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A SHELTER BELT STUDY—RELATIVE SHELTER, EFFECTIVE WINDS AND MAXIMUM EFFICIENCY

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SUMMARY

Daily run-of-wind measurements were made for 3 years at distances of $3^1/_2\ h$ and 7 *h* to leeward of a 7-row shelter belt about 6 m high. After elimination of variations in wind direction, the monthly values of relative shelter at these positions showed no evidence of an increase with time. The variations in wind direction were eliminated by regressions of monthly values of relative shelter on the monthly percentage frequency of effective winds, i.e., winds from the normal windward side of the shelter belt. Using these regressions the maximum efficiency of the belt at $3^1/_2\ h$ was found to be 61%, and at 7 *h* it was 40%. It is suggested that such values may be used as objective indices of the degree of shelter provided at a fixed point.

INTRODUCTION

This study is based on a series of wind observations made at Stockbridge House Experimental Horticulture Station, which is in the Vale of York, some 20 km south of the city of York. Although it is only about 7 m above sea level there is little obstruction to wind from any quarter and soon after the station was established in 1950, shelter belts of mixed species were planted along the south and west boundaries. In order to compare the increase of shelter with the growth of the trees a cup-counter anemometer was installed 23 m from the leeward margin of the belt and observations were made from 1952 to 1959; these observations have been discussed by HOGG (1961). Another series of observations was made from December 1959 to January 1963 to continue this comparison; the analysis of these data led to some concepts which may well have a more general application in the study of shelter belts. This paper is concerned with the results of the investigation and also with the concepts which have emerged from the analysis of the data.

THE SHELTER BELT

The shelter belt close to which the measurements were made consists of seven rows of trees occupying a strip of land 9 m wide; its length is about 475 m and it runs northwest–southeast. It was designed mainly to provide protection from southwesterly winds. The belt has a central core of deciduous trees, with conifers on each side; the detailed composition of the belt is given in Table I.

At the time of the commencement of the second series of observations in December 1959, the belt was some 6 m in height.

OBSERVATIONS

Two cup-counter anemometers, Mk II, see METEOROLOGICAL OFFICE (1956), were set up on the northeastern side of the shelter belt, at distances of 22 m and 44 m from its margin, i.e., at approx. $3^1/_2$ h and 7 h where h is the height of the belt. The cups were 1.8 m above ground; this is a satisfactory height according to the criteria quoted by CABORN (1957). These instruments were read daily at 09h00 G.M.T. to give the run-of-wind for 24 h. The readings of the unobstructed run-of-wind and of wind direction were obtained from the agrometeorological station some 750 m to the north.

RESULTS

The previous investigation had already shown that by 1959 the relative shelter at 23 m had increased to about 40%. The data obtained from December 1959 onwards are given in Table II, which contains for each month the average daily unobstructed run-of-wind in km, the relative shelter at $3^1/_2$ h and 7 h and the percentage frequency of effective winds (these terms are defined later).

DISCUSSION

There is no significant correlation between average daily run-of-wind and relative shelter at $3^1/_2$ h; therefore, in the following discussion, all data have been pooled and no account has been taken of variations in the absolute values of wind speed.

Relative shelter

The second and third lines in Table II refer to the relative shelter at $3^1/_2$ h and 7 h. This term is derived from the relative wind, which has been widely used in the past, see for example CABORN (1957). The relative wind is defined as $S/U \times 100$, where S is the run-of-wind at a sheltered site and U the corresponding value from the unshel-

TABLE I

COMPOSITION OF SHELTER BELT[1]

CP	CP	CP	CP	CP	CP	CP	CP	CP	CP	CP	CP	CP	CP	CP
M	J	J	J	J	J	M	J	J	J	J	J	M	J	
J	J	J	NM	J	J	J	J	J	NM	J	J	J	J	
	Bi	Bi	Bi	Bi	Bi	Bi	Bi	Bi	Bi	Bi	Bi	Bi	Bi	Bi
NM	J	J	J	J	J	NM	J	J	J	J	J	NM	J	
J	J	J	M	J	J	J	J	J	M	J	J	J	J	
CP	Am	CP	CP	CP	CP	CP	CP	CP	CP	CP	CP	CP	Am	CP

[1] CP = Corsican pine, *Pinus nigra* (var. *calabrica*); M = mountain ash, *Sorbus aucuparia*; J = Japanese larch, *Larix leptolepis*; Bi = silver birch, *Betula pendula*; NM = Norway maple, *Acer platanoides*; Am = serviceberry, *Amelanchier laevis*.

