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Abbreviations Used in this Report

AHDB	**Agriculture and Horticulture Development Board** 2018
ALC	Agricultural Land Classification
BMV	Best and Most Versatile
CP	Crude Protein
DDGS	Dried Distillers Grains with Solubles
DM	Dry Matter
DUP	Digested Undegraded Protein
FAO	Food and Agriculture Organization of the United Nations
GHG	Green House Gas
IPCC	Intergovernmental Panel on Climate Change
ME	Metabolisable Energy
MJ	Mega Joules
RDP	Rumen Degraded Protein
SBM	Soya Bean Meal
SOC	Soil Organic Carbon
UKCEH	UK Centre for Ecology & Hydrology
UKCP18	UK Climate Projections

Abbreviations and some of the technical terms used in this report are expanded on in the programme glossaries: https://erammp.wales/en/glossary (English) and https://erammp.cymru/geirfa (Welsh)

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1 Introduction

Welsh Government has identified the need to establish whether the expansion of cultivated crops on Welsh farms would be an effective mechanism for improving farm business resilience and for reducing Greenhouse Gas (GHG) emissions. Home grown feeds could reduce livestock feed sourced from other parts of the UK and imported from overseas. However, there may be negative effects on GHG emissions from cultivation of soils, with the additional costs of inputs such as fertilizers to achieve an economic yield where the Welsh climate is less favourable for such crops.

This report reviews the GHG emissions from arable crops, and then examines the particular issue of the impacts of imports of soya bean meal for animal nutrition, and what are the alternatives. Soya bean meal has become a critical component of feeds for high yielding dairy cattle, pigs and poultry because of the types of protein and amino acids that it contains. The scope for growing these alternatives in Wales is discussed, assessing the GHG emissions and other environmental impacts.

2 Executive Summary

- Wales cannot be self-sufficient in animal feed for the current livestock production levels but an increase in home production could help to increase resilience by reducing exposure to global markets for imported feedstuffs.
- There are several risks and barriers associated with increasing animal feed production from arable crops in Wales to balance against the potential benefit of increased resilience from greater Wales based production. Welsh Government will need to take account of the likely environmental risks of increased GHG emissions, increased biodiversity impacts from greater pesticide and fertilizer use, and increased water pollution from soil erosion and greater run-off of fertilizers and pesticides. Any incentives by Welsh Government to encourage the transition will need to be based on implementing a strong regulatory and advisory framework to manage the risks.
- An increase in alternative arable crops in Wales would put Welsh livestock farming at an economic disadvantage because of the uncompetitiveness of production compared with areas in the UK which produce higher yields. Farmers will require additional capital for cultivation and harvesting equipment and for on-farm facilities for drying and storing the harvested crops.
- Expansion of arable cropland in Wales by cultivating grassland would cause substantial additional GHG emissions compared with importing cereals from the established arable areas of the eastern regions of England where arable cropping over many years has depleted soil carbon levels and reduced GHG emissions. Wales could have advantages if climate change predictions of lower rainfall and increased droughts occur to a greater extent in the east of England than in Wales.
- Based on several assumptions, home-based cereals production for animal compound feed in Wales would need to increase by about 800,000t annually and require about 165,000ha of additional arable land to achieve self-sufficiency.
- Wales used an estimated 138,400 tonnes of imported soya bean meal for livestock in 2018-9 chiefly for dairy cows, poultry and pigs. Of the alternatives for soya bean meal that can be grown in Wales, cereals and rapeseed meal are the most suitable feedstuffs. These options would require arable land to increase by about 81,000ha – almost doubling the arable area of 92,941ha in 2021.
- The options to replace soya bean meal and increase home grown cereal production would require about 250,000ha of additional arable land. These are guides to the required expansion of arable areas for total substitution of animal feedstuffs by crops grown in Wales but could be scaled to the extent of substitution that is targeted.
- In practice Wales has very limited area for expanding arable crops that can be grown efficiently – based on the amount of ALC Grades 1-3a land suitable for expanding arable crops – approximately 321,500ha. Climate change scenarios forecast that the area of the best land would decrease by 2050 though cereal growing would be favoured by drier and warmer conditions.
- Conversion of grassland to arable causes a substantial loss of soil carbon which contributes to the GHG emissions from agriculture. In Wales this will typically be about 91-102 t CO_2e/ha mainly in the first two years after the conversion to arable from grassland. Conversion of 250,000ha of grassland to arable would increase

GHG emissions from 463kt CO_2e in 2018 to 11,800kt CO_2e/year for the first two years, **tripling the current agriculture emissions. Over the following 20-30 years increased GHG emissions of about 1400kt CO_2e annually would occur in addition to the current emissions of about 400kt CO_2e annually from land use and land use change.**

- Returning arable to grassland by rotational management will sequester some of the lost carbon but at a lower rate than for the initial loss.
- Apart from the loss of soil carbon, there are additional GHG emissions from practical arable operations particularly fertilizer manufacture and its application. Increased fertilizer and pesticide applications for arable crops also increase the risks of water pollution and eutrophication of semi-natural habitats.
- Alternative strategies are to use all-forage diets for dairy cattle but with the reduction of daily milk yields by about 50%. This would have negative effects on GHG emissions if overall milk production in Wales was to be maintained by doubling cattle numbers. Lower yielding dual-purpose milk-beef breeds could help to maximise the use of forage crops.

3 Overview of Research of GHG Fluxes from Soils and Vegetation from Cereal Growing

Expansion of arable crop production by converting grassland has a significant effect on GHG emissions because there are additional emission sources:

- Release of soil carbon stocks from grassland by ploughing and cultivation
- Release of soil nitrogen via N_2O by incorporation of organic material (grass, roots, crop residues)
- Emissions from farm machinery for cultivation, crop protection and harvesting
- Emissions from application of fertilizers (manufacture and application)
- Emissions from pesticides manufacture

3.1 Changes in Soil Carbon Stocks

Emmett et al. (2010) reported soil carbon stocks in Wales from Countryside Survey 2007 to be 56.0 t C/ha for arable, and 68.1 t C/ha for improved grassland – emphasising the reduction of soil carbon stocks by emissions of carbon dioxide on converting grassland to arable. The lower soil carbon stock in arable soils reflects the fact that agricultural practices like ploughing, which mix soil layers and break soil aggregates, accelerate top-soil organic C decomposition (Conant et al., 2001). Changes in Soil Organic Carbon (SOC) through time are non-linear after a change in land use or in grassland management.

Smith et al. (2019) differentiated the National Soil Inventory class 'rotational grass' (i.e., grass that is sown and then tilled every few years as part of an arable rotation) from the class 'arable' to represent continuous arable management. In Wales, the likelihood is that most arable will be rotational rather than continuous arable. Mean UK SOCs were 43.2 t C/ha based on 552 sites and 58.7 t C/ha based on 301 sites under arable and rotational grass respectively, showing the large depletion of SOC in continuous arable soils.

Carbon is lost more rapidly than it is gained after a change in land use (Soussana et al., 2004). As a result of periodic tillage and re-sowing, short-duration grasslands tend to have a potential for soil C storage intermediate between crops and permanent grasslands. The carbon storage increases in line with less frequent ploughing (Soussana et al., 2004). Increases in SOC stocks do not occur instantaneously but over a period of years. The current IPCC good practice guidance for GHG inventories assumes a period of 20 years for a new equilibrium to occur after conversion (IPCC, 2006).

The strongest negative effect on SOC reported by Guo & Gifford (2002) is from conversion of pasture to crops. Freibauer et al. (2004) reported decreases in the range of 1.0 to 1.7 t C/ha/yr. Another study shows that converting a permanent grassland to an annual crop can decrease SOC at a rate of 0.96 t C/ha/yr over a 20-year period (Soussana et al., 2004). De Klein et al. (2006) estimated that soil carbon losses were 30.3-60.6 t C/ha over 30 years for temperate grassland converted to continuous arable land, with an average loss of 1.01-2.02 t C/ha/yr.

FAO (2016) emphasizes that the decrease of carbon stocks in arable soils is affected strongly by the return of crop residues to the field, the application of organic manure and the degree of tillage intensity. FAO (2016) estimated significant depletion of soil organic carbon on arable land – the average carbon loss was about 0.4tC/ha/yr for conventional agriculture. In the Countryside Survey 2007 soil monitoring Emmett et al. (2010) estimated an average loss of 0.19t C/ha/yr for arable land.

It is important to recognise that the estimates of average losses are over periods of 20-30 years, but mask the initial substantial loss of soil carbon from land use change. There is a loss of soil carbon of between 10 and 32t C/ha over two years after grassland ploughing, even where grass is sown afterwards (Linsler et al., 2013).

Welsh farmers are likely to plough land for two reasons – to grow arable crops (continuously or in rotation with temporary grassland), and to renovate a pasture by converting grass back to grass. Jordan et al. (2022) demonstrated substantial increases in soil organic carbon (SOC) stocks across Great Britain are possible if arable land is in rotation with grass leys. Including grass-based leys in an arable rotation with low frequency (one year ley followed by two years arable, increased SOC stocks by 3 tC/ha within 30 years compared with continuous arable cropping. SOC stocks increased by 16 tC/ha within 30 years if four year leys are followed by two years of arable crops. These increases were relative to SOC stocks from continuous arable cropping. Growing over-winter cover crops in every year of an arable rotation has the potential to increase cropland SOC stocks in GB by an average of 10 tC/ha (20.3%) after 30 years, compared with no cover cropping.

