Although the specific focus of today's event is shelterbelts, the benefits that trees and shrubs bring are not exclusive to one tree-planting design and so this presentation will look at the general benefits of the presence of trees in farming systems with more detailed examples of the benefits to livestock.

Overall, with appropriate planting designs and scale, the benefits to the environment, crops and livestock include:

↓ soil erosion

↓ water runoff through increased infiltration

↓ greenhouse gas emissions

↓ nitrate leaching

↑ moderation of local climate including shade and shelter

↑ biodiversity

↑ animal welfare

↑ overall productivity through buffered crops and/or secondary crops from the trees themselves

↑ improved soils

Trees can play an important part in managing surface water through improved infiltration.

This established ash silvopasture in Ireland has extended the existing grazing system by a remarkable 17 weeks (3 weeks in the spring)

With deeper root systems than pasture or arable crops, trees can access deep sources of nutrients and recycle them to the surface. They can also capture surface-applied nutrients that have gone beyond the reach of crops and are able to reduce nitrate leaching by about a third.

Trees act as temperature buffers, creating a beneficial greenhouse effect protecting crops and livestock from both cold and hot conditions.

In winter, minimum ground surface temperatures can be raised by as much as 6^{o}C providing warmer conditions for winter and spring crops and some easier grazing conditions for livestock.

The increase in warmth and shelter offered by trees also enables outwintered animals to seek out a more comfortable resting area in colder weather.

Animals have both higher and lower critical temperatures outside of which there are increasing risks to good health and welfare.

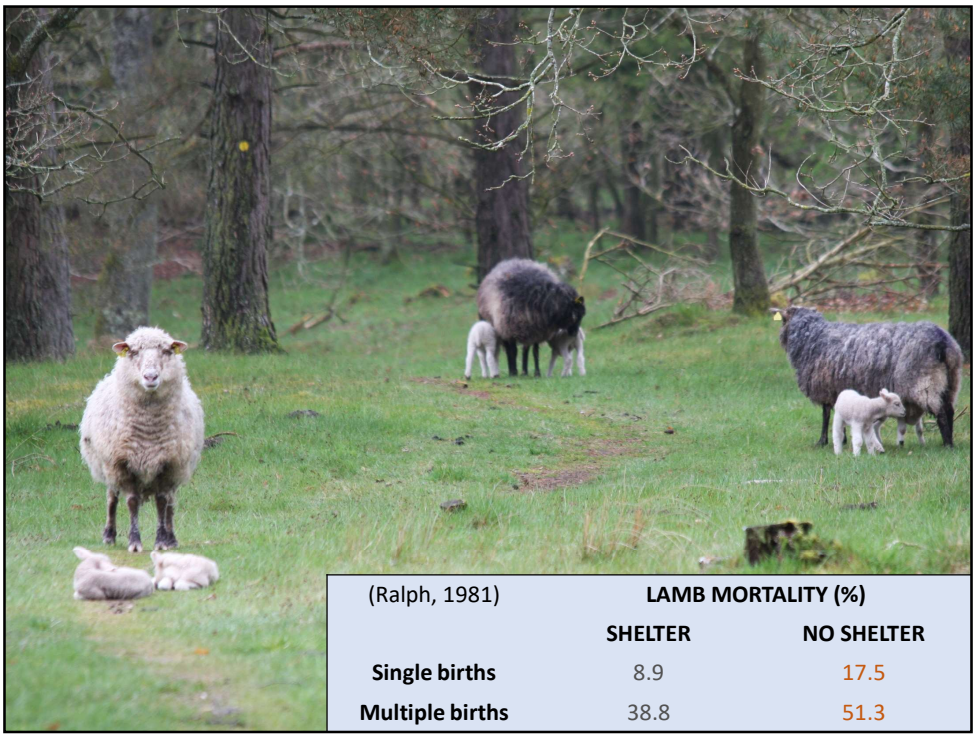
For example, the rule of thumb for beef animals is that for every 1^{o}C below the lower critical temperature, 2% more feed is needed to compensate. For a healthy beef animal with a developed winter coat, that is dry, its lower critical temperature is 0^{o}C. Below this temperature, if the animal cannot find shelter it will need to find more energy to maintain its core body temperature.

First and foremost, offering shelter helps to fulfill animal welfare needs but it can also have a measurable impact on production since cold livestock maintain body temperatures by redirecting energy away from production.

Wet coats dramatically increases body heat loss.

If the healthy beef animal now has a wet coat, its lower critical temperature rises sharply to 15.5^{o}C, requiring 31% more feed to compensate.