TABLE II

MONTHLY VALUES

		Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1959	Average daily run-of-wind (km)												370
	Relative shelter at $3^1/_2$ *h*												39
	Relative shelter at 7 *h*												27
	Frequency of effective winds (%)												42
1960	Average daily run-of-wind (km)	288	309	333	323	256	282	237	183	183	230	259	214
	Relative shelter at $3^1/_2$ *h*	31	38	17	38	33	37	46	34	25	7	35	30
	Relative shelter at 7 *h*	23	27	13	28	26	26	31	23	17	3	21	17
	Frequency of effective winds (%)	39	45	16	40	32	40	71	48	27	19	47	48
1961	Average daily run-of-wind (km)	253	272	303	216	254	238	216	254	193	283	221	200
	Relative shelter at $3^1/_2$ *h*	27	38	41	24	32	39	31	44	45	37	31	28
	Relative shelter at 7 *h*	15	21	28	15	22	25	21	29	30	23	21	18
	Frequency of effective winds (%)	35	61	58	37	39	67	48	68	73	68	37	29
1962	Average daily run-of-wind (km)	327	396	238	303	301	257	212	272	230	172	237	267
	Relative shelter at $3^1/_2$ *h*	49	30	20	28	30	38	30	50	45	47	21	31
	Relative shelter at 7 *h*	31	20	11	18	19	25	20	35	33	34	13	19
	Frequency of effective winds (%)	71	47	23	53	42	47	52	71	60	52	30	39
1963	Average daily run-of-wind (km)	204											
	Relative shelter at $3^1/_2$ *h*	10											
	Relative shelter at 7 *h*	6											
	Frequency of effective winds (%)	6											

tered or control site. It is, however, generally more convenient to use the term relative shelter, 100 ($1-S/U$), when the shelter effect is under discussion. Although such a term appears not to have been used until recently, see HOGG (1960), the need was apparent earlier and KREUTZ (1952) quotes values of percentage deviation of run-of-wind from the unsheltered site. These are all negative and "... show the magnitudes of the shelter effect". They are, in other words, values of relative shelter. More recently, SHAH (1962) in describing wind tunnel experiments of different types of shelter belt models has used the term "protective efficiency"; this also is identical to relative shelter.

If the data for relative shelter from Table II are plotted against time, they show no evidence of consistent variation. It is clear that any such variation is likely to be swamped by the variations in predominant wind direction from month to month and this was eliminated by taking account of the effective wind.

Effective wind

The shelter belt was designed to give protection mainly against southwesterly winds, but some protection will be given against any wind blowing from between west-northwest and south-southeast and any such wind is called an effective wind for this shelter belt. Wind directions have been observed daily at 09h00 G.M.T. at the agrometeorological station. Although these data have some limitations they have been used to define the days on which the wind is effective. The percentage frequency of effective winds in each month is given in the fourth lines of Table II.

Fig.1 and 2 show the percentage frequencies of effective wind plotted against the monthly values of relative shelter at $3^1/_2\ h$ and $7\ h$. These show close linear relations with correlation coefficients of $+0.87$ at $3^1/_2\ h$ and $+0.77$ at $7\ h$. The regression lines are shown in the diagrams and the corresponding regression equations are as follows:

$$R' = 0.52\,E + 9.41 \qquad (1)$$

$$R'' = 0.34\,E + 6.31 \qquad (2)$$

where R' and R'' are the monthly values of relative shelter at $3^1/_2\ h$ and $7\ h$ and E is the percentage number of mornings on which an effective wind was blowing.

Using the appropriate equation a theoretical value of the relative shelter may be computed for each month and the difference between the theoretical and actual values. The monthly differences at $3^1/_2\ h$ and $7\ h$ are plotted against time in Fig.3. These suggest that no observable change in shelter effect has occurred during the period. In fact, the equations give a fairly close estimate of the relative shelter over the whole period. For $3^1/_2\ h$, the estimate is not more than 5 percentage units in error on 29 out of 38 occasions. At $7\ h$ the shelter effect is less and the variability is therefore greater.