The emissions from conversion from grassland to arable needs to be compared with the baseline sequestration rates for undisturbed grassland. FAO (2016) estimated a carbon sequestration rate of 0.114 tC/ha/yr is used for permanent pastures without grassland renovation, with an assumed minimum and maximum rates of between 0 and 0.228 tC/ha/yr. Soussana et al. (2010) estimated an average grassland C sequestration rate of 0.05 ± 0.30 tC/ha/yr for grasslands under constant management. Countryside Survey 2007 soil monitoring (Emmett et al 2010) estimated the sequestration rate of 0.05t C/ha/yr for improved grassland.

From these literature values, soil carbon changes and rates of sequestrations/losses are summarised in Table 3.1

Table 3.1 Soil organic carbon changes and sequestrations/losses of land use changes

Land Use Change	Soil Carbon (tC/ha)	Carbon Sequestration (tC/ha/yr)
Grassland to continuous arable	From 58.7-83.8 to 43.2-56.0	- 0.96 to -2.02 -5 to -16 in first 2 years
Arable to rotational grassland	From 43.2 to 58.7	+0.1 to +0.53*
Arable remaining arable	Range of 43.2 to 56.0	-0.19 to -0.4**
Undisturbed grassland	Range of 68.1-83.8	-0.25 to + 0.35 mean value of +0.05

*Notes * Depending on rotation between grassland and arable*
*** Depending on how many years continuous cropping has occurred and the initial SOC of the soil.*

Nitrous oxide emissions also occur when incorporating vegetation into soils. Vellinga et al. (2004) found in Holland that emissions are very high directly after ploughing and decrease slowly. Each time grassland was renovated, N_2O emissions of 1.8 to 5.5 t CO_2 e/ha occurred. Grassland ploughing in the spring offered realistic opportunities to lower the N_2O emissions. Davies et al. (2000) also concluded that leaving swards ungrazed and unfertilized over winter before ploughing in spring has the potential to reduce such emissions considerably. Baggs et al. (2000) found that when grass/clover and ryegrass grassland were ploughed up, most N_2O emissions occurred over the first 21 days after and reduced to pre-cultivation emissions after 36 days.

Conversion of permanent or temporary grassland to arable land will lead to reduction of SOC by emissions of carbon dioxide over 20-30 years, whereas permanent grassland is estimated to sequester carbon at a small rate. There would be a surge of emissions for the first years after conversion to arable crops. Arable-grassland rotations reduce emissions compared with continuous arable cropping.

Grassland renovation by ploughing causes the loss of SOC which is rapid compared with the rate of sequestration as grassland re-establishes. Direct drilling to reseed leys is practised but commonly uses glyphosphate herbicide to reduce the competition from existing vegetation. Emissions from grassland renovation release soil carbon, and this has to be balanced against future carbon sequestration rates and the increased performance of the restored sward.

Establishing cover crops rather than leaving bare arable stubbles or cultivated soil over winter benefits SOC but many crops commonly grown in arable rotations are established in the autumn (e.g. winter wheat or winter oilseed rape) which are less compatible or incompatible with over-winter cover crops. A shift to spring-sown cultivars would likely incur a yield penalty which is a disincentive for farmers and risks displacing cultivation elsewhere.

3.2 GHG Emissions from Arable Cropping Operations

A range of estimates of the GHG emissions from growing arable crops has been made, with considerable variation in the numbers, depending on assumptions about the boundaries of the life cycle analysis and particularly the extent of fertilizer use - the main source of the emissions.

Williams et al. (2010) estimated that UK bread wheat production had GHG emissions of 0.42 tonnes CO_2 e /tonne of product. Mosnier et al. (2011) estimated GHG emissions of 0.538 tonnes CO_2 e /tonne of product for wheat in France, and 0.503 tonnes CO_2 e /tonne of product for barley.

Audsley and Wilkinson (2014) reviewed GHG emissions for a range of crop systems and estimated emissions for the arable crops (Table 3.2). The emissions may be less in Wales where animal manures are used to a greater extent to supplement manufactured fertilizers compared with the practices in England.

Table 3.2 GHG Emissions from Arable Crop Management

Crop	GHG Emissions (t CO_2e/tonne of product)
Winter Wheat (Bread)	0.51
Winter Wheat (feed)	0.46
Winter barley	0.42
Spring barley	0.38
Oil seed rape	1.05
Field beans	0.51

They assumed that soil carbon levels in continuous arable systems were stable because losses of soil carbon had occurred in the past. To reduce GHG emissions agronomic options were assessed including:

i. 20% decrease in applied N; one effect of reducing total N input is that the concentration of protein in the crop is also reduced. This reduces the likelihood of wheat grain being of a suitable quality for bread-making. (Wheat for bread requires a minimum 13% protein content).

ii. no-till cultivation for all cereals and legumes; no-till causes a reduction in GHG emissions as a result of lower primary energy use for cultivation. Jordan et al. (2022) concluded that there no-till cultivation had little effect on soil carbon levels.

iii. zero straw incorporation for all cereals and oilseed rape because incorporating straw into soil causes N_2O emissions from soil – a similar process described above for when grassland vegetation is incorporated into soil.

Where all three agronomic options were appropriate to the crop, reduced N had the greatest effect on GHG emissions. The combined effect of the options on the percentage reduction in GHG emissions was highest for the cereal crops (average 15% reduction). For winter bread wheat the reduction would be from 0.51t CO_2e/t product to 0. 42t CO_2e/t product. Berry et al. (2010) estimated that in the UK the average emission factor for winter wheat is 0.503t CO_2e/t.

Smith et al (2019) compared the GHG emissions for organic vs conventional production for arable crops – see Table 3.3. Their estimates were lower than those of Berry et al (2010).

Table 3.3. Comparison of Emission Factors for Arable Crops in Conventional and Organic Systems

Crop	Emission factor t CO_2e/t product - Conventional	Emission factor t CO_2e/t product - Organic
Wheat	0.42	0.33
Barley	0.38	0.31
Oats	0.35	0.37
Oil Seed Rape	0.89	0.76

The differences between conventional and organic practices reflect the differences in inputs, particularly of fertilizers and pesticides. For bread wheat, organic production uses about 20% less energy per tonne of product than non-organic, while occupying about three times the land area (including additional seasons required for fertility building and cover crops). Smith et al. (2019) concluded that although emissions/ha are lower from organic crops, yields are about halved and nitrogen fixing crops are needed. Hence the overall emissions in many cases are little changed. Fertiliser production, cultivations and harvesting are the main energy consumers, with fertiliser production dominating non-organic production (53%) and field work dominating organic production (60%).

Excluding emissions from land use change, arable cropping leads to GHG emissions from cultivation, fertilizers and pesticides and harvesting operations in the range of 0.31-0.54 t CO_2e/t product, depending on the cereal type and management. The main contributors to GHG emissions are from fertiliser manufacture and the nitrous oxide emissions from its application to the soil.

3.3 Comparison of GHG Emissions for Cereal Growing in Wales and East of England

For the option of growing more crops in Wales, assessment of GHG emissions needs to take account of yields in Wales relative those of the main cereal growing areas in the eastern regions of England. Also soil carbon losses need to be considered for conversion of grassland to arable in Wales. Transport emissions for moving cereals to Wales also need to be included in overall GHG emissions.

Table 3.4 summarises the average crop yields for the main grain growing areas of England in Yorkshire, East Midlands, Eastern England and SE England for 2011-2021. These are compared with the crop yields for Wales over the same period estimated indirectly from yields in contiguous regions in the west of England (DEFRA 2021).

Table 3.4 Comparison of Average Crop Yields for East of England Regions and Wales - 2011-2021

Crop	Crop Yields (t/ha) East of England regions	Crop Yields (t/ha) Wales	Percentage Reduction of Crop Yields in Wales compared with East England Regions
Winter wheat	8.03	7.2	10.3
Spring barley	5.8	5.1	12.0
Winter barley	6.8	6.5	4.6

To expand the arable area in Wales, additional land area for cereals can come from converting grassland to arable production, Berry et al. (2010) estimated that the GHG emissions caused by ploughing grassland would cause emissions to rise from 0.503 to 0.713t CO_2e per tonne of grain produced. This was based on the assumption that over a 30-year period the GHG emissions resulting from converting temperate grassland to arable crop land were 111- 242t CO_2e/ha (De Klein et al., 2006). The study assumed a mid-range value of 180t CO_2e/ha over a 30-year period, or an average of 6t CO_2e/ha/yr, for converting temperate grassland. This is an average over 30 years but in practice major losses occur in the first few years. Obviously a crop rotation between arable and grass leys would reduce this loss of SOC.

In addition to the losses summarised in Table 3.5, the SOC losses will surge following conversion of grassland to arable, and this will occur for the first few years of arable cropping. This will be significant for grassland converted to arable land in Wales, whereas in Eastern England most cereal growing areas are likely to be managed as continuous arable land, and therefore have lower SOC and smaller loss rates.

Assuming arable operations are the same for England and Wales, the GHG emissions per tonne of product will be less in England because of the higher yields and minimal loss of soil organic carbon based on the assumptions of Audsley and Wilkinson (2014).

How minimal these losses are is open to debate. For England soils, Table 3.5 uses the estimated average loss of 0.19t C/ha/yr for arable land (Emmett et al. (2010). Emissions are quoted as a range between 0 and the values calculated from the estimate by Emmett et al. The combined emissions per tonne of cereal are summarised in Table 3.5 for England and Wales, taking account of the lower yields in Wales for the same arable operations. The emissions from arable operations are based on the estimates of Audsley and Wilkinson

(2014). Land use change emissions for Wales are based on a grassland to arable transition using the estimate of Berry et al. (2010) – 0.21t CO_2e/t cereal.

