SOME EFFECTS OF SHELTER-BELTS AND WIND-BREAKS*

By R. W. GLOYNE, B.Sc.

Introduction.—Considerable information is available concerning the physical and biological effects of wind-breaks and shelter-belts, although, owing to the difficulties inherent in field work and to the complexities of the interactions involved, the accuracy and reliability of this information varies widely.

Most of the pioneer work has been carried out in hot arid regions of the world, and this, together with the fact that the action of a given belt is decisively affected by its physiographical and climatic setting, makes necessary a very critical examination of the conditions under which any results were obtained before they can be applied to the British Isles.

Physical effects of shelter-belts and wind-breaks.—A barrier will alter the air flow (mean flow, and vertical and horizontal gradients of flow) and the flux of radiation (direct and diffuse) towards and from surfaces within the "zone of influence" of the barrier.

These basic changes, acting singly or in combination and in conjunction with the properties of the surface (slope, aspect, roughness etc.), will effect consequential changes in:—

(i) Air and soil temperature—absolute values, vertical and horizontal gradients (in practice we are also concerned with the temperature of exposed surfaces).

(ii) Heat balance and exchange—heat changes, at natural and artificial surfaces (both wet and dry), by forced and free convection and by radiation.

(iii) Moisture content of the air—absolute and relative values, horizontal and vertical gradients.

(iv) Evaporation (i.e. water loss)—from open water surfaces, soil, evaporimeters, and through the plant (i.e. by transpiration).

(v) Erosion, transport and deposition of small particles—generally soil or snow, but also insects, spores, bacteria and pollution.

(vi) Properties of the soil—affecting the soil moisture by the influence on the amount of precipitation reaching the ground and on the subsequent loss by evaporation, run-off and percolation; affecting the soil freezing through the influence on snow-cover and shading; and affecting the mechanical properties related to cultivation and "trafficability".

An essential prerequisite for an estimate of the effects due to a barrier in any given case, is an adequate appreciation of the interaction between the sheltering from the wind and the shading from sun and sky. The data which follow have been selected as being appropriate to conditions in the British Isles. Consequently relatively recent work from Denmark, Holland, Germany and Switzerland has been drawn upon, in preference to the older and more widely known results obtained in Russia, the United States and elsewhere.

When considering the results of field work in this subject, it is particularly important to consider critically the instruments used and techniques adopted for the measurement and analysis of the meteorological factors. The limitations so revealed have been given due weight in the presentation of the results to follow.

*This paper is based upon one presented to the Committee on Hedgerow and Farm Timber of the Forestry Commission, and is published with their permission.

Reduction in mean speed of the wind.—For convenience barriers may be classified into open barriers (density or "blockage-ratio" less than 40 per cent.), medium dense barriers (density 40–80 per cent.), and dense barriers (density 80–100 per cent.). It is assumed that the density is uniform over the face of the barrier.

Wind speeds in the protected area are normally expressed as a percentage of the simultaneous wind speed in the "open", the measurements being made at some convenient reference height less than the height of the barrier and generally between 4 and 6 ft. (see Table I). If, in addition, horizontal distances are measured in terms of the height h of the barrier, scale effects are, for practical purposes, eliminated. Although some effects can be detected certainly at $60h$, and possibly to greater distances, for most purposes effects beyond $30h$ or $40h$ may be ignored. These percentage figures are valid for "free" wind speeds of between about 5 and 20 m.p.h., and for many purposes hold sufficiently well for higher speeds, say 25 m.p.h.

TABLE I—TYPICAL VALUES OF THE HORIZONTAL WIND SPEED EXPERIENCED BEHIND BARRIERS OF DIFFERENT DENSITIES

Down-wind distances measured in terms of the height h of the barrier

Type of barrier	Wind speed at distance down wind of								
	$0h$	$2h$	$5h$	$10h$	$15h$	$20h$	$25h$	$30h$	$40h$
	percentage of "free" wind speed								
Open (density about 30%)	90	80	70	75	85	90	95	100	100
Medium dense (density about 50%) ...	40	25	20	25	50	60	75	90	100
Dense (density about 100%)	0	20	40	65	80	85	95	100	100

Typically, the dense barrier gives rise to a region of still air immediately to its lee, followed by a rapid recovery in speed, giving but little reduction beyond $20h$.