These results do not imply that the shelter belt as a whole has not become more effective. There can be little doubt that the leeward extent of shelter has increased

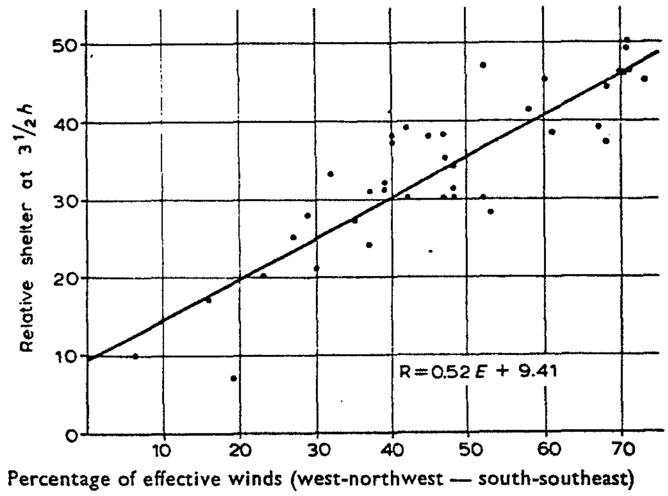

Fig.1. Relation between relative shelter at 3 ½h and percentage of effective winds.

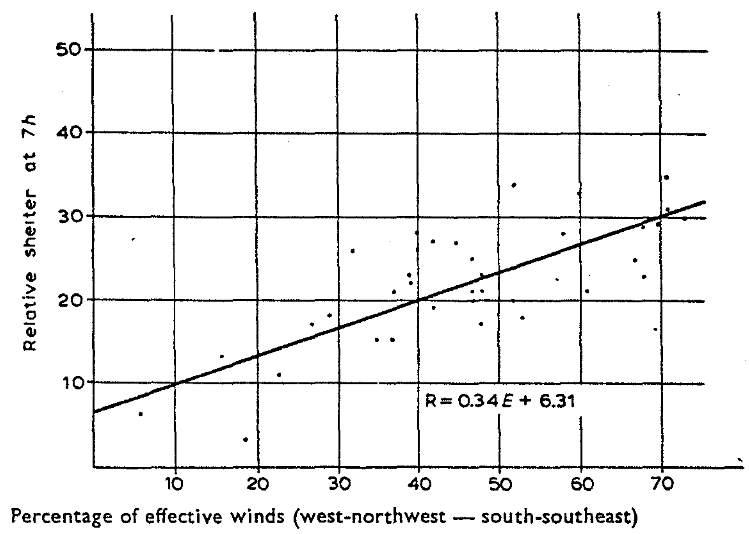

Fig.2. Relation between relative shelter at 7h and percentage of effective winds.

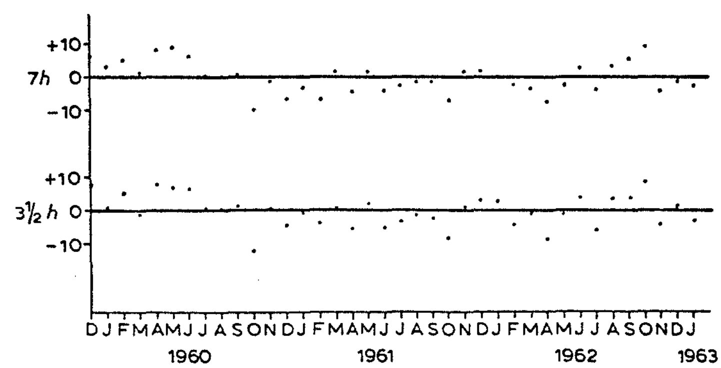

Fig.3. Deviation of observed monthly relative shelter from computed values.

during this period, but measurements were not made beyond 7 *h*. There is a need for a long-term series of observations to provide detailed information on the increase of shelter effect up to 20–30 *h*.

Periods of effective winds

The possibility of a change in shelter effect may also be examined by considering only periods when effective winds have been blowing on several consecutive mornings. It is therefore probable that effective winds will have persisted over these periods. Table III contains values of relative shelter for all occasions on which the wind was effective on at least four consecutive mornings, i.e., over periods of at least 3 days. In order to eliminate effects of varying leaf-cover only the data for summer (June, July, August) and winter (December, January, February) have been used.