Table 3.5 GHG Emissions for Cereal Crops in England and Wales

Crop	**Soil Carbon Emissions from land use (t CO_2e/t Cereal)**	**Arable Operation Emissions (t CO_2e/t Cereal)**	**Total Emissions (t CO_2e/t Cereal)**
Winter wheat - England	0- 0.09	0.46	0.46 – 0.55
Winter wheat - Wales	0.21	0.51	0.72
Spring barley - England	0 - 0.12	0.38	0.38 - 0.50
Spring barley - Wales	0.21	0.43	0.64
Winter barley - England	0 - 0.10	0.42	0.42 - 0.52
Winter barley - Wales	0.21	0.44	0.61

Note: Arable operation emissions/tonne have been amended to reflect lower yields in Wales.

Transporting grain from the East of England to Wales on a 400 mile round trip for an articulated Heavy Goods Vehicle holding 29 tonnes of grain would result in emissions of about 620kg CO_2, equivalent to 0.021t CO_2/t grain (AECOM, 2016). This is much less than the additional emissions from growing the crops in Wales.

Table 3.5 shows that expansion of arable cropland in Wales by cultivating grassland would cause additional GHG emissions compared with importing cereals from the established arable areas of the eastern regions of England even taking account of transport emissions. However, in the future, climate change may lead to decreased yields of cereals in the east of England because of reduced rainfall and higher temperatures, reducing the yield advantage compared with crops grown in Wales. See Section 5.3.

4 Replacing Soya Bean Meal (SBM) With UK-Grown Protein Crops

4.1 Consumption of SBM in animal diets

Over the past decade, there has been increasing concern to encourage the supply of alternatives to SBM for livestock production in the UK, as a way of reducing reliance on imports which cause environmental impacts through clearance of tropical rainforest and tillage of tropical grasslands. As well as the emissions from land clearance and loss of carbon sequestration of forests and soils, there are other major concerns about the impacts on biodiversity, and socio-economic effects on local populations in the source areas. Reduction of imported SBM would also improve the resilience of Welsh agriculture.

SBM is the by-product of the extraction of soybean oil from whole soya beans. Several processes exist, resulting in different products. SBM is usually classified for marketing by its crude protein content. High-protein types are obtained from dehulled seeds. Other types of SBM include the hulls or part of the hulls.

The UK imported 3.5 million tonnes of soya in 2019 (EFECA - UK Roundtable on Sustainable Soya, 2020). When combined with the volume of embedded soya in foods imported into the UK, the total consumption amounts to around 4.2 million tonnes soybean equivalent. The majority of this, approximately 75%, is used within animal feed, and embedded imports in meat, dairy and eggs. Embedded soya is in imported products that have soya ‘embedded’ within them, for example, poultry or pork which will have been reared abroad on a diet including soya and then exported for consumption in the UK market. Where soya beans are supplied to the UK market, the SBM equivalent is used to express import volumes – calculated at 72.5% yield. The 2,412,400t of SBM used by UK agriculture (Table 4.1) is equivalent to 3,331,600t of soya beans.

The sources of UK imported soya are Argentina (42%), Brazil (27%), North America (14%), Paraguay (8%), China (2%) and other countries (6%). It is estimated that 62% of soya imported into the UK in 2019 was covered by a deforestation and conversion-free certified soya standard. If soya sourced from territories considered at low risk of deforestation (North America and Canada) and soya covered by an Amazon Soy Moratorium contract are added to this figure, the total proportion of soya imported into the UK in 2019 considered to be from sources at low risk of deforestation/conversion or covered by a deforestation and conversion free certified soya standard amounted to 62%.

Table 4.1 summarises the consumption of soya bean meal (EFECA - UK Roundtable on Sustainable Soya, 2020). The survey identified 1.9 million tonnes reported by processors and allocated a ‘missing’ 0.4 million tonnes to on-farm processors. For Wales, the estimates were based on the proportion of the UK animal population in Wales where the major uses of SBM are for dairy cattle and broiler chickens.

Table 4.1 Consumption of soya bean meal by the livestock sector in July 2018-June 2019

Species	UK Annual Feed Use (tonnes)	UK Soya Bean Meal (tonnes)	Wales Annual Feed Use (tonnes)	Wales Soya Bean Meal (tonnes)
Dairy cattle	3,235,200	360,600	420,800	46,900
Beef cattle and calf	1,179,400	62,700	129,800	6,900
Pigs	2,112,000	358,700	10,600	1,800
Poultry - meat	5,374,860	1,213,800	268,800	60,700
Poultry - eggs	1,875,540	284,500	93,600	14,200
Sheep	858,000	28,300	239,500	7,900
Total	**15,654,300**	**2,412,400**	**1,163,100**	**138,400**

Note. For Wales, estimated consumption has been based on the proportion of the UK animal population in Wales.

The 138,400 tonnes of soya bean meal used in Wales would be produced from 190,900 tonnes of soya beans (72.5% yield) and at an average yield of 3.2 tonnes soya/ha, would require overseas land of about 59,700ha – of which about 77% is assumed to be in South America.

SBM is considered to be an ideal protein source because

- It has one of the highest protein contents of all agricultural crops (about 55% crude protein in DM)
- It contains significant amounts of all the essential amino acids particularly lysine, cysteine and threonine which are necessary for monogastric animals (pigs and poultry) which are unable to synthesise them and therefore require a dietary source.
- It has low levels of anti-nutritional factors which can limit animal growth
- It has high palatability and low fibre content (4.5%)
- It has a high phosphorus content (0.65-0.8% P) valuable for non-ruminants
- It has consistent quality for compound manufacturers to produce reliable feed compositions
- It is the lowest cost protein source for livestock. The SBM price determines the price for all other protein feeds.

For ruminants, SBM is very high in crude protein, providing a small quantity can reduce protein deficiencies in diets. The supply of amino acids from SBM comes from two sources.

- Feed is passed to the rumen where it is degraded by micro-organisms to ammonia before being synthesised into amino acids and subsequently protein to meet the needs of the rumen micro-organisms. The microbial protein passes into the true stomach and is digested and absorbed. (Rumen Degraded Protein - RDP).
- Protein which is not degraded in the rumen but digested in the true stomach and small intestine to provide additional amino acids. (Digested Undegraded Protein – DUP).

Selection of protein sources needs to take account not only of total crude protein content but also rumen degradability. Digestibility is also important as there is no merit in selecting a feed which escapes rumen degradation but is then indigestible.

SBM is attractive due to its higher level of DUP compared to other protein sources. For ruminants, this means that about a third of the soya is able to pass through the rumen undegraded and enters the fourth stomach and intestine where protein is directly available to the animal. DUP is an essential component of diets of high producing ruminants, especially high yielding cows and ewes in late pregnancy. Their high production level means that the demand for protein cannot be met fully by microbial protein from rumen microbes. This is especially the case for methionine and lysine where protected supplementation has been shown to increase milk yield (Nichols et al., 1998). Also for animals on high-forage diets, histidine is often the first limiting amino acid due to the greater reliance on microbial protein (Lee et al., 2012). Milk yield increases as dietary protein increases. But as DUP levels increase, the nitrogen utilisation in milk decreases and the amount of nitrogen excreted in urine increases. In turn this can lead to an increase in nitrous oxide emissions when urine is deposited on the soil.

Wilkinson and Lee (2018) concluded that for the highest daily milk yield of 45 litre, no forage diet would provide the energy demand of the cow. Even at 35 litre/day the Metabolisable Energy (ME) from forage would not meet the energy demand. Therefore, for a modern high-yielding dairy cow there is the need for supplementation.

For beef cattle, grass and conserved forage form the basis of the diets but are supplemented by high starch feeds such as cereals, sugar beet pulp and protein supplements. Compound feeds containing SBM are used to improve rates of liveweight gain. For sheep, concentrates such as cereals and concentrates containing SBM are used for pregnant ewes and during early lactation.

For monogastric livestock (pigs and poultry), SBM has an excellent nutritional profile, and a good balance of essential amino acids. This is particularly important for these livestock which cannot synthesise some amino acids such as lysine, threonine and cysteine. In contrast to ruminants, pigs and poultry have very limited ability to transform their dietary proteins in the digestion process and are therefore reliant on the correct balance of essential amino acids in the diet to ensure efficient utilisation of the feed. Typically, monogastric livestock diets are comprised predominantly of wheat (11% protein) and maize grain (8.8% protein), with SBM as the major source of supplementary protein. In Wales, the large poultry numbers require diets totally dependent on cereals and concentrates. Free range and organic systems also require the use of cereals and high protein compound feeds.

4.2 Analysis of Protein Alternatives

The challenge of dairy cow nutrition is to establish the minimal amount of protein required by high-producing dairy cows to achieve optimal milk production while minimizing environmental emissions. In a meta-analysis of supplementary proteins Huhtanen et al. (2011) reported that rapeseed meal can be substituted successfully for SBM. Both milk and protein yield responses to increased Crude Protein intake were greater with rapeseed meal compared with SBM supplementation. They showed that the productive value of rapeseed meal protein was at least as good as SBM protein for lactating dairy cows. The supply of amino acids available for rumen absorption from rapeseed meal diets is the same as from SBM diets. Better production responses to rapeseed meal are at least partly associated with greater increases in feed intake that can be related to a better balance between amino acids and energy in absorbed nutrients. For high-yielding dairy cows, the supply of DUP is important. Heat treated expelled rapeseed meal and wheat DDGS provide DUP concentrations similar to that of SBM (Schingoethe et al., 2009).