The medium dense barrier (a barrier of density 60 per cent. is found to give the best results) allows air to filter through, thus avoiding complete stagnation, and producing a minimum speed equal to about 20 per cent. of the "free" speed at $3h$–$5h$ down wind with a relatively slow recovery to 60 per cent. at $20h$, and to about 100 per cent. at $40h$.

With a very open barrier (such as is presented by close-mesh wire fencing) the wind speed is reduced to perhaps 70 per cent. of the free value at $5h$, but usually beyond $10h$ there is hardly any reduction. The absolute height of the barrier, the wind speed and the stability of the air modify the results, but not to an extent sufficient to prejudice the general applicability of the figures quoted.

It is generally agreed that straightforward cumulative effects do not arise with a succession of simple barriers set $40h$ or more apart.

Eddies and turbulence.—Eddies form in an air stream when a barrier is encountered, and behind an impermeable barrier such eddies cause damage to crops. Indeed, the benefit to certain easily bruised crops (e.g. tulips, citrus fruits), expected from the reduction in wind speed caused by an impermeable barrier, may be completely cancelled out by the damage caused by eddies.

It is found that an eddying type of flow is mainly confined to a zone $10h$ or $15h$ down wind from the barrier, and the motion in the remainder of the wake (recognizable at any rate to $40h$) can in practice be regarded as a mean horizontal flow with relatively small-scale turbulence superimposed upon it.

An eddying region can be identified until the density of the barrier becomes as low as 20–30 per cent., although little damage to crops appears to occur with barriers of density less than 50 or 60 per cent. (this is the density of the most efficient barrier regarded from the point of view of evenness of wind reduction over a wide strip).

Modifications in air flow induced by barriers of limited cross-wind length and of considerable thickness.—Even if the wind approaches a barrier at right angles, it will "cut-in" around the ends so reducing the area effectively protected, and when the wind blows obliquely to the barrier, the protected area is further reduced. It must be remembered that only at particular sites will the wind always approach from one or two very limited ranges of direction, and only in special circumstances will it be winds from only one direction against which protection is desirable. To obtain the full benefit from a barrier of height h it must have sufficient cross-wind length—one of length about $20h$ is hardly sufficient.

The protective effect of a dense barrier formed by a thick belt of trees (at least 40–60 yd. thick) is much as is given in Table I, but the vigorous eddying inseparable from a narrow dense barrier seems to be much reduced with a wide barrier such as that formed by a plantation of trees whose canopy presents an extensive and very rough surface to the air stream. If the tree belt is very deep (of the order of miles) then the protective effect in the lee margins exceeds the values quoted in Table I (e.g. 100 per cent. at $60h$–$70h$ instead of $40h$)[16].

Although, as mentioned earlier, there is no indisputably convincing evidence of a cumulative influence exerted by a succession of narrow barriers set $40h$ or more apart, a succession of large plantations does appear to exert such an effect. This, however, is as likely to be due to a progressive reduction of the general wind (which reduction is very difficult to determine in such circumstances), as to a straightforward cumulative shelter effect. There is evidence, however, that the decrease of protected area due to "end-effects" is reduced by a succession of parallel barriers, and indeed that the protected zone extends laterally to a further $7h$–$12h$, and in this sense some cumulative protection is achieved[34].

Shading.—The extent of the shadow will depend on the orientation of the barrier, but its importance will depend upon the amount of sunshine—especially in the six months October–March—and near a dense belt the loss of light is quite sufficient to depress growth in the spring.

As well as the direct effect upon illumination, the shading will affect soil and air temperatures (including the extent and intensity of freezing), water loss and soil moisture.

Little investigational work has been done on the influence of various types of barrier upon illumination reaching the surface. Bates's work[18] almost stands alone, but his results are not directly applicable to conditions in the British Isles as he was working in the presence of continuous, rather than intermittent, sunshine.

Soil temperature.—Temperature at or near the ground surface fluctuates markedly in response to sunshine and to direct shading, but the contrast between temperatures in shaded and unshaded areas decreases with depth.

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The Dutch workers Van der Linde and Woudenberg[31] report an occasion when temperatures at a depth of 4 in. in parts of a wind-sheltered area exceeded those in the open by up to 6°F.; such an excess was transitory and rather greater than the values reported by other workers. In the immediate shadow the corresponding temperatures were at times 2–4°F. lower than in the open. Differences tend to disappear at night, in overcast weather, or when winds are strong.