Cold winds have a strong, negative effect on temperature.
For example, with an air temperature of 2^{o}C and a windspeed of 16 mph, the effective temperature becomes -7^{o}C.
In these conditions, the beef animal with a dry coat, will require 14% extra feed. If its coat is also wet, the extra feed required to compensate for heat loss increases to 45%.
Offering shelter reduces the extra expense of higher feed bills but most importantly enables animals to choose an environment appropriate to their needs and comfort.
In a similar way, wind breaks offer the same protection for crops, as well as limiting direct damage to crops from driving winds.
Both wind and rain are major causes of top soil erosion and the presence of trees can reduce this by up to 65%



(Ralph, 1981)	LAMB MORTALITY (%)	
	SHELTER	NO SHELTER
Single births	8.9	17.5
Multiple births	38.8	51.3

All species of animals benefit from the presence of shelter for newborns and these benefits are particularly clear for lamb welfare.
Exposure to cold is one of the biggest causes of lamb loss in outdoor lambing systems but, with the provision of good shelter, losses can be reduced by 30%.
Juvenile animals typically have limited body reserves to compensate for cold stress and can lose heat very quickly – as much as 10^{o}C in the first 30 minutes of life.
Encouraging ewes to remain at the sheltered birth site for as long as possible (avoiding overcrowding and positioning feed and water sources close by), also strengthens ewe-lamb bonds further increasing lamb survival to weaning.
Unsurprisingly, growing lambs with shelter are expending less energy on maintaining core body temperatures and so have higher growth rates (up to 21%) than lambs without shelter.

During hot and dry summer periods, the presence of trees can help to buffer the environment and limit the damage from such adverse growing conditions.

Since trees, crops and livestock all need water, there may well be some competition for this resource in low-rainfall conditions (and the shading capacity and root patterns of different tree species will influence their part in this). However, in hot and dry conditions, the competition is more than offset by shading against solar radiation and limiting the loss of water through evapotranspiration. A classic image of this effect is usually from the dehesa system in Spain, however the photo used here is one taken in Wiltshire in 2018 where the only green grass to be seen is under the tree canopy (although the clover and tap rooted plants are showing more resilience to the drought conditions.

Furthermore, trees increase the water-retaining capacity of the soil so that, overall, more stable moisture levels can be maintained.

Globally, shade is the single most important benefit that trees provide for animals.

Heat stress happens when an animal is faced with temperatures higher than its upper critical temperature - where heat load is greater than its capacity to lose heat.

With milder heat stress, animals can fully recover with cooler periods (e.g., night time) but this can still affect production levels where a reduction in milk yield of approximately 3 litres/cow/day has been recorded.

Heat stress causes blood to be redirected from the digestive and reproductive systems to the outer parts of the body to help with cooling. For the digestive tract, up to 50% blood is redirected, causing the gut membrane to become permeable. This permeability compromises gut integrity and allows endotoxins and mycotoxins to enter the blood stream, triggering an inflammation cascade, causing short and long term health problems.

For example, dairy cattle with no shade have higher levels of mastitis than those with shade. Cows who have experienced heat stress during late gestation have lower IgG levels in their colostrum, produce smaller heifer calves who then go on to produce less milk in their first two lactations compared to calves from cows who were cooled during the dry period. So, reduced growth, loss of yield, fertility problems, foetal health issues and increased disease incidence caused by heat stress are estimated to cost the US dairy industry over $900 million and their beef industry around $400 million each year, reflecting high levels of poor welfare for the animals involved.

With trees for shading, solar radiation can be reduced by 58% compared to open pasture and skin temperature of cattle is 4oC lower. Under these more benign conditions, animals can maintain normal behaviour patterns, so grazing activity is maintained (where loafing becomes the dominant behaviour with no or limited shade), and cattle reach their target body weight 20 days earlier than those without shade.
Animals in silvopasture also utilise the landscape and its resources more evenly so there is a more even spread of recycled nutrients (nitrogen, phosphorus and potassium) though note that limited access and distance to water will inhibit this. Overall, silvopasture produces more forage per unit area than pasture alone.

Trees and emissions

Shelterbelt guidance for ammonia capture:

http://www.farmtreestoair.ceh.ac.uk/sites/default/guidance/index.html

When you get to 'Tree Species', a link to
'Tree Calculator for Ammonia Mitigation' tool will appear.

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Unwanted effects of many current farming systems include increased emissions such as greenhouse gasses. In various ways, trees can help to control and reduce levels of carbon, methane and ammonia, helping to prevent their release into the atmosphere.