A major study by Jones et al. (2014) examined the possible replacements for soya bean meal for UK livestock with the main focus on the economic factors. They concluded that to replace soya bean meal on any significant scale would require a mix of protein crops and industrial by-products. Table 4.2 summarises the properties of the main crops and crop products that were considered. The digestible crude protein figure gives an indication of its value to the animal. Metabolisable energy represents energy that is available for use by the animal and is calculated as the digestible energy minus energy lost in urine and combustible gases.

Table 4.2 Crops and Crop Products suitable for UK livestock as protein sources

Crop	Digestible Crude Protein (% DM)	Metabolisable Energy (MJ/kg DM)	Maximum Inclusion Rate in Feed Rations (%)		
			Dairy	**Beef**	**Poultry**
Soya bean meal	55	13.6	35	35	25-35
Rapeseed meal	38	10.5-12.1	25	25	0-2.5
Rapeseed meal Heat treated	35	12.9	25	25	0
Lupins	28	11-14.5	12.5	15	0.5-7.5
Sunflower meal	28	7.1-10.2	25	25	0-10
Dried peas	23	13-15.4	30	30	0-7.5
Field beans	26	13.5-15.8	20	20	0-5
Linseed meal	18.5	18.9-20.5	20	20	0-2.5
Grass - sileage	14-15	10.8-11.2	100	100	0
Lucerne - dried	18	10	30	30	0-2.5
Naked oats	9.4	12.2-13.2	25	35	0-15
Wheat	12.6	13.8-16	40	40	50-60
Wheat feed	16-21	11.5	30	30	25-30
Barley	9	13.2-14.5	50	50	25-70
Rye	8.5	12-13.5	25	30	2.5
Triticale	11.6	13.5-14.5	30	35	10-35
Sugar beet pulp	7.2	12.5	30	40	0
Wheat DDGS	34.8	13.7	30	30	25

Note. MJ = mega joules: DM = Dry Matter

Advantages and disadvantages of each alternative are summarised below.

1. Oilseed rape meal is high protein with a similar amino acid profile to soya. It has a high fibre content which reduces its energy content and hence its value for non-ruminants particularly poultry. Rapeseeds yields about 35% oil and 65% meal when

fully extracted by crushing followed by solvent extraction. Solvent extraction usually involves pre-heating seeds to around 35 °C, rupturing the seed coat by passing through rollers, conditioning the seeds by heating to 80-90 °C to rupture oil cells, crushing the seeds by passing through a series of screw presses, followed by solvent extraction with hexane, and then heat treatment to remove solvent by toasting the meal (Crawshaw, 2019). This heat treatment lowers rumen degradability of protein. Lower rumen degradability results in higher proportions of protein as DUP.

2. Hot pressed rapeseed has 18.4% DUP, similar to that of soyabean meal (21.7% DUP). The hot pressing protects proteins from digestion in the rumen. This oil extraction method involves heat treatment to condition the seeds, followed by mechanical extraction in an expeller. Expeller meal has a higher ME concentration due to higher residual oil content (>80 g/kg) compared with <40g/kg for solvent extracted rapeseed, and a higher digestibility of DUP (Newkirk et al., 2003).
3. Lupins seeds contain relatively high protein contents but have poor amino acid profile especially of lysine and methionine. Lupins have relatively high contents of non-structural polysaccharides making them less suitable for non-ruminants. Lupins require supplementation with synthetic amino acids to improve nutritional value for pigs and poultry.
4. Sunflower meal has a protein content in the range 29-45% depending on the processing. It is rich in sulphur-containing amino acids but low in lysine and available threonine. It is high in fibre and low energy and is best suited to less productive stock. Complete substitution of soya leads to productivity losses in pigs and poultry, but partial substitution up to 20% is possible.
5. Peas are highly palatable and high protein feeds with an amino acid profile suitable for most livestock. Peas have high levels of lysine and reasonable levels of other amino acids. Protein digestibility is slightly lower than for soya. Peas contain anti-nutritional factors which affect livestock species to varying amounts. Can be fed to poultry
6. Beans are a good source of protein, but lower than soya. The amino acid profile is similar to that of soya with good levels of lysine but lower levels of methionine and cysteine. Beans have high energy and low fibre content but they have anti nutritional factors – tannins, urease, phytates, haemagglutinins, glucosides – making them unsuitable for poultry because the tannins interfere with digestion.
7. Linseed meal is oil-extracted but the residual meal still contains high levels of energy, oil and available carbohydrates but only moderate protein content and low levels of essential amino acids, particularly lysine. Linseed is a rich source of omega-3 polyunsaturated fatty acid (PUFA) and lower in saturated fatty acids. It has been used in animal diets to increase PUFAs in milk and meat for benefits to human health. Linseed can have a laxative effect in ruminants, soft carcass fat and oxidation of fat in milk. It is not suitable for poultry because of the poor amino acid profile, high fibre content and the laxative effect.
8. Dried grass quality varies greatly depending on the grass crop and quality of harvesting and storage. It is not a high protein feed and requires supplementations to correct protein deficiencies.
9. Lucerne has moderate protein content – higher than grass. It has no anti nutritional factors. High fibre content limits inclusion in high yielding rations.

10. Dried Distillers Grains with Solubles (DDGS) is produced from fermentation of wheat, barley and maize to ethanol for biofuels, beers and spirits. It is high in energy and protein. It has moderate levels of digestible fibre. Heating during processing makes the protein partly rumen undegradable. It has good palatability. It can have high copper levels if distillation is in a copper still. The high copper levels make it unsuitable for sheep, but it is suitable for poultry and pigs.
11. Wheat feed is a by-product of flour milling comprising wheat bran, endosperm and other starch screenings. It has a useful protein content and is high in starch and digestible fibre.

Jones et al. (2014) ran economic scenarios which were based on constraining soya use by raising the price of the feed, and constraining imports of alternative feed stocks. Availability of DDGS was also constrained by varying amounts. The growing and utilisation of home-grown crops was unconstrained to assess the extent that substitution may take place. Modelled results for annual changes are summarised below.

Jones et al. (2014) used a Land Use Allocation Model (LUAM) to predict how much land would be required for additional protein sources and what land uses would be displaced. This was based on 2009 land areas in the UK. The trends that were identified were

- Increases in crop area for: wheat, beans, peas and lupins
- Decreases in crop area for: barley and other cereals
- An increase or decrease in rapeseed crop area, dependent on the levels of imports of rape seed meal competing with home production.

The main conclusions by Jones et al. (2014) were that based on improvements to the nutritional qualities of the alternatives to SBM, combined with increased availability of synthetic amino acids, it would be technically feasible to replace up to 50% of all imported SBM. None of the scenarios would eliminate the dependence on SBM unless there was a move away from intensification particularly in the dairy and poultry sectors, and/or a reduction in total livestock numbers.

If no SBM was included in feedstuffs, all livestock compound feeds would increase in price. If this change was implemented in Wales and UK and not in other countries producing livestock, then Welsh and UK production would be disadvantaged, and food imports would increase. From a self-sufficiency viewpoint, there is the need to ensure that crops can be grown productively in Wales, whilst not increasing GHG emissions and other environmental impacts such as air and water pollution.

4.3 GHG emissions from Soya and Alternative Crops

In allocating GHG emissions to animal feed products, it is important to allocate emissions to the primary product and by-product feedstock. For example, soya beans are processed to produce oil and SBM, rapeseed is processed to produce rapeseed oil and rapeseed meal, and Dried Distiller Grains with Solubles (DDGS) are a by product produced from fermentation of cereals to produce ethanol for beverages or fuel. Two methods of allocation are used based on their mass outputs or market values (Benavides et al. (2020).

- The mass-based estimate assumed that to convert the feedstock into the different products, the same amount material and energy inputs were required to produce the same number of products by mass.

- The market value-based method allocates the GHG emissions and energy consumption burdens assuming that the greater market value of individual products requires greater amounts of energy and material inputs.

Given the varying market values of products from one feedstock, the mass-based estimates are described here. All emission figures are quoted in t CO_2e/t product for ease of comparison, although some papers quote emissions in kg CO_2e/kg product.

4.3.1 Soya Bean Meal

Opio et al. (2013) reported that in Brazil, deforestation (conversion of forest to annual cropland) releases an average of 37t CO_2e/ha, and in Argentina, conversion of forest and shrub land to annual crops releases a total of 17 and 2.2t CO_2e/ha, respectively. GHG emissions from soybean-driven Land Use Change (LUC) were calculated as the accumulated emissions for one year resulting from the total area deforested during the period 1990–2006 divided by the total soybean production in 2006. According to IPCC guidelines, emissions arising from LUC are allocated over a 20-year period (the "amortization" period).

Based on this data, two LUC emission intensities based on four life cycle assessment methods were estimated for soybean meal produced in Brazil and Argentina. Values for Argentina were in the range 0.34-4.23t CO_2e/t soybean meal and 2.98-7.69t CO_2 e/t soybean meal from Brazil. Castanheira and Freire (2013) estimated that when emissions from LUC are excluded, the GHG intensity varies from 0.3 to 0.6t CO_2e/t soybean meal, depending on fertilizer and cultivation methods. This GHG intensity would apply to cropping areas in other countries such as USA which supply the UK. Benavides et al. (2020) estimated the GHG emissions to be 0.482tCO_2e/t soyabean meal based on a mass-allocation between oil and meal, excluding LUC emissions.

