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WINDBREAKS AND SHELTERBELTS

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Historical Background

The use of trees for personal shelter or for the shelter of livestock is as old as the history of humanity although this has tended to be opportunistic. Planting for shade around habitation or along roads has a long and established history, but only recently have there been systematic efforts to improve climatic conditions through tree planting. Over the last 200 years there has been a much more systematic approach to the use of trees to shelter agricultural crops and human habitation as part of the European agricultural reforms of the eighteenth, nineteenth, and twentieth centuries, particularly in Germany. Part of the motivation has been the expansion of agriculture onto land previously not used for crop production. This has included the prairies of North America, the steppes of Russia and the Ukraine, and the heathlands of Denmark. More recently shelterbelts have been planted extensively in parts of China, Japan, New Zealand, and Australia. In addition, shelter from trees and the way they modify microclimate is a critical component of agroforestry systems and is of particular importance in the drier tropics and subtropics.

Shelter Basics

The principal aim of planting trees for shelter is to modify the local microclimate. Trees can provide shelter from the wind, precipitation, blowing snow, and the sun. They are also effective at capturing dust and pollution (see Further Reading section for recent reviews of current knowledge).

Wind is the flow of air in response to atmospheric pressure differences, and modifying this flow is the principal way in which shelterbelts are used to affect microclimatic conditions. Modifying the airflow not only affects wind speed but also turbulence intensity, temperature, humidity, and soil erosion. At the same time the shelterbelts may affect the amount of sunlight falling on adjoining fields and heat loss due to radiation.

Shelterbelts and windbreaks present a porous obstacle to the approaching airflow, creating an increase in pressure ahead of the belt and a decrease behind (**Figure 1**). The high pressure slows the

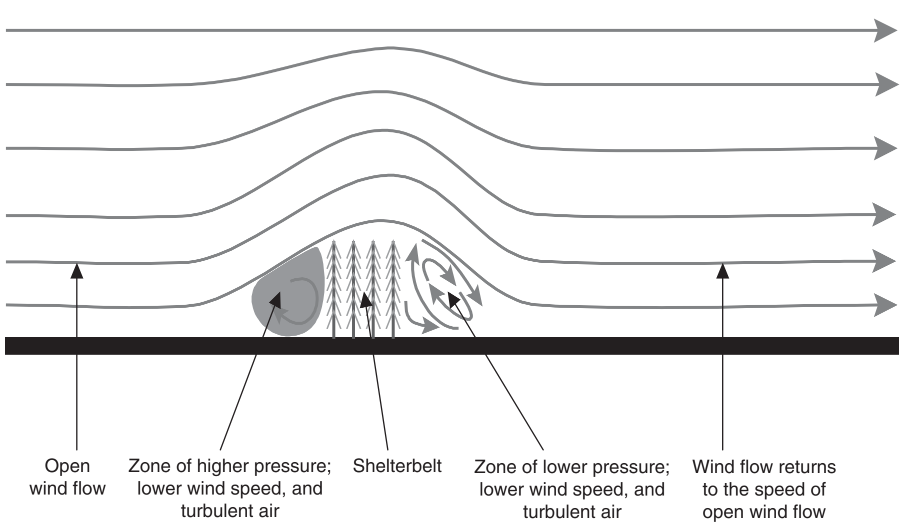

Figure 1 Flow pattern over shelterbelt or windbreak. Crown Copyright 2004.

approaching flow down and forces it to be deflected upward in a region referred to as the displacement zone (**Figure 2**). Above the top of the shelterbelt the wind is accelerated and the increased wind shear leads to an increased production of turbulence. Some of the approaching flow filters through the shelterbelt with a reduced velocity due to the drag provided by the trunks, branches, and foliage. If the shelterbelt is extremely dense then almost no air penetrates through the wood and a stagnant slow circulating eddy is formed behind the shelterbelt. The more open the shelterbelt is, the weaker this feature becomes until it disappears completely and the wake zone begins immediately behind the shelterbelt. The wake zone is the region in which fast-moving air displaced above the shelterbelt begins to mix with the slower-moving air that has filtered through the shelterbelt. Downstream of the shelterbelt, within the wake zone, the wind speed gradually increases until it is the same as the wind speed upwind. The wake zone is the main area where there are microclimatic benefits of shelter.

Microclimatic Benefits

A summary of the main microclimatic changes associated with shelterbelts is given in **Table 1**.

The wind speed is reduced ahead of and behind the shelter. However, turbulence levels may be increased in the cavity zone, which can lead to increased lodging and abrasion damage to crops. Within the shelterbelt itself the wind speed of the flow through the trees is generally reduced. However, if the wood has a very open understory squeezing of the flow between the canopy and the ground may increase the wind speed under the canopy.