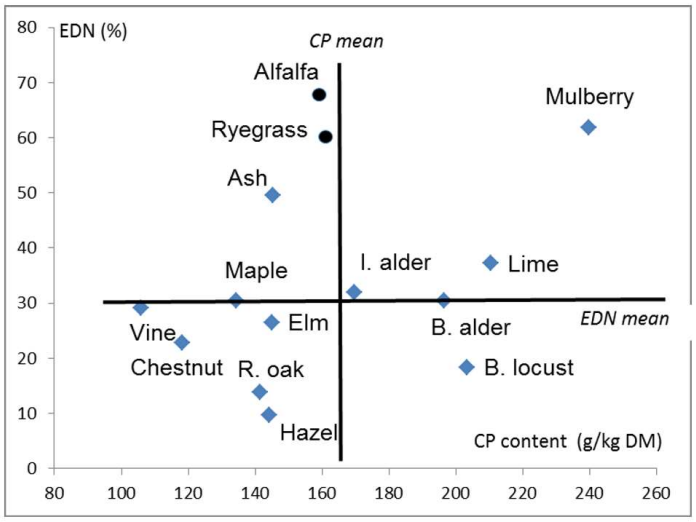
For example, ammonia emissions are strongly (but not exclusively) associated with pig and poultry systems but 10m wide shelterbelts around housing have been shown to reduce emissions by 53%.

Above is a link to a website which includes good advice on how trees can help manage ammonia levels from livestock operations as well as a calculator for how this might work under different conditions and planting designs in UK.

For methane emissions from livestock, different feedstuffs cause different levels of CH_4 production during digestion. Plants which contain condensed tannins help to reduce emissions and the CH_4 (ml/g) produced off willow is less than half that off lucerne.

The potential for carbon capture is greatest in farming systems that include trees. Fast and slow-growing trees will influence the amount of carbon captured over different time scales. For example, at a density of 150 trees per hectare, the average carbon storage (tC/ha) for a rotation is 75 tonnes for slow-growing trees (50 year rotation) and 35 tonnes for quick-growing trees (15 year rotation).

Relationship between **effective degradability of nitrogen** (EDN, %) and nitrogen concentration (CP, g/kg DM) in leaves of woody species during summer. (Emile et al., 2016)



Condensed tannins to **up to** 5% of DM in diet has a positive effect.

The average diet of domestic livestock includes grasses, forbs and browse. For cattle, the average intake of browse is 12 % of total diet, for sheep it is 20 % and for goats it is 60 %. The amount of browse in the diet can increase substantially under different seasons or weather conditions, for example, in drought when grasses and forbs do not thrive, or in spring when the attractiveness of young tree shoots is high. During these times, intake of browse can increase to a higher percentage of total diet: cattle = 55 %, sheep = 76 % and goats = 93 %.

Sourcing good protein for animal feed is a global issue. Crude and degradable protein levels in tree leaves, particularly in ash, lime and mulberry, compare well with levels found in alfalfa and ryegrass.

Additionally, although condensed tannins in browse inhibit normal digestion of protein in the rumen, the bonds that prevent proteins breaking down in the rumen are broken down in the abomasum, effectively delivering a good-quality rumen bypass protein to the small intestine.

Rumen microbes are specialised and increase slowly over time so uptake of nutrients is reflected in this.

Leaf nutrition in tree species compared to hay and red clover (%). In: Birks et al, 1989.

Tree species	Moisture	Ash	Fat	Sugar	Protein	Fibre
Wych elm	12.6	9.9	2.9	49.2	13.2	12.3
Rowan	11.9	5.9	6.5	50.4	9.9	15.4
Goat willow	11.5	6.1	3.8	50.3	11.6	16.7
Aspen	10.8	8.5	6	43.5	13.3	20.9
Ash	11.6	6.3	3	50.4	12	16.7
Grey alder	11.9	3.9	5.9	43.6	17.6	17.4
Birch	11.7	3.9	7	49.2	12	16.2
Meadow hay	14.96	5.42	2.2	44.43	8.51	24.56
Red clover	15.65	5.17	1.88	36.76	10.98	28.56

These data illustrate how leaf nutrition compares well with grasses grown in the same landscape.
NOTE: the trees named here do not reflect the preferred species by animals but more the species that were available to the farmer in the Swedish farming landscape.
Farmers in these older systems would feed the least palatable (e.g., alder) at the beginning of winter and keep the more palatable (e.g., ash) for feeding prior to the next grazing season.