Air temperature.—In conditions of light wind, temperature in the protected area exceeds that in the open during those parts of the day when there is a net gain of radiation at the surface, and falls below it when the surface is, on balance, losing heat[20]. In regions subject to long spells of clear skies the mean temperature over a 24-hr. period differs little between sheltered and unsheltered areas. In our conditions of intermittent sunshine there is a small net gain over the 24 hr. unless the barrier is so sited as to form a frost "pocket" on still nights, when the net effect may be negative[31].

In the Dutch investigations the highest day temperature occurred in the protected zone just beyond the limit of the shadow[31]. The largest temperature increases were of the order of 2–3°F. at 4 ft. from the ground and about twice that amount at 4 in.; these differences occurred within a strip $5h$ or less from the barrier. At night the position of the minimum temperature appeared to be closely linked with that of the minimum wind (a secondary minimum was also identified immediately behind a live barrier[31]). At 1–2 ft. above the surface, minimum temperatures were of the order of 1°F. lower in the sheltered than in the unsheltered areas, little difference being reported at 4 ft. The same workers[31] report anomalously high maximum temperatures in unshaded but sheltered margins.

Recently Kreutz[25] has published results showing an increase of 4½°F. in maximum and a decrease of 2½°F. in minimum temperatures a foot or so from the surface within the close network of artificial and natural screens.

With "free" wind speeds between about 5 and 12 m.p.h. temperature differences become insignificant beyond about $10h$; with stronger winds both the temperature differences and the area affected decrease.

Heat balance.—The heat exchange of a body exposed to the elements, besides being a function of the physical and geometrical properties of the body, is affected by wind, humidity, direct and diffuse radiation as well as by the air temperature measured in the meteorological screen.

These considerations are particularly important with livestock, and, in practice, every case must be considered on its merits. The potential benefits of a shelter-belt to livestock must not be judged with respect to the changes caused in air temperature alone.

As regards buildings it is reported[34] that the heat loss from a house is about doubled with an increase of wind from 5 to 20 m.p.h., and that in the central regions of the United States the fuel bill can be reduced by up to 40 per cent. by exploiting the protective effect of shelter-belts.

Humidity.—Within a zone extending down wind for about $10h$ to $15h$ from the shelter, absolute and relative humidities in the middle of the day are generally higher than in the open. The differences are, however, small beyond about $5h$. Within the narrower zone, typical values[31] for the increases a foot or two from the surface are 5–10 per cent. for relative humidity and 1–3 mb. for absolute humidity in conditions when the general level is about 10–16 mb.

In the very disturbed eddying flow behind a dense barrier both absolute and relative humidity may be lower than in the open due to the increased loss of water vapour by eddy diffusion. In the high-temperature zone adjacent to an unshaded but sheltered margin, similar differences occur[31].

Dew-fall is higher in the protected zone, being appreciably greater near to the belt[25]; this effect extends down wind to $5h$ or $10h$.

Evaporation.—Practically all investigators, and especially the earlier ones, attach great importance to the ability of a shelter-belt to decrease evaporation (or more strictly the water loss from various types of evaporimeters). Evaporation is very difficult to measure in a way free from serious criticism, but there is sufficient qualitative agreement between the various measurements, and ample biological confirmation, that the "evaporative potential" imposed upon the ground and upon plants is reduced by the interposition of a barrier. Results from some recent work[25] at the agricultural-meteorological station at Giessen, Germany, are given in Table II; it is not clear what type of evaporimeter was used. The similarity in trend of the results is of interest. No explanation is given by the author for the rather anomalous result at $2\cdot8h$—variability of that order is not uncommon in field studies however.

TABLE II—WIND SPEED AND EVAPORATION AT DIFFERENT DISTANCES FROM A HEDGE

April 5, 1949

	Value at distance from hedge of:					
	$0\cdot4h$	$1\cdot6h$	$2\cdot8h$	$4\cdot0h$	$5\cdot2h$	$6\cdot4h$
	percentage of "open" value					
Wind speed ...	52	59	63	61	74	80
Evaporation ...	70	80	84	80	86	95

Reviewing the mass of the data available it would appear that the effect of a barrier upon water loss:—

(i) is similar in pattern to that for wind speed but less marked in extent

(ii) extends to $5h$ or $10h$ and exceptionally to $20h$

(iii) is strongly modified by direct shading

(iv) is a function of the absolute speed of the wind.