Table III shows no evidence of an increase in relative shelter, but the shelter provided in summer appears somewhat higher than in winter. Treating each of the entries in Table III as an individual observation, the relative shelter in summer at $3^1/_2$ *h* during these spells of effective winds is 54.7 compared with 49.3 in winter. At 7 *h* the summer value is 36.9 and the winter value 31.8. These differences are significant at the 0.01 level and it thus appears that relative shelter is about 5 percentage units greater in summer than in winter. This small difference is probably due to the fact that the outside of the belt is largely coniferous; with a belt entirely composed of deciduous trees, the difference between seasons is no doubt greater.

TABLE III

RELATIVE SHELTER DURING PERIODS OF EFFECTIVE WIND

	Summer			*Winter*		
	period	*3½ h*	*7 h*	*period*	*3½ h*	*7 h*
1959–1960				17.12.59–20.12.59	50	34
				22.12.59–27.12.59	50	32
				18. 2.60–21. 2.60	48	33
1960–1961	6.6.60–10.6.60	51	33	24.12.60–28.12.60	51	33
	4.7.60– 7.7.60	53	35	29. 1.61– 1. 2.61	51	34
				6. 2.61–13. 2.61	45	29
1961–1962	24.7.61–27.7.61	53	35	5. 1.62–17. 1.62	52	33
	20.8.61–23.8.61	49	33	19. 1.62–24. 1.62	51	32
	25.8.61–28.8.61	62	43	3. 2.62– 7. 2.62	49	31
				9. 2.62–12. 2.62	52	33
1962–1963	22.6.62–25.6.62	48	31	8.12.62–11.12.62	51	32
	19.7.62–23.7.62	56	38	14.12.62–21.12.62	41	26
	3.8.62- 6.8.62	58	41			
	9.8.62–12.8.62	62	42			
	19.8.62–28.8.62	55	38			

Maximum efficiency of a shelter belt

The regression equations given above permit the estimation of the maximum and minimum possible relative shelter at these distances. For a month with no effective winds the relative shelter at $3^1/_2$ h is estimated as 9% and at 7 h, 6%. During such a month, these values are, in fact, estimates of relative shelter on the windward side of the belt, and the presence of a small sheltered zone to windward has been demonstrated in many previous series of measurements, see GLOYNE (1954). In a month with 100% effective wind the $3^1/_2$ h relative shelter is 61% and the 7 h value, 40%; these are the present values of maximum efficiency for this belt. Shelter belts are often described in qualitative terms of density, e.g., open, moderately dense, etc. This is not a satisfactory method, as any optical estimation depends on both the apparent density per row and the number of rows in the belt. It is therefore suggested that these values of maximum efficiency could be used as an index of the physical quality of a mature belt in providing shelter at a stated point on the leeward side. Thus, after rounding off, the maximum efficiency of this shelter belt at $3^1/_2$ h is seen to be 60%, a value which can be compared with $3^1/_2$ h values from any other shelter belt.

This concept is largely climatological in that it deals with the maximum shelter over a month and in this respect it differs from the suggestions made by GRUNDMANN and NIEMANN (1954). Also, since we are not directly concerned with the shelter on specific occasions, factors such as stability may be neglected. It is, of course, necessary to ensure that any comparisons of maximum efficiency refer to anemometers at about the same height, which should be above the zone of maximum variation in wind pattern and velocity due to the ground surface. The values quoted above are based on readings at 1.8 m but 2 m would be a more convenient standard height.

Before such a concept can be of significant practical value, a large number of data relating to different types of shelter belts will need to be collected. These data must provide as a minimum the total monthly run-of-wind and the daily wind-direction, and they must be collected over periods of several months. Possibly it would be sufficient to make estimates of direction from synoptic charts for some localities, but in many places actual daily observations would be essential.

It has so far been assumed that the maximum efficiency is reasonably constant throughout the year and that a single value may therefore be regarded as characteristic. The data from Table III throw some doubt on this, and the values for the nine summer months and eleven winter months were therefore tested for seasonal differences in the regression of relative shelter on effective wind. No significant differences emerged and it thus seems reasonable to use the annual regression, and the derived maximum efficiency as characteristic of the belt.

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