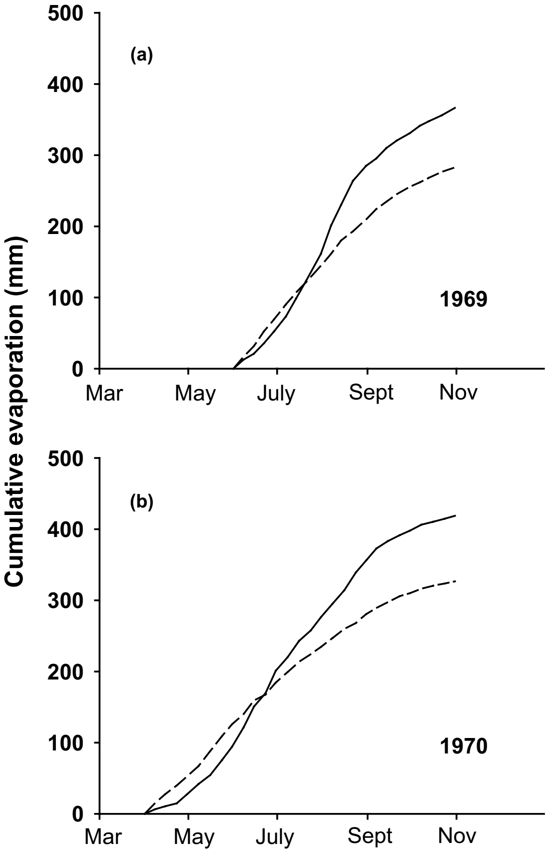

Fig. 5. *Cumulative evaporation from woodland (—) and grassland (----) in the Kingston Brook catchment, Leicestershire in (a) 1969 and (b) 1970 (after McGowan and Williams,1980b).*

Three hypotheses have been suggested to explain the contrast between the Black Wood and Bridgets Farm results with those of the other woodland/grass comparisons. Given the importance of the Chalk aquifer in lowland England (around half of all groundwater abstracted comes from the chalk), it is crucial that water resource planners and policy makers understand the situations under which broadleaved woodland and grassland water use might be similar.

HYPOTHESIS 1 'EDGE EFFECTS'

Because evaporation is enhanced at the edges of forests, in any woodland versus grass comparison in a small area of woodland or at a woodland edge, evaporation may well be substantially greater than from adjacent grassland.

Apart from Black Wood, all the forest sites are either small blocks of woodland (Wellhouse Farm and Rempstone Hall) or the woodland measurements were made close to the edge of the woodland (Clipstone and Straits Inclosure). Black

Wood is different in that the hydrological studies were carried out well within the body of a relatively large woodland area (2.7 km^2).

There is abundant evidence that evaporation processes are enhanced at woodland edges and therefore measurements of evaporation and transpiration made close to a woodland edge or in a small patch of woodland are probably enhanced by the 'edge' factor. Forest edges are normally characterised by the leaf area extending down to ground level and exposed to full solar radiation. As a consequence of the fuller canopy and changed microclimatic conditions, transpiration loss is likely to be enhanced at a woodland edge. In addition, wind speeds at the edge of a forest or woodland, rather than close to the edge of a forest ride, will approach those experienced on more open ground. Here, because of exposure, the woodland edge is likely to provide a more turbulent exchange surface with the atmosphere and rainfall interception losses are likely to be greater than elsewhere in the forest.

Despite studies to quantify the extent that air must travel over a forest before turbulent exchange reaches an equilibrium with the forest (e.g. Gash, 1986; Gardiner *et al*., 1994), a good basis does not yet exist on which to predict the exact extent of the edge of individual forests and woodlands in terms of turbulent exchange (Veen *et al*., 1996) While studies in native broadleaved woodlands in New Zealand by Young and Mitchell (1994) and Davies-Colley *et al*. (2000) showed that microclimatic influences into woodland from surrounding vegetation can penetrate only about 50 m, Chen *et al*. (1995) reported that edge effects on microclimate may extend as far as 240 m into a Douglas fir forest. So, although it could be postulated that this penetration of edge microclimate might influence evaporative conditions for any understorey and the lower parts of tree canopies, no measurements are known to support such suggestions. In fact, few studies have tried to quantify to what extent and how far into a woodland evaporation is actually enhanced. Nevertheless, some documented cases indicate that, in mature broadleaved woodlands, the edge may extend up to 50 m into a woodland from its boundary. The water content of soil cores taken within 50 m of the edge at Black Wood were significantly drier than cores taken further into the forest (Kinniburgh and Trafford, 1996). However, in terms of influencing rainfall interception losses, Neal *et al*. (1991) considered that the influence of the woodland edge at Black Wood extended into the forest by only about 20 m. Hence, all the studies reported in this paper, except those at Black Wood, are likely to have been influenced significantly by an edge effect with, consequently, a high probability of overestimation of forest evaporative losses.

HYPOTHESIS 2 'ADVECTION'

Hypothesis 2 proposes that the mechanism for enhanced evaporation from woodland edges is not enhanced leaf area, radiation capture or interception losses but energy advected from surrounding areas which contributes significantly to evaporation from the woodland.

Any land surrounding a woodland has the potential to be a substantial source of advected energy particularly if the land is dominated by dry bare soil, if it is fallow or if any vegetation is water-stressed and, therefore, not transpiring actively. Little information is available on the penetration of advected energy into a woodland stand but it could well be some tens of metres. Studies of short rotation poplar and willow (Allen *et al*., 1999; Hall *et al*., 1998; Lindroth and Iritz, 1993), found evidence of a contribution of advected energy which enhanced transpiration (measured by sap flow techniques or porometry) more than could be supported by the direct input of net radiation. [It should be noted that the areas of short rotation coppice were small, amounting to 1.8, 10 and 2.8 ha respectively in relation to the references above]. Greater transpiration of edge trees compared to inner trees in a blue gum (*Eucalyptus globulus*) plantation was interpreted as evidence for enhancement of transpiration of the edge trees by advection of wind energy by Taylor *et al*. (2001).