In a study of the potential environmental impact of a range of diet formulations for dairy cows yielding 40 kg milk/day, Wilkinson and Garnsworthy (2017) used the value for soya bean meal of 1.056t CO_2e/t DM, which is comprised of 0.625t CO_2e/kg DM derived from growing, processing and transporting the crop, and 0.431 kg CO_2e/t DM derived from land use and land-use change. This emissions factor is considerably lower than the value used in some studies (e.g. 7.690t CO_2e/t DM for Brazilian soya bean meal (Opio et al., 2013) due to a difference in allocation of land-use change. It acknowledged that most soya bean production is on land that has been in arable cropping for more than 20 years and is now in carbon equilibrium.

Using the average figure by Wilkinson and Garnsworthy (2017), Wales' use of 138,400t SBM corrected to 125,700t DM causes emissions of 132,730t CO_2e in 2018-19, but this would be greater if the maximum emission factor of Opio et al. (2013) is used.

4.3.2 Rapeseed

Smith et al. (2019) estimated the GHG emissions from rapeseed to be 0.89t CO_2e/t rapeseed. Audsley and Wilkinson (2014) estimated rapeseed had a GHG emissions of 1.05t CO_2e /t product compared with 0.70t CO_2e /t product for soya. However, when compared with Crude Protein, the soya meal had a value of 1.96 kg CO_2e /kg CP compared with 5.33 kg CO_2e /kg CP for rapeseed.

Fridrihsone et al. (2020) estimated total GHG emissions were 1.335t CO_2 e/t for spring rapeseed and 1.128t CO_2 e/t for winter rapeseed in N Europe. From the LCA for production of the crop and processing, averaging spring and winter crops, GHG emissions were allocated according to the mass of the products – oil (35%) and meal (65%). The estimated GHG emissions are 0.467t CO_2 e/t oil and 0.868t CO_2e/t meal.

In 2020, there was a 41% decrease in crop area to just over 1 million hectares in the UK with a yield of 2.7 tonnes/ha, below the five-year average of 3.5 tonnes/ha. There was a general decline of yields of rapeseed because of flea beetle damage following the ban on neonicotinoid insecticide treatment of the seed, coupled with unfavourably wet winter conditions and a dry spring in 2019-20.

4.3.3 Sunflower

Sunflower meal is the by-product of the extraction of oil from sunflower seeds. In terms of production, it is the 4th most important oil meal after soyabean meal, rapeseed meal and cottonseed meal. There are two major constraints on production of a successful sunflower crops in the UK, both are related to heat availability. The first is the length of the growing season, as determined by the earliest date at which sowing is practicable and the latest date at which maturation ends and harvesting can no longer be delayed. The second is the amount of heat available for use by the crop during this growing season. Soil temperature needs to be between 7-9˚C in the top 10cm for drilling and a base daily air temperature of above 6˚C.

Organic Centre Wales has researched the feasibility of growing sunflowers in Wales (Nixey et al., 2014). The south-east corner of Wales and pockets of land in Pembrokeshire, Anglesey and the extreme NE of Wales could support a crop. They yield between 1.5-2.5 t/ha when grown conventionally in the UK. In practice, very little sunflower is grown in the UK with annual production of 3000t in 2008. No updated figures are available. In the UK, crop yields are limited by variable weather conditions and late harvests.

From a meta-analysis of studies in the main production countries, Alcock et al. (2020) estimated total GHG emissions averaged 1.85t CO_2e /t oil. Based on oil extraction rates of about 37% by weight of the sunflower seed, 1t seed produces 0.37t oil with the remaining 0.63t being meal. Allocating the emissions between oil and meal on a mass basis, this leads to an emission factor of 1.17t CO_2e/t meal.

4.3.4 Lupins

White lupin (*Lupinus albus* L.), yellow lupin (*L. luteus* L.) and blue lupin (*L. angustifolius* L.), are native European legumes. Their seed protein content is high (up to 40%). Lee et al (2016) found the inclusion of blue lupins in the diet of laying hens at a rate of 150 g/kg DM resulted in no adverse effects in production or hen health and could be used as part of a balanced ration to reduce reliance on soya protein.

Lupin production in Europe is about 200,000-300,000 tonnes annually. In the UK, around 2000ha are grown (J Nix Pocketbook, 2022) – 60-70% white (mostly in South and East), 15-20% blue and the rest yellow. Soya UK recommends that blue lupin can be grown in

Wales[1] UK yields are in the range 2.5-3.5t/ha, resulting in annual UK production in the range 5000-7000 tonnes. No data on GHG emissions have been found, but as lupins are legumes which fix nitrogen, their emissions would be expected to be similar to those of other legumes such as beans.

4.3.5 Beans and Peas

In the UK, peas are grown mainly for human consumption, with only a small proportion of low grade samples used for animal feed. Field beans are planted in spring and autumn. 53% are spring sown. In England, 135,000ha of field beans were grown in 2019, and 64,000ha of peas (DEFRA June Survey, 2020). No data are available for Wales although the area will be small. Yields are in the range of 3-5t/ha (John Nix Handbook, 2022). A recent report on two farms in Monmouthshire indicated yields of spring beans as high as 7t/ha (Farmers Weekly, 11th February 2022). Audsley and Wilkinson (2014) estimated the GHG emissions for field beans to be 0.51t CO_2e/t product and the emissions per kg Crude Protein to be similar to Soya. Beans and peas are important as a break crop because they fix nitrogen which is left in the soil for following crops. The nitrogen fixation leaves about 50kgN/ha in the soil after a spring bean crop (Farmers Weekly, 11th February 2022)

4.3.6 Dried Distillers Grains with Solubles (DDGS)

Production of DDGS is GHG-intensive because production requires the processing steps of cereal extraction and drying. Using a mass allocation for dividing the emissions between ethanol production and the DDGS production, the GHG emissions were estimated to be 0.869t CO_2e /t product (Benavides et al., 2020). This does not include emissions from land use change.

4.3.7 Wheat Feed

In the production of white flour, about 75% is extracted and the remaining 25% constitutes the residue called wheat feed. This varies considerably in composition, depending on the original grist and the extraction rate. The crude protein content is generally within the range 16-21% DM and metabolizable energy content is 11.5 MJ/kgDM. Although the GHG emissions from wheat production are known (see Table 3.5) no data on GHG emissions from the processing were found.

4.3.8 Amino-acids

Mosnier et al. (2011) studied the incorporation of feed-use (FU) amino acids (AAs) in diets to reduce the use of protein-rich soybean meal for pigs and poultry. FU AAs are now commonly used in pig and poultry feed formulations. In pig and poultry, lysine, methionine and threonine are the most limiting AAs for muscle deposition and are available as synthetic industrial products. This study investigated whether the incorporation of L-lysine. HCl, L-threonine and FU-methionine reduces the environmental impacts of pig and broiler feeds using Life Cycle Assessment. The GHG emissions for the three amino acids were calculated to be

- L-lysine and L-threonine 4.294t CO_2e/t product.

[1] http://www.soya-uk.com/lupin/

- L-methionine 2.96t CO_2e/t product.

Although the GHG emissions from production of amino acids are high, because the incorporation of the amino acids into feed mixes occurred at levels of around 1% or less, they made little contribution to the overall GHG emissions of the complete feed mix.

For dairy cows, responses to additional essential amino acids such as methionine and lysine on milk yields are variable and difficult to predict (Sinclair et al., 2014). They advocate dietary strategies that aim to optimise microbial protein synthesis may go some way to mitigating expected reductions in intake and milk yield when feeding low Crude Protein diets. Synthetic amino acids need to be protected from degradation in the rumen.

Pigs and poultry are reliant on the correct balance of essential amino acids in feeds to ensure efficient utilisation of the feed since they have very limited ability to transform the composition of their dietary protein. For example, broilers require methionine, lysine, threonine, isoleucine, valine and arginine (Dozier et al., 2008).

4.4 Expansion of Forage Crops to Replace Imported Feeds

Apart from grassland – grazed and harvested grass, the main forage crops grown in Wales are turnips, swede and kale. Maize silage is also grown for dairy cattle.

Fodder beet is grown in Wales as a break crop. These crops have particular value as winter feed resources for cattle and sheep. Inclusion rates are recommended to be in the range 35-50% of total dry matter intake, with access to hay and straw. This is to prevent bloat and goitre (iodine deficiency).Table 4.3 summarises the forage yields and quality in the UK (Yeates and Simpson, 2010), comparing arable crop forages with grass – grazed and conserved.

Table 4.3 Yields and quality of forage crops

Crop	Utilisable Yield (tonnes DM/ hectare)	Energy (MJ/kg DM)	Crude Protein (% in DM)
Grass (grazed)	8.8	11.5	17
Grass (grazed) (high white clover)	8.8	11.5	19
Grass (grazed) old pasture	6.0	10.5	15
Grass silage (3 cuts – clamped or baled/wrapped)	10.2	10.8-11.2	14-15
Turnip (summer)	5.1	11.2	17
Swedes	6.5	12.9	10
Kale (grazed)	7.5	11	16.8
Chicory, ryegrass, white clover (grazed)	8.0	11	20
Maize silage	11.7	11.2	9
Fodder beet	12.8	13.0	12.5

Forage crops provide an important feed source for ruminants in winter months to supplement silage and hay supplies harvested in the summer. Data for grass and silage are included for comparison.