Trace elements in leaves from trees

Sample Reference		A GLUTINOSA 240815 Alder	S VIMINALIS 240815 Osier willow	F EXCELSIOR FRESH 21	S CAPREA FRESH210616 Goat willow	U MINOR FRESH 210616	F EXCELSIOR AD 2403 Ash	S CAPREA AD 240317	U MINOPR AD 240317 Elm
Determinand	Unit	FORAGE	FORAGE	FORAGE	FORAGE	FORAGE	FORAGE	FORAGE	FORAGE
Total Nitrogen DUMAS	% w/w	3.16	2.23	1.78	2.66	2.23	2.21	2.16	2.31
Total Phosphorus	mg/kg	2240	2971	3144	4243	2292	3661	5501	2362
Total Potassium	mg/kg	9051	10364	14065	13942	14722	20015	18977	20884
Total Calcium	mg/kg	13365	18769	12776	10204	10998	15987	14522	16758
Total Magnesium	mg/kg	2481	1764	2235	1930	1889	2681	2682	2798
Total Sulphur	mg/kg	1890	4124	1840	2056	1313	2348	2571	1655
Total Manganese	mg/kg	129	284	25.5	35.5	37.2	31.6	46.3	37.9
Total Copper	mg/kg	11.2	5.5	7.4	7.6	6.5	9.6	10.9	9.3
Total Zinc	mg/kg	53.2	245	18.5	118	31.7	22.9	144	40.1
Total Iron	mg/kg	91.6	73.1	91.2	75.7	138	116	142	258
Total Boron	mg/kg	28.9	36.7	15.7	12.7	19.3	17.5	18.2	26.0

This analysis of macro and micro mineral content of tree leaves was carried out to investigate their value as a feed or sustainable supplement for livestock.
Although palatability of alder is low (rarely requiring protection even from deer), the higher level of nitrogen in the leaves reflects its superior nitrogen-fixing properties.
Despite the limited number of species included and minerals analysed, it illustrates how well trees can access nutrients, increasing their availability to both crops and livestock.
Note that different species can have different amounts of any given mineral even when growing in the same field. This reflects different strategies (of all plants) for the transport of different chemicals from below ground to above ground plant parts.
The three basic strategies are:
Accumulators: metals are concentrated in above-ground plant parts from low or high soil levels.
Indicators: uptake and transport of metals to the shoots are regulated so that internal concentration reflects external levels.
Excluders: metal concentrations in the shoot are maintained constant and low over a wide range of soil concentration up to a critical soil value above which the mechanisms break down and unrestricted transport results.
For example, willow (and particularly osier willow) is an accumulator of zinc, having high levels in its upper parts irrespective of soil levels. Plants with this strategy are often used in the management and cleaning of polluted ground.

Trees on farm can fulfill multiple roles but whatever their primary purpose, they all need to be managed in some way and particularly important is the management of light levels first by appropriate species selection and second by practical management such as mechanically thinning or removing lower branches.

Different crops tolerate different levels of shade and pasture plants have shown good tolerance of 50% shade with some tolerating up to 80% shade.

Another way to manage light competition is to select complementary components such as winter crops and trees with late spring leafing.

There is some evidence to show that whilst crop yields may be reduced under shade, the protein content is higher increasing its value as a feed source.

In terms of biosecurity, hedgerows and shelterbelts act as natural barriers between groups of livestock and between fields of crops, helping to prevent the spread of disease both within and between different plant and animal species.

Access to browse offers animals diversity in diet and choice.

The ability of animals to self-regulate intake is often discussed and there is an increasing body of evidence that supports them being able to balance nutrient requirements over each day (rather than at each meal). Changes in feeding behaviour and plant selection show an awareness both of specific deficiencies and that the deficiency can be rectified by eating specific food sources. A disturbing example of animals seeking nutrients is cattle kept on moorland, a phosphorus-poor environment, seeking out and eating bones as a source of the mineral. A quick look at the mineral table would show that access to goat willow could be a solution with a handy 2:1 calcium : phosphorus ratio in the bargain. Other 'alternative' sources of micronutrients include soil and faeces. And it worth remembering that abnormal behaviour becomes normal in an abnormal environment!

Salicylic acid is well-known as a painkiller but is also has antibiotic, antipyretic, anti-inflammatory and fungicidal properties. When ewes were offered two different varieties of willow to browse on, they selected the one highest in salicylic acid McKinnon et al. (2000). It is not clear why but it is clear that they could distinguish a difference.

Although tannins are largely anti-nutritional, a controlled intake (max 5% of dry matter

intake) can be of benefit. They help control internal parasite burdens by reducing the number and size of maturing larvae so that fewer eggs are produced. Sheep with high worm burdens switch to eating plants with high levels of condensed tannins and giving sheep access to such plants can reduce worm burdens by 50%. An improved protein nutrition status of an animal also increases resistance and resilience to internal parasites.

There is an increasing recognition of the value that trees can and do bring to the farmed landscape, not least reflected in the political commitments to a massive increase in tree planting over the coming years.

The above quote, taken from Kipling's 'Puck of Pook's Hill', reflects the recognition of, and value placed on, the benefits of trees incorporated into crop and livestock farming systems.

Now is the time to recover these benefits for all.