HYPOTHESIS 3 'GEOLOGY'

The third hypothesis envisages that the development of soil moisture deficits under grass on non-chalky soils limits evaporation from the grass at all of the woodland/grass comparison sites except at Black Wood/Bridgets Farm (the only study on chalk subsoil).

There is substantial evidence (Anderson, 1927; Bunting and Elston, 1966; Wellings and Bell, 1980; Gregory, 1989) that although chalk below soils may remain unrooted by trees and crops it nevertheless provides a large resource of water, particularly during dry periods, for vegetation growing above it. The chalk contains a continuous matrix of fine pores. Under normal conditions the pores in the chalk matrix will be filled with water after winter and can continue to supply water upwards in all but the driest summers (e.g. Wellings and Bell, 1980) when the hydraulic conductivity of the chalk would limit upward movement of water to the rooted soil. In the soils below the vegetation at the sites other than Black Wood and Bridgets Farm, water uptake relies upon a finite depth of soil populated by roots.

A comparison of Penman potential evaporation and actual evaporation of grass at Bridgets Farm in 1999 and 2000 (Roberts *et al*., 2005) showed that at no stage did actual evaporation deviate significantly from potential evaporation.

Generally, the chalk subsoil appears to play a major role in this situation, providing an adequate supply of water upwards to the zone in the soil where roots can remove it; only in the very dry summer of 1976, at Bridgets Farm, did actual evaporation fall below potential evaporation (Wellings and Bell, 1980). At the other sites, in contrast, it is very likely that soil water deficits developed at some stage during the summer months and these deficits caused a reduction in grass transpiration. At the grassland site in the Kingston Brook catchment, McGowan and Williams (1980b) estimated that when soil moisture deficits of around 60 mm had developed (a likely event in most years) evaporation from the grass began to be restricted.

Although there is evidence for the enhancement of evaporation at woodland edges, there is little evidence to suggest that it plays a major role in explaining why soil water differences between woodland and grass differ between Black Wood/Bridgets Farm and the other comparison sites. It is reasonable to assume that an edge influence will be present all year round and this would mean that plots of soil water change (or evaporation) between woodland and grass would diverge at all times and particularly so after the leaves had emerged on the trees. In fact, inspection of Figs. 2 to 5 inclusively shows that differences in soil water content and evaporation between woodland and grass at Straits Inclosure, Clipstone, Wellhouse Farm, and Rempstone develop and are sustained after midsummer. This relationship suggests that enhanced evaporation at the woodland edges of all the woodlands other than Black Wood is not the explanation of the differences between those woodlands and their associated grassland and why Black Wood and Bridgets Farm show similar soil water changes.

There is very little evidence for Hypothesis 2 (the involvement of advected energy in enhancing transpiration from small forest areas and forest edges) and the contention must therefore remain a speculative one.

Hypothesis 3 offers the most plausible explanation for the similarity in woodland and grassland behaviour between Black Wood and Bridgets Farm and the differences from the other comparisons. The presence of the chalk subsoil at Bridgets Farm means that, even though the surface soil may become dry, an adequate water supply is still available from the chalk for the grass to exploit. At the other sites, with neither woodland or grass on chalky soils, the soil moisture and evaporation patterns (Figs. 2 to 5) show that up to around midsummer in each case, soil moisture changes in the profile (and evaporation) are similar for woodland and grassland. After midsummer however, a divergence between woodland and grass suggests that critical soil water deficits within the profile have been reached at the grassland site but that soil water abstraction and evaporation continues in the woodland without restriction.

Although the underlying soil might play the major role in determining whether differences exist between woodland and grass in the development of soil moisture and evaporation differences, there may also be a partial involvement of edge influences (Hypothesis 1) and advection (Hypothesis 2). The involvement of advected energy in evaporation from woodlands may be enhanced whenever evaporation from short vegetation in the surrounding vegetation is limited because of either crop maturity or senescence. Alternatively, the development of soil water deficits might lead to a reduction in transpiration from short vegetation surrounding the woodland.

It is clear from the present studies that although there was little difference in water use between broadleaved woodland at Black Wood and grassland at Bridgets Farm, clear differences occurred when other broadleaved woodlands were compared with grassland. The Black Wood/Bridgets Farm comparison differs in two important ways from the other comparisons. The studies at Black Wood were made well within a large woodland and both Black Wood and Bridgets Farm are located on shallow soils above chalk. Hence, two areas of research need to be developed if the impact of broadleaved woodland on chalk groundwater resources is to be predicted better.

Firstly, although there are indications that evaporation may be enhanced over some tens of metres from a forest edge, there is no known means of defining this distance more accurately nor is there any simple method to quantify the intensity of the edge effect. As many of the newer woodland plantings tend to be small in area, research should be directed at improving knowledge of evaporation enhancement at woodland edges.

Secondly, the capacity of chalk subsoil to support transpiration from grass (and woodland) during drought should be investigated. So far, limited evidence from the dry summer of 1976 indicates that upward transmission of water in the chalk matrix is not always assured. An improved physical understanding of the limits to upward movement of water in chalk is needed for occasions when the rate of transpiration from vegetation growing on chalk falls below potential evaporation.

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