Utilisable grass yields are less than actual grass yields because residual vegetation is left to regrow. In the UK, average grass yields were 9.2tDM/ha in 2021 (Grasscheck UK). Improvements to grass management have aided yield increases of up to 12tDM/ha for the best farms – although this may rely on heavy use of artificial fertilizers with associated GHG emissions. GHG emissions are not available for turnips, swedes, kale and fodder beet.

Forage crops are an important component of diets – silage and root crops being important in winter, and grass in the growing season, but they are not a replacement for the high protein content provided by SBM.

4.5 Summary

Taking account of the GHG emissions to produce a tonne of crude protein, from Table 4.2 and literature values of emissions (Wilkinson (2011): Wilkinson and Garnsworthy (2017); Audsley and Williams (2014)). Table 4.4 provides a summary for alternative crops.

Table 4.4 Summary of GHG emissions of crops to produce crude protein

Crop	Crude Protein (CP) (%)	Emission Factor t CO_2e/t product	GHG Emissions t CO_2e/t CP
Soya Bean Meal	55	1.056-7.690	1.92 – 13.98
Rapeseed meal – solvent extracted	38	0.868	2.28
Rapeseed meal – expelled and heat treated	35	0.868	2.28*
Sunflower meal	28	0.31-1.12	1.11-4.0
Beans	26	0.69**	2.65
Winter wheat	12.6	0.72	5.71
Spring barley	9	0.64	7.83
Wheat DDGS	34.8	1.08***	3.10

Based on GHG emissions being similar to that of solvent extracted rapeseed meal ** Assumes bean yield of 4t/ha * Based on emission factor for wheat and yield of DDGS/tonne of cereal*

The range of GHG emissions per tonne of CP varies widely for each feed, but generally, emissions are lower for CP for the feeds with a high protein content. Cereals have low CP contents, resulting in high emissions per tonne of protein. Heat treated expelled rapeseed meal, wheat DDGS, and beans have the lowest emissions.

For high-yielding dairy cows, the supply of DUP is important. Heat treated expelled rapeseed meal and wheat DDGS provide DUP concentrations similar to that of SBM (Schingoethe et al, 2009).

For pigs and poultry which cannot transform proteins to the required amino acid profile, diets supplemented by amino acids are required to replace SBM.

5 Extrapolation to Wales

Assessment of the cropping options for Wales requires an estimate of the land suitable for expansion of arable crops, coupled with an analysis of the possible crops that could be grown successfully in Wales – taking account of soil, climate (now and future) and the demand for the crop outputs within the farming system.

5.1 Area estimates

In 2021, Wales has an area of crops and horticulture estimated to be 92,941ha (September 2021) with 155,923ha assigned to grassland under 5 years old which is assumed to be temporary grassland possibly in rotation with arable. These data originate from responses to the annual June Agriculture Survey. Detailed data on crops come from Welsh Government Survey of Agriculture and Horticulture (November 2021). Table 5.1 summarises the data.

Table 5.1. Agriculture Land Use in Wales 2021

Crop	**Area in 2021 (ha)**
Wheat	23,223
Winter Barley	8,482
Spring Barley	12,105
Other cereals (including oats)	6,700
Potatoes	2,341
Crops for stock feeding e.g. roots, kale	16,265
Maize	14,821
Oil seed rape	4,841
Other crops	4,163
Horticulture including orchards, hardy nursey stock, vegetable & salad crops	1,500
Total	**94,141**

Grassland over 5 years old (interpreted as permanent grassland) covered 1,141,336 ha together with 241,533 ha of sole rights rough grazing.

Arable cropping is likely to be limited to Agricultural Land Classification (ALC) land grade 1: excellent quality agricultural land, (4,000ha), Grade 2: good quality agricultural land (125,800ha), and Grade 3a: good to moderate quality agricultural land (191,700ha). Grade 3a land provides moderate to high yields of narrow range of arable crops (e.g. cereals), or moderate yields of grass, oilseed rape, potatoes, and less demanding horticultural crops. Only agricultural land up to Grade 3a (total of 321,500ha) will typically be suited to tillage and horticultural crops (MAFF, 1988), although the Wales Crop Requirements Report (ADAS 2019) indicated that Grade 3b land (487,900ha) would be suitable for some cereal crops – rye, oats, naked oats and triticale. This is a penalty of lower and more variable yields.

Grade 1 land is located in small pockets of lowland North East and South Wales. Similarly, Grade 2 land is mainly located in lowland North and South Wales, Anglesey and Pembrokeshire. Grade 3 land is more widely distributed and is located in low lying coastal and inland areas, river valleys (e.g. the Wye and Severn) and along the Welsh/English border. Grade 4 (412,200ha) and Grade 5 agricultural land (461,100ha) are located in the central upland areas of Wales.

It is not possible to assign where cropland and grassland is situated in the ALC grade areas, but it is likely that the cropland and temporary grassland (total of 248,864 ha) occupies most of the Grades 1-3a land (total of 321,500ha). Any expansion of arable crops would be focused on land in these Grades.

5.2 Effects of Climate Change Scenarios on Arable Cropping Areas in Wales.

It is important to take account of the likely changes in ALC land areas modelled from climate change scenarios (Keay and Hannam, 2020). The modelling was based on UKCP18 projected scenarios (UKCP18) for low, medium and high emissions. The projected scenarios are that average annual rainfall changes little over the projected periods, but the distribution of rainfall changes between seasons. There is an increase in rainfall in the winter and less rainfall in the summer months up to 2080 for all emission scenarios.

Accumulated temperature is a measure of the relative warmth of a locality and is the excess of daily air temperature above 0°C. Accumulated temperatures above 0°C increase to 2080 for all emission scenarios with significantly warmer summer months by 2080 compared with the baseline. Moisture deficits show a significant increase to 2080 for crops (wheat and potatoes). The largest deficits are predicted in the Welsh-English borders areas, South Wales, Pembrokeshire and Anglesey by 2080.

Focusing on the effect of these scenarios on the Best and Most Versatile (BMV) land (Grades 1-3a) (Table 5.2), there would be an increase in the BMV area by 2050, as Grade 3a land increased mainly at the expense of higher quality Grades 1 and 2 land. There would be some increase of Grade 3b land as a result of Grade 4 land decreasing.

Table 5.2. Percentage Land Areas in ALC Grades based on Climate Change Scenarios to 2050 and 2080

ALC Grade	Percentage of land area (baseline)	Percentages of Land Areas in 2050 Climate Change Scenarios			Percentages of Land Areas in 2080 Climate Change Scenarios		
		Low	Medium	High	Low	Medium	High
1	0.31	0.18	0.19	0.15	0.11	0.09	0.06
2	7.92	7.1	7.43	4.76	2.92	2.02	0.53
3a	11.84	16.35	16.21	16.77	15.06	13.74	8.09
3b	28.75	33.28	32.99	33.78	34.26	34.37	28.03
4	24.22	17.20	17.27	18.89	22.45	24.51	38.61
5	26.95	25.89	25.90	25.65	25.41	25.27	24.69

Total BMV (Grades 1-3a)	20.09	23.63	23.83	21.68	18.09	15.85	8.68

By 2080 the projected climate would cause a substantial decrease of Grades 1 and 2 land particularly under the high emissions scenario. Grade 3a land area would decrease between 2050 and 2080 so that the total BMV land area would decrease particularly under the high emissions scenario. Grade 3b land area would increase by 2080 under the low and medium scenarios as a result of transfer from Grade 4 land but this trend would reverse under the high scenario. Throughout the period to 2080, Grade 5 land area would remain unchanged.

5.3 Impacts of Climate Change on Crops

The climatic suitability of land for crops can be based partly on the ALC since climatic factors form part of the assessment of land suitability for crop growing. Soil properties are the other main factor in determining ALC grades. The climatic criteria are considered first when classifying land. Climate can be overriding in the sense that severe limitations will restrict land to lower grades irrespective of favourable soil or site conditions. In general, limitations to agricultural use increase as rainfall increases and average temperature decreases.

Important climatic factors include the length of the growing period, which is dependent on the accumulated temperature - the excess of daily air temperature above 0°C. This is also dependent on the altitude of the land. Other related factors include the number of frost days, and the number of sunshine hours.

The mean annual temperature is another factor in determining the ALC grade. The interaction between temperature and yield can be complex. For cereals, increasing temperatures can reduce yield by shortening the time to reach maturity i.e. flowering and seed set (Wheeler et al., 1996). The duration to maturity depends on the temperature and in many cases day length (Bindi and Howden, 2004). In some cases, a temperature increase would shorten the length of the growing period, hence reducing yields (Porter and Gawith, 1999). For many field-grown horticultural crops any increase in temperature could be beneficial by increasing the geographic range and harvesting period in Wales.

Rainfall and the pattern of rainfall are important for crop productivity. For example, warm, dry summers reduce crop growth and subsequent yield. Plants can recover from short periods of water shortage that reduce crop canopy expansion during their vegetative stage (reducing the potential for photosynthesis) but longer periods will have a permanent impact on crop yield. Conversely, too much rainfall can cause problems with crop establishment (in autumn) and/or reduce yields (spring/summer rainfall) due to increased disease pressure and low sunlight levels. High rainfall is associated with soil wetness, which can reduce the productivity and versatility of the land and impact on crop productivity/yield.

Compared with east of England regions, Cho et al. (2012) reported wheat production in the northern and western areas of England and Wales is most likely to benefit from a warmer and drier climate. Climate sensitivity will vary with crop. For example, Semenov (2009) reported that the earlier flowering wheat Avalon could be expected to produce larger yield increases compared with Mercia wheat breed under climate change scenarios by the 2050s. UK winter wheat yields will be negatively affected by droughts with increasing potential costs for some farmers, who may need to invest in irrigation systems. Climate change in the UK can impact crop product quality in addition to overall yields (Rial-Lovera et al., 2017).