The daytime temperature and relative humidity are generally increased in the cavity and wake zones. However, close to and within the shelterbelt there may be shading from the sun, which will reduce the temperature. This may be a disadvantage if solar heating is important, but if crop scorching or sunburn to animals is a consideration it may be of benefit. Within the shelterbelt the night-time temperatures will be raised because the canopy reduces radiation transfer to the atmosphere. However, the night-time temperature may be reduced in the cavity zone if the belt is very dense because it will restrict mixing of cold air near the ground with warmer air above.

Within the wake zone the reduced wind speed and turbulence leads to a reduction in the movement of gases to and from the ground. This means that moisture levels are higher and there is reduced water

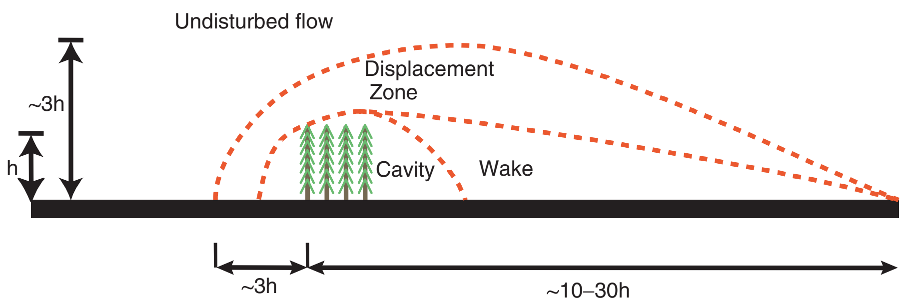

Figure 2 Description of flow zones in vicinity of shelterbelt or windbreak. Crown Copyright 2004.

Table 1 Changes in microclimatic conditions in different areas adjacent to a shelterbelt. Crown Copyright 2004

Area	*Increased*	*Reduced*
Displacement zone	Windspeed above shelterbelt Turbulence	Windspeed at ground level Sunlight close to shelterbelt
Inside shelterbelt	Windspeed (only for very open shelterbelt) Nightime temperature	Windspeed Daytime temperature Sunlight
Cavity zone	Turbulence Daytime temperature Humidity Lodging and abrasion Waterlogging on wet soils	Wind speed Night-time temperature Sunlight close to shelterbelt
Wake zone	Daytime temperature Humidity Carbon dioxide	Windspeed Turbulence Erosion Water loss

loss from the soil. Close to the shelterbelt, within the cavity zone, this may lead to waterlogging if the soil is particularly wet or to increased plant growth if the soil is prone to drought. The reduced wind speeds also lead to reduced soil erosion.

Factors Controlling Shelterbelt Performance

Height

The height of the shelterbelt, together with its porosity, is the most important factor controlling performance of a shelterbelt. The area ahead of and behind the shelterbelt over which it is effective is a direct function of shelterbelt height. The higher the shelterbelt the larger is the area of shelter.

Porosity

In simple terms, porosity is a measure of how open the shelterbelt is and how easily the air can flow through it. The porosity of the shelterbelt directly influences the intensity and area of shelter produced by the shelterbelt. Porosity is affected by planting density, canopy distribution, species mix, shelterbelt width, and time of year.

A dense shelterbelt will result either from closely spaced trees and shrubs or a large width of woodland or a combination of both factors. Shelterbelts tend to have lower porosities when they are young. With time the porosity tends to increase as the trees grow and mortality occurs. In addition, a shelterbelt of deciduous trees may have a low porosity in summer but a much higher porosity in winter.

In a dense shelterbelt the majority of air is forced over the trees by the high pressure ahead of the shelterbelt. So little air passes through the shelterbelt itself that the flow separates and a cavity zone and a large drop in pressure is created behind the wood. This low pressure causes the high-speed wind above the shelterbelt to return quickly to the surface giving a short region of shelter but with very reduced wind speeds.

A medium-density shelterbelt allows much more air to flow through the belt. This reduces the chance of flow separation behind the wood so that the cavity zone may not exist and the wake zone begins immediately. The pressure changes across the shelterbelt are also less severe than with the dense belt and, therefore, the return of the faster-moving air towards the ground is more gradual. The result is the maximum area of shelter that any shelterbelt can provide but the intensity of the microclimatic changes are less dramatic.

An open shelterbelt has a limited area of shelter and the reduction in wind speed downwind may be minimal. If the lower part of the shelterbelt canopy is completely open it is possible actually to increase the wind speeds within and just downwind of the wood compared to the open field values.