Snow cover, soil moisture.—Snow will tend to accumulate within, or be confined to, those regions adjacent to a barrier where eddying takes place. The region to leeward extends to about $12h$–$15h$ from a permeable barrier and rather less from a dense barrier, although in the latter case the maximum vertical extent of the region is greater[17].

Particularly if the snow falls before the ground is frozen, the soil will become saturated under the drifts. Surfaces clear of snow are more liable to freeze.

The differential supply of water to the soil is not, however, regarded as likely to be of importance in the British Isles, where, certainly in the hill areas, the soil in all parts is almost invariably at "field capacity" in the early spring. Under such conditions differences in soil moisture in the summer should be related to evaporation from the surface, or transpiration from plants. There appears, however, to be no suitable numerical data to quote, and the possible higher moisture content of the soil in sheltered areas can only be inferred from the behaviour of crops and the state of the soil surface. The soil will dry out less readily in sheltered areas which, from an agricultural point of view, may be a disadvantage.

Erosion, transport and deposition of small particles.—Wind erosion is a phenomenon of only a few well defined areas in the British Isles. Experience elsewhere[33] has show the immense value of barriers of all kinds, from forest-like plantations to slat fences and stubble, for stabilizing the soil.

Judging from the behaviour of snow there is a tendency for airborne material to be deposited in the shelter of a barrier. If such material consists of insects, spores and bacteria, the agricultural implications are obvious.

Some biological consequences of shelter-belts and wind-breaks.—In semi-arid regions shelter-belts are valued mainly for their ability to reduce the blowing of soil, and to mitigate the effect of strong drying winds; it is to this latter effect that the large increases in the yield of crops are attributed. In the British Isles, however, the areas where blowing is of consequence are limited in extent, and prolonged severe dessicating winds do not often occur. The benefit derived by crops from shelter in these islands is at least as much to be attributed to the reduction in physical damage and to other effects, as directly to the reduction in water loss. With livestock the main benefits can be traced to the reduction in heat loss. It would be out of place in this present survey to consider biological effects to any extent, but sufficient information will be given to enable the reader to judge of the importance of the subject in agricultural meteorology.

Shelter-belts are known to influence the growth, development, activity and productivity of plants and animals. Amongst the effects noted by various observers are the following:—

(i) Increase in yield of crops—linked with the reduced water loss, reduced physical bruising, slightly higher temperature and humidity in the protected zone. Often, however, shading is detrimental and the root competition from any trees or shrubs forming the barrier is usually disadvantageous.

(ii) Earlier crops—frequently the direct consequence of protection from the cold dry E. and NE. winds of early spring. An "early bite" of grass can be induced by the use of shelter-belts.

(iii) Better-quality produce—particularly of the leafy delicate crops and of fruit and flowers readily bruised by the wind.

(iv) Livestock benefit in many ways from protection afforded by barriers against cold winds (especially when in association with rain), against hot sunshine, and indirectly through the better herbage frequently to be found near shelter-belts.

(v) The balance of pests and predators is often altered by the interposition of a barrier (whether live or artificial) and this may or may not be an advantage. One advantage is the greater activity of pollinating insects when protected from boisterous conditions.