Climate change could lead to opportunities for new crops. Coleman et al (2021) have investigated growing soybeans in the UK to substitute for imports with the soybean crop being successfully matured in all field trials conducted. Yields ranged between 0.4 t/ha in 2018 to 2.9 t/ha in 2017 with an average of 1.7 t/ha. These early results suggest that by 2050 soybean could be a viable crop across most of England and south Wales under both a mid-range and high climate change scenario.

Table 5.3 summarises the suitable ALC grade for specific crops with an indication of climate sensitivity. Most cereal crops require ALC Grade 1-3b land. Although the BMV land is considered to be limited to Grades 1-3a, use of Grade 3b land could increase the potential area of cropland from 22-24% to about 56% in 2050. Crops would be lower and more variable as result of weather conditions.

Table 5.3 Suitable ALC Grades and climate sensitivity for crops.

Crop	**ALC Requirements**	**Climate sensitivity**
Wheat	1-3b	Development is governed by temperature, vernalisation (in winter varieties) and day length. Waterlogging in winter crops. Lodging in wet summer conditions
Barley	1-3b	Development is governed by temperature, vernalisation (in winter barley varieties) and day length. Waterlogging in winter crops. Lodging in wet summer conditions
Oats	1-3b	Land at high altitude will be unsuited due to soil wetness and temperature. Lodging in wet summer conditions
Oil seed rape	1-3b	Land at high altitude will be unsuited due to soil wetness and temperature
Maize	1-3a	Sites >180 m are marginal and only likely to be suitable with lighter, drier soils. Require set amount of solar energy in order to develop from germination through to harvest for grain.
Field bean	1-3a	Land at high altitude will be unsuited due soil wetness and temperature
Soya bean	1-3a	Very sensitive to frost at seed emergence and pod filling. Require soil temperatures of >10°C to germinate but between 13-16°C is optimal. Excess moisture severely affects germination and early growth
Peas	1-2	Sensitive to soil moisture deficits at the beginning of flowering and during pod swelling. Land at high altitude will be unsuited due to soil wetness and temperature

ADAS (2017). ADAS (2019).

For cereals the most suitable areas in Wales currently are located in Anglesey, Monmouthshire, Flintshire, and the lower Wye Valley in Powys, with a smaller area in south Pembrokeshire and Vale of Glamorgan. From the climate change scenarios, moisture deficits show a significant increase to 2080 in the potential deficit of water available for crops (wheat and potatoes). The largest deficits are evident in the Welsh-English borders, South Wales, Pembrokeshire and Anglesey by 2080. Monmouthshire is likely to be the first area in Wales to experience a decrease in land suitability for growing crops. Drought effects are likely to be experienced in this area within the next twenty years. The area of Wales with most agricultural opportunity between 2050 and 2080 seems to be north Pembrokeshire around the Preseli mountains, northern Carmarthenshire, and south Ceredigion. Increased drought conditions in the east of England could make the Best and Most Versatile (BMV) land in western England and Wales even more important for human food production.

Overall, the availability of BMV land on which cereals and other crops can be grown is predicted to be stable. A future Wales' climate with drier and warmer conditions will favour cereal production, with benefits (e.g. dryer summers reducing lodging and improving harvest timeliness) and disbenefits (e.g. wetter winters increasing waterlogging) impacts on wheat and barley crops.

5.4 Options for Cereal Crop Expansion to Meet Wales' Animal Feeds Requirements

To assess self-sufficiency of Wales to meet animal feed demands, Table 5.4 summarises the livestock numbers in the UK and Wales in 2020. **Although UK animal feed statistics are produced by AHDB (AHDB 2022), disaggregating these to Wales is complicated by the lack of information on how much cereals are used by each animal sector.**

Table 5.4 Livestock population for UK and Wales in 2020

Livestock	UK Population	Wales Population	Wales Share of UK Population (%)
Sheep	32,700,000	8,990,000	27
Cattle	9,610,000	1,120,000	12
Dairy breeding	1,850,000	250,000	14
Beef breeding	1,510,000	160,000	11
Poultry	181,960,000	9,840,000	5
Pigs	5,050,000	30,000	0.6

AHDB reports on UK cereal usage, and these are summarised in Table 5.5

Table 5.5 Annual Average Cereal Usage in UK

Cereal	Sector	Annual Average UK Usage for Animal Feed 2016-21 (kt)
Wheat	All	7,165
	Integrated Poultry Units	1,175
	Other animals	5,990
Barley	All	4,147
	Integrated Poultry Units	71
	Other animals	4,076
Oats	All	316
Maize	All	1,368
Total Cereals	All	12,996

To assess the cereal requirements for animal feed in Wales it is assumed that the current production in Wales is used mainly on-farm with very little sent to feed compounders for incorporating into feeds, or for ethanol production. This assessment is based on the small scale of cereal growing in Wales.

Welsh farmers buy an estimated 1,163,100 tonnes of additional feed (Table 4.1). Animal Feed Statistics for Great Britain (Defra, 2018) indicate that the proportion of cereals is about 70% with the remainder being high protein sources – cakes and meals of oil seed rape, soya, and sunflower. The amount of cereals required in the compound feed are therefore 814200 tonnes. To be self-sufficient in cereals, Wales would need to grow this quantity of wheat, barley and oats. Wheat is the major cereal component – about 80%, with the remainder being mainly barley with a small amount of oats. Whole and flaked maize is the other cereal in animal feed, but it cannot be grown successfully in Wales at present. Table 5.6 provides estimates of the cereals for meeting the requirements for compound feeds, and the additional cropping area required.

Table 5.6 Cereals Requirements to meet Wales' Compound Feed Demand.

Compound Feed Needs - Wales	Percentage composition of total compound feed (%)	Amounts of each feed component (tonnes)	Additional cereal area required (ha)*
Total compound feed	-	1,163,100	
Total cereal feed	70	814,200	
Total wheat feed	55.5	646,000	89,700
Total barley feed	13.93	162,000	27,000
Total oats feed	0.54	6,280	1,300
Total area required	118,000		

**Based on average yield of 7.2t/ha for wheat, 6t/ha for winter and spring barley, and 4.8t/ha for oats.*

In practice, the expansion of arable areas by about 118,000ha would occur on land that is already cultivated on a rotation basis i.e. the 161,000ha of improved grassland. It would require a major expansion from the 50,510ha currently used for cereal crops. The challenge is to find crops which have a higher nutrient value than improved grass for livestock in Wales. Obviously converting improved grassland into arable reduces the most productive grassland and would require a reduction in livestock numbers unless other grassland can be improved. This would require more intensive management of the 763,000ha of 'improved grassland' identified by Countryside Survey 2007 (Smart et al. 2009). Expansion of arable land must take account of the GHG emissions from loss of soil carbon and from arable cropping inputs. There will also be other environmental and biodiversity implications to consider.

In summary further research is required to estimate total cereal needs for animal feeds in Wales, in particular to find the breakdown of cereal type and use by each livestock sector in Wales. Current reports provide estimates for the UK but not for Wales. Based on a number of assumptions, to meet Wales' requirements would require expansion of cereal growing by about 118,000ha, a large increase compared with the currently available land of good quality for cereal growing, and the current cereal growing area.

5.5 Options for Arable Crop Expansion for Protein Production

5.5.1 Sector analysis

On a sector basis, taking account of the preferred substitutes for livestock types, the main possible substitutes for imported feedstuffs are:

- Dairy – heat treated rapeseed meal. Huhtanen et al. (2011 reported that rapeseed meal can be substituted successfully for soybean meal for dairy cows. Garnsworthy et al. (2021) also reported that cows fed rumen protected rapeseed products will have similar or improved milk production compared to a control (soya-based) diet. The diets included wheat DDGS to provide additional crude protein.
- Poultry (meat and eggs) – rapeseed meal, wheat DDGS, field beans. Practically the most likely options are to increase cereal and rapeseed meal fractions of the diet and supplement with amino acids. Currently the UK yields of field beans are too variable for compounders to use.
- Beef and sheep – cereals, cereal by-products (wheatfeed, maize gluten, brewer and distiller grains) and forage crops. High levels of production are achievable from grazed pasture and high quality silage. Warren et al. (2008) reported the finishing of Holstein-Friesian and Aberdeen Angus steers at 24 months old at 614 and 686 kg, respectively, off grass silage ad libitum with no supplemental feed. Lee et al. (2009) finished dairy cull cows on grass and red clover silage ad libitum with average daily live weight gains of 1.3 kg. Both studies indicate that feeding high-quality silage with no supplement can result in acceptable live weight gains.

For the present time, taking account of the small amounts of lupins and sunflowers currently grown in the UK and the climate requirements for adequate yields, it is unlikely that compounders will be interested in the technical demands of providing feeds of consistent quality from variable amounts and quality of these feeds. Compounders currently rely on imports of sunflowers (about 300,000-400,000t/yr on sunflower cake and meal (AHDB 2022).

The challenge in replacing SBM would need to be met by the expansion of cropping to produce rapeseed and cereals and include by-products such as wheat DDSG for high-yielding dairy cows, and rapeseed, cereals and field beans for poultry and pigs.

5.5.2 Options for reducing SBM use in Wales

5.5.2.1 Option 1. Eliminate SBM from sheep and beef cattle diets

As noted above, high quality forage could reduce the need for high protein concentrates based on SBM for the beef and sheep sectors. This would reduce SBM use by 14,800 tonnes in Wales.