Width

Width is generally not of such direct importance as height except in the way it affects porosity. A two-row shelterbelt is as effective as a six-row belt provided they both have the same porosity and it also uses less land. In extremely windy climates the leading rows of trees may be stunted in their growth and, therefore, a wider shelterbelt will be necessary to obtain the required height.

Very wide shelterbelts (width $>2\times$ height) do not provide more shelter than a narrow belt because they behave very similarly to a dense shelterbelt and wind speeds recover very quickly in their lee. Furthermore, the turbulence intensity over wide shelterbelts is greater and can lead to problems of lodging and plant abrasion.

However, an advantage of wider shelterbelts is that it is much easier to replace them when they get old and trees begin to die while at the same time retaining some shelter. With a narrow shelterbelt there will inevitably be a period of little shelter when the belt is replaced.

Length

To be effective, the shelterbelt must be longer than the length of the area requiring shelter. This is due to the triangular shape of the sheltered zone behind the shelterbelt. The air speeds up around the edge of the shelterbelt resulting in higher wind speeds and turbulence levels at the ends of shelterbelts. Behind the shelterbelt this high-speed turbulent air begins to encroach into the sheltered wake zone in an identical manner to the air that was displaced over the shelterbelt.

Orientation

The orientation of the shelterbelt to the wind affects the area provided with shelter. The greatest area of protection is provided when the wind strikes the shelter at right angles but this is reduced when the wind strikes at a smaller angle. Therefore, the shelterbelt is ideally located when it is perpendicular to the wind direction of particular concern (the long axis of the shelterbelt should be at right angles to the wind). However, it is possible to construct shelterbelts that provide protection from more than one direction.

Another effect of orientation is on porosity. A narrow shelterbelt is most porous to the wind when the wind strikes it at right angles. As the angle is reduced the porosity decreases because the effective width of the shelterbelt is increased. The effect is more marked with wide shelterbelts.

Openings

Any opening in a shelterbelt has the same effect as the ends of the shelterbelt by increasing the wind speed and turbulence through the gap. The wind speeds within the opening may be significantly higher than the upwind values. If an opening is required for access then it should be angled through the shelterbelt or a 'dog-leg' included.

Profile

The ideal profile for a shelterbelt is generally straight-sided. This provides the maximum shelter for the minimum use of ground. A profiled edge will tend to deflect more air over the shelterbelt and allow less to flow through the trees. The result is to produce a sheltered area very similar to that achieved with a dense shelterbelt.

Types of Shelter

Clearly the benefits of shelterbelts have to be balanced against the disadvantages. To ensure benefits are maximized careful shelterbelt design is required. Poor design can lead to a potential benefit becoming a disadvantage. In **Table 2** a summary of the type of shelterbelts to use for different purposes is presented. In general, semipermeable shelterbelts (porosity 40–60%) are used where a large area of moderate shelter is required. Typical enterprises are

Table 2 Shelterbelt types, their impact on windspeeds and their application. Crown Copyright 2004

Shelterbelt type	*Features (porosity/height/length)*	*Porosity profile*	*Area of windspeed reduction*	*Reduction of open windspeed*	*General application*
Windbreak	Semipermeable As tall as possible As long as necessary	60–40%	20–30 times height of the wood	20–70%	Crops Improved pasture
Windshield	Close to impermeable As tall as necessary As long as necessary	<40%	Up to 10 times height of the wood (maximum shelter at 3–5 times the height)	Up to 90%	Lambing/calving areas Feeding areas Farm buildings
Hybrid	Impermeable understory; canopy semi-permeable As tall as possible As long as necessary	<40% understory 60–40% canopy	5 times (approx.) height of the understory 20–30 times height of the canopy	Up to 90% 20–70%	Where a combination of applications suit both windbreak and windshield shelterbelt types

Table 3 Benefits and disadvantages of shelterbelts for crops. Crown Copyright 2004

Benefits	*Disadvantages*
Increased ambient temperature leading to improved germination and growth rates	Competition with crops for light, moisture, and nutrients leading to reduced crop yields close to belts
Reduction of moisture loss and control of snow drifting	Increase in lodging due to increased turbulence
Reduction of mechanical damage leading to improved crop quality	Reduction in pollination for certain crops
Increased soil organic matter by production of leaf litter	Land taken out of production
Trapping or recycling nutrients	Waterlogging of soil close to dense belts
Reduction of soil erosion	High costs of establishment and management
Reduction of crop lodging	
Promotion of mineralization of soil nitrogen	
Retention of heat in the soil and air thereby extending the growing season	
Reduction of soil acidification in certain soil types	
Improvement of pollination efficiency for certain crops	
Control of spray drift	
Reduction of infiltration of water to groundwater systems preventing the rise of saline water tables	