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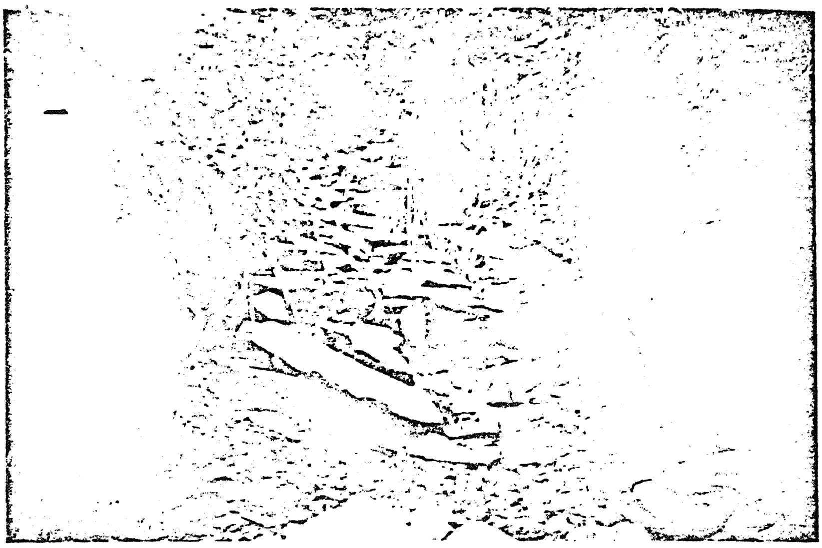
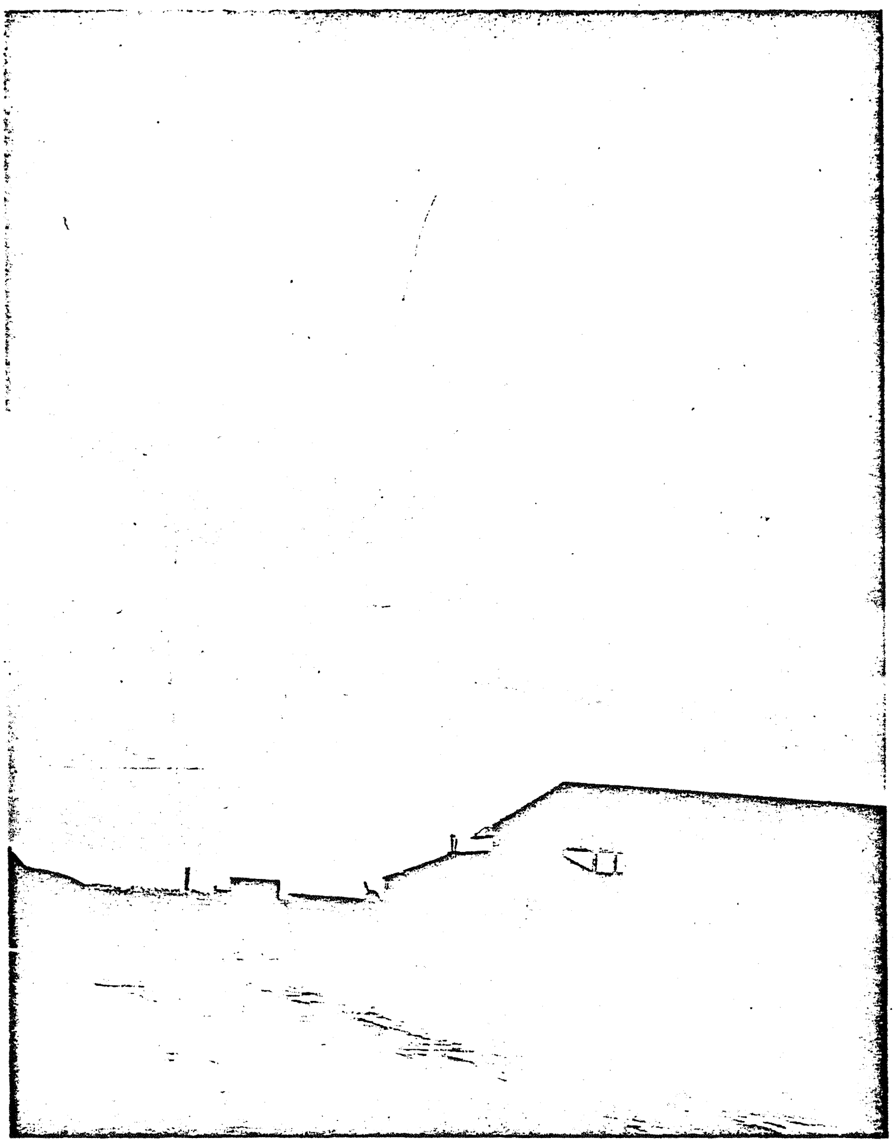


FLOOD DAMAGE IN FORMER MOUNTAIN STREAM BED BEHIND GELLI-HIR FARM
(see opposite)

MR. P. N. SKELTON, M.B.E.
(see p. 290)



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TORNADO SEEN AT LUTON AIRPORT, JUNE 8, 1955

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A SOUTH WALES THUNDERSTORM

By G. MELVYN HOWE

The thunderstorm which raged over a portion of the Llynfi Valley in mid Glamorgan during the afternoon of August 22, 1954 was undoubtedly the worst in living memory. It was of exceptional severity and the extensive flooding of roads and basements of houses and shops in the Garth district of Maesteg, together with the havoc caused by swollen torrents at the nearby Gelli-hir farm made the occasion unique and worthy of investigation. Fortunately such