5.5.2.2 Option 2. Substitution of SBM by rapeseed meal and wheat DDGS for dairy cattle

For the dairy sector to reduce the usage of 46,900t SBM, the diet formulation used by Garnsworthy et al. (2021) for dairy cows provides a useful basis for the amount of substitution. The study used rations containing 115-117kg/t Dry Matter of rapeseed meal (expelled or extracted) to substitute for 96kg/t Dry Matter soyabean meal to achieve a similar milk yield performance. The diet containing rapeseed meal was also supplemented by the addition of 77-78kg/t Dry Matter of wheat DDGS.

- Substitution of 46,900t SBM would require 56,670t rapeseed meal
- At a composition of rapeseed of 35% oil and 65% meal, the total rapeseed required is 87,185t
- At a yield of 2.7t/ha, the UK average in 2020, this would require 32,290ha of land.
- Substitution of 46,900t SBM would require 38,100t wheat DDGS from 129,150t of wheat. (From 1t of wheat, 295kg of wheat DDGS is produced)
- At an average winter wheat yield of 7.2t/ha in Wales, this would require 17,940ha of arable land.
- The required land would expand arable cropping area for oil seed rape and winter wheat by about 50,000ha in Wales, compared with the current arable area of 92,941ha. Expansion would take a substantial part of the remaining Grades 1-3a land (total of 321,500 ha).
- From Table 4.4, GHG emissions for rapeseed meal would be 64,000 t CO_2e and from wheat DDGS production would be 41,200 t CO_2e, making total emissions of 105,200t CO_2e.
- In the initial transition from grassland to arable, the GHG emissions could amount to 5-16tC/ha equivalent to 250,000-800,000tC for 50,000ha. This would be regained partly if arable land is in rotation with grass leys.

5.5.2.3 Option 3. Substitution of SBM by rapeseed meal for poultry and pigs.

50% substitution of SBM would reduce that required by 38,400t

- Taking account that 1000kg soyabean meal contains 480kg crude protein and 1000kg rapeseed meal contains 339kg crude protein, the amount of rapeseed meal required to replace 38,400t SBM would be 54,370t. This assumption needs to take account that the amino acid digestibility will vary between the protein sources.
- Amino acid supplements would also be required but are not quantified. Changes to GHG emissions would be small because of the small amounts that are used.
- For the production of 54,370t of rapeseed meal, 83,650t of rapeseed would be required.
- At an average yield of 2.7t/ha, this would require 30,980ha of additional arable land, compared to the 92,941ha currently used for arable crops in Wales.
- GHG emissions would be about 60,000t CO_2e once arable land is established, but the initial conversion from grassland to arable could lead to GHG emissions of 5-16tC/ha equivalent to 155,000-500,000tC for the 30,970ha. This would be regained partly if arable land is in rotation with grass leys.

5.5.2.4 Option 4. Reduction of SBM in dairy cows.

SBM use could be reduced or eliminated by the use of forage crops. The potential of an all-forage diet to support milk production from cows and heifers in the United Kingdom was reviewed by Wilkinson and Lee (2018). Rae et al. (1987) trialled the use of high-digestibility ryegrass silage to the cows from calving in late winter to the start of the grazing season. Thereafter, the animals received grazed pasture as the sole feed until the autumn when the cows were housed and given lower digestibility silage for the remainder of the lactation and during the dry period. Whole lactation milk yields were low and averaged 4680 kg for cows and 4006 kg for heifers at 3.94% fat and 3.14% protein. Animal health and fertility were satisfactory.

In a review by Fulkerson and Trevaskis (1997) they concluded that a milk yield of 20-25 litres per day from Friesian cows was achievable from pasture as a sole feed. This is a substantial reduction on the daily yield of up to 45 litres that is obtained from high yielding Holstein cows. The potential exists to increase milk production from pasture by improving the protein: carbohydrate ratio. One strategy commonly being used in high-grazing regions is to ensure a high level of non-structural carbohydrates in the pasture by adjusting time of grazing (Miller et al., 2001).

In the Welsh context the ability to use forage crops should be maximised, given the environmental and climate conditions which favour grass growing. But to maintain the overall level of milk production would require a possible doubling of the dairy herd with associated increases in GHG emissions. There would be a reduction in beef cow numbers, because of more cull dairy cows and more dairy bred calves for beef. One option would be to increase dual purpose breeds for dairy and beef production to maximise the use of forage crops. The GHG emissions from arable crops would also be reduced, but GHG emissions from cattle would increase. Economically such a system change would have major impacts on cattle farming in Wales.

5.5.2.5 Option 5. Substitution of SBM by Insect Protein in poultry feed.

There is commercial research looking at the use of insect meal in poultry diets, particularly fly larvae (PROteINSECT 2016). These are grown on organic matter, before the insects are harvested and ground into meal. Insect meal is high in good quality protein and is highly digestible but has not yet been approved for feeding to animals that enter the human food chain. The environmental benefit of this technology is that poultry manure and other food waste streams could be used as a feed source for the insects. (Gasco et al 2019).

Insects are generally rich in protein content (30–68% DM) with well-balanced amino acid profiles. Insect meal has a high (37-49%) protein value. The insect nutrient profile can be modulated by appropriate dietary strategies, according to specific animal dietary requirements. In addition, some deficiencies in essential amino acids or minerals can be easily compensated for by an appropriate diet supplementation with synthetic amino acids or mineral concentrates. Insect-derived product digestibility is influenced by the insect species, the inclusion levels and by the process (drying, defattening). High digestibility values have been recorded.

As for the other feed ingredients, well-defined protocols and controls of insect material must be implemented and regulated to protect animal and human safety. Complete substitution of the 75,100t of SBM used in the poultry sector would be a huge challenge.

5.5.2.6 In summary

Options 2 and 3 for replacing SBM with additional rapeseed and cereals would require a doubling of the current arable area in Wales, to replace SBM use for dairy cows and a 50% substitution of SBM for pigs and poultry. Given the low quantity of high quality land in Wales, this would have a huge impact on the resource remaining available for high quality grassland for livestock.

Options 2 and 3 would increase GHG emissions in Wales by about 165kt CO_2e compared with total GHG emissions of 5,600kt CO_2e – a 3% increase. There would also be a substantial initial surge in emissions as soil carbon is lost in the conversion from grassland to arable land, mediated in part if arable was in rotation with grass leys.

The more drastic option of relying on all-forage diets for dairy cattle would lead to reduction of milk yields by about 50% - requiring more cows for the maintaining the same overall milk production. This would have substantial economic impacts as well as increasing GHG emissions substantially. In practice the likelihood would be for a compromise - accepting partially reduced yields and possibly using dual purpose breeds which are capable of reasonable milk yields and suitability for beef production.

Insect proteins have a potential role for poultry and pig feeds provided that regulatory approval is given.

6 Integrated Assessment of Co-benefits and Trade-offs

Table 6.1 Integrated Assessment of co-benefits and trade-offs

Attribute	**Benefit**	**Disbenefit**
Global equity	Replacement of soya imports would reduce Wales' dependence on overseas land (about 59,700ha) particularly in South America, which contributes 77% of UK imports	
Economics	Reduces dependence on imported feedstuffs Diversification of crops helps resilience against crop failures (pests and weather)	Alternatives are currently more expensive than soya, threatening viability of Welsh livestock enterprises. Composition of feed concentrates is controlled by feed compounders, using feedstuffs with lowest cost
GHG emissions	Reduces emissions of soya production from overseas tropical areas and conversion of forest to cropland	Homegrown arable crops will increase Wales' emissions particularly in the first few years after conversion of grassland to arable.
Soil Carbon	Retention of soil carbon in tropical forests	Loss of soil carbon in Wales with conversion to arable
Soil structure	Cultivation can improve structure of panned soils, depending on type of equipment	Damage from heavy equipment particularly in wet soils
Water quality	None	Greater risk of soil erosion particularly in winter months, and when fields are tram-lined up slopes. Greater risk of run-off from pesticides and fertilisers
Air Quality	None	Possible ammonia emissions from more intensive application of manures and fertilisers
Biodiversity	Reduction of soya dependence on tropical areas with large biodiversity resources. Cover and forage crops in Wales can provide protection for birds and mammals and supplement feed sources. More diverse habitats are possible with arable crops.	Loss of grassland habitat
Flood control	Cultivation can improve structure and permeability of panned soils, depending on type of equipment.	Heavy equipment can make soils impermeable

7 Conclusions

The expansion of arable crops in Wales for cereals and high protein crops such as rapeseed faces the challenge of finding sufficient high-quality land when ALC Grades 1-3a are limited in area in Wales - amounting to 321,500ha. Much of the best quality land is already used for arable crops and improved grassland for intensive use. Yields of cereal crops in Wales are lower than in eastern England regions, penalizing Welsh farmers to some extent.

Climate change is likely to lead to the loss of the highest quality land, although Wales may secure advantages compared with eastern English regions where climate change is forecast to have greater adverse effects on yields because of lower rainfall, higher average temperatures and drought episodes.

Soil carbon losses from converting grassland to arable will add significantly to the GHG emissions of Wales, in the first few years after conversion.

Finding suitable alternatives for soya is difficult because the alternatives have lower protein levels coupled with anti-nutritional components which affect digestibility and appetite. Alternatives which can be grown successfully in Wales are wheat and other cereals, rapeseed, and grass and forage crops. Other crops such as sunflowers and lupins could become important – depending on future climate change.

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