Table 4 Benefits and disadvantages of shelterbelts for livestock. Crown Copyright 2004

Benefits	*Disadvantages*
Increased yield of pasture and root crops used for feed	Overcropping close to shelterbelt
Earlier grass growth in spring	Spread of disease by concentration of animals close to shelter
Reduced heat loss leading to increased animal productivity (milk production and weight gain)	Increase in insect pests in low wind speed region behind dense belts
Reduced mortality of newborn animals and shorn sheep	Reduction in air temperature on clear nights behind belts
Increase in range of breeds that can be utilized	
Shade provision reducing overheating and sunburn	
Increased animal welfare by provision of protection from wind, rain, snow, and sun	
Increased fertility due to better condition and provision of more comfortable conditions	
Reduction in heat loss on clear nights if animals able to move under trees	
Shelter for wildlife and game animals (deer, pheasants, etc.)	

Table 5 Benefits and disadvantages of shelterbelts for buildings and roads. Crown Copyright 2004

Benefits	*Disadvantages*
Reduced heat loss during cold weather leading to energy efficiencies	Land use
Shading in summer providing a reduction in requirements for air conditioning	Damage to buildings by the roots of trees planted too close
Improved conditions in the vicinity of buildings such as lower wind speeds and increased temperatures	Shading by trees reducing the heating benefits of the sun
Reduction in building damage from driving rain and diurnal temperature fluctuations	Increased snow build-up from poorly designed or positioned snow belts
Increased animal comfort in barns sheltered by trees	
Roads kept free of snow drifts	
Visual screening of buildings and roads	
Reduction in noise levels	
Capture of pollution such as dust, soot, spray, and gases	

the protection of crops and improved pasture. Dense shelterbelts (porosity $<40\%$) are used where intense shelter is required over a short distance, such as for the protection of lambing and calving and buildings. In some cases it is beneficial to have some of the features of both a semipermeable and a dense shelterbelt. This can be achieved with a hybrid shelterbelt in which the upper part of the belt is relatively open and the bottom of the belt is made dense by planting shrubs or slow-growing shade-tolerant trees.

Generally shelterbelts should be kept as narrow as possible. This is partly to minimize the land used but also to maintain the effective area downstream. Wide forests are found to be very ineffective at providing a large area of shelter. However, where snow retention is the objective, a wider wood can provide a larger area of snow accumulation. (Snow accumulation is useful in protecting roads from drifting or helping to stop snow blowing off farmlands where it accounts for a significant part of the total precipitation, such as the northern prairies of the USA). It has been found that multiple shelterbelts have no cumulative benefit but rather the increased turbulence behind upwind belts can slightly reduce the effectiveness of subsequent shelterbelts.

Shelterbelt Use

Shelter of Crops

Shelter can provide positive and negative benefits to crops as summarized in **Table 3**.

Shelter of Livestock

Much less work has been carried out on the benefits of shelterbelts for livestock in comparison to crops (see **Table 4**).

Shelter of Buildings and Roads

The benefits of shelter for buildings and roads are summarized in **Table 5**.

See also: **Hydrology**: Snow and Avalanche Control. **Afforestation**: Species Choice.

Further Reading

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WOOD FORMATION AND PROPERTIES

Contents

Formation and Structure of Wood

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Introduction

Close examination of a piece of wood with a microscope reveals a minute cell structure that usually escapes casual observation. Remarkably, it is this minute cell structure that is responsible for many of the physical properties and characteristics of a piece of wood. All materials exhibit some degree of dependence on the fine structure of their components; however, this tendency is very pronounced with wood. An understanding of the appearance, properties, and potential of wood for use requires complete comprehension of both the physical properties and the fine structure. Knowledge of the formation processes is also required for complete awareness because wood is produced in a biological environment and the tree is subject to varying growth conditions. The formation of wood and its anatomical structure on the micro- and macroscopic scale are described in this section. Chemical and physical properties are described elsewhere (*see* **Wood Formation and Properties**: Physical Properties of Wood; Mechanical Properties of Wood.

Tree Growth and Wood Formation

Features of Woody Plants

Woody tissue is formed in a variety of plants, but it is the wood in trees that is of interest here. Characteristics of all woody plants include the following:

- possess vascular tissue that is specialized conducting tissue consisting of xylem (wood) and phloem (inner bark)
- are perennial and live for a number of years