The Carbon Footprint of an upland livestock farm in South West Scotland

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Abstract

Auchencheyne Farm is an upland livestock farm in South West Scotland. Its owner is very 'green minded' and has implemented a range of environmental friendly measures into his business model. All the electricity used on the farm is renewable and comes from two micro-hydropower systems installed on the land. Machinery used has chipped engines to reduce fuel consumption or is converted to LPG to reduce CO_2 emissions. Ongoing and future projects include the building of a carbon neutral house and the development of a wind farm on his land.

This project aimed to find out the carbon footprint of the Auchencheyne farm to see if the measures put in place had made the business carbon neutral or even negative. Two different free online carbon calculators were used so the results could be compared.

The results from the calculators differed greatly in some areas due to the detail of the data required by them and the assumptions made by their differing methods. The overall carbon budget result showed that Auchencheyne farm was not carbon neutral but had positive emissions.

A break down in the results highlighted that the draining of peat land and the large head of livestock at the farm contributed the most to the carbon footprint.

Recommendations put forward to reduce the carbon budget focused on these two areas and included the planting of trees, reduction in the amount of livestock and change in their farming system.

Introduction

Neil Gourley owns and manages Auchencheyne farm (AF) in South West Scotland. It is an upland commercial livestock farm covering 5000 acres of wetland, moorland, heather hills and improved pastures. He produces mule ewe lambs and fat lambs from 3200 blackface ewes and store and finished beef animals from 450 suckler cows.

Neil Gourley has a keen interest in the environment and won "Green Energy Farmer of the Year" in 2011. Making use of hill tributaries and lakes on his land Neil has installed two micro-hydropower systems that generate electricity for the farm and to export to the grid. Were possible thirsty oil burners have been converted to run on electricity, all the farms ATVs are electric or run on LPG and the tractors are all Valtra EcoPower machines that have chipped low revving engines that improve on fuel consumption.

Neil's ongoing plans include building a 'carbon negative' farmhouse and installing a 330kW wind turbine that would supply 90% of the local villages electricity needs. He has planning permission for the development of a 23 turbine wind farm in the future.

Neil is keen to find out the carbon footprint of his farming business and what other methods he could employ to reduce it and his impact on the environment.

A carbon footprint is a measure of the impact of human activities on the climate, expressed in terms of the total amount of greenhouse gases (GHG) produced. The carbon footprint of a product describes emissions from all stages of its life cycle, from manufacture and processing to packaging, transport, retailing, consumption and waste disposal. All direct, on-site emissions as well as indirect emissions incurred off-site should be included in the calculation of a carbon footprint.

In 2010 the agriculture sector was responsible for 8% of total UK Greenhouse gas emissions equating to 50.7 $MtCO_2$. Agricultural emissions are primarily made up of non-CO_2 GHG although it is responsible for around 4$MtCO_2$ emissions arising from the use of machinery and consumption of fuel in farm buildings *(Committee on Climate Change).*

The two main sources of GHG emissions resulting from agricultural practices are Nitrous oxide (N_2O) making 56% of total emissions and Methane (CH_4) that contributes 36% of total agricultural emissions. There is a lot of pressure on agriculture to reduce emissions of these gases because methane is about 20 times and nitrous oxide around 300 times a more powerful GHG than carbon dioxide *(Goulding 2011).*

The majority of N_2O emissions result from fertilisers applied to agricultural soils. The nitrogen in the fertiliser is needed to make crops grows and is crucial to ensure high yielding productivity. The most dominate source of fertiliser used is manmade fossil fuel – based fertiliser which is used to produce about half of the worlds food. Under certain conditions excess nitrogen remaining in the soil is converted into N_2O and released into the atmosphere as a harmful GHG that depletes ozone as well.

Methane emissions are released from livestock and manure. The breakdown of grass material by ruminates such as cattle and sheep during digestion in a process called enteric fermentation produces methane that is released mostly through burping as they re-chew the cud. Methane is also released as a bye product of anaerobic decomposition of manure. During storage, handling and application manure also emits N_2O through nitrification and denitrification.

Around 60% of the UK agricultural land is only suitable for growing grass as a crop. This land is used for beef and lamb production by grazing it with cattle and sheep or producing feed in the form of hay and silage. 1.1 million tonnes of red meat is supplied to the human food chain annually from the slaughter of around 2.9 million cattle and 16.7 million sheep.

English beef production is currently generating a GWP100 of around 13.9 kg of CO_2 equivalent and is consuming just over 31 MJ of primary energy per kilogram of meat produced. 30% of prime carcase beef is derived from upland and hill suckler herds such as the one found at AF the environmental impact of beef production from these systems generate a GWP of 16.98 kg CO_2e/kg and consume 33.38 MJ/kg of primary energy.

English sheep production is currently generating around 14.6 kg of CO_2 equivalent GHG emissions and consuming 22 MJ of energy per kilogram of meat produced. 69% of ewes in upland and hill flocks such as the ones found at AF contribute to prime carcase lamb production. The environmental impact of lamb produced in upland and hill systems generate a GWP of 32.26 kg CO_2e/kg and consume 38.84 MJ/kg of primary energy.

The higher levels of GHG emissions and lower levels of primary energy inputs overall in lamb production compared to beef production suggests a greater reliance on more extensive systems with less dependence on purchased feed and fertiliser in lamb production. The lower quality of nutrition in forage found in upland environments increases production times resulting in meat derived from hill farms to have a higher GHG emissions per kilogram than meat produced in lowland or more intensive systems. Global warming potential also increases in extensive upland farming systems because a higher head of livestock is required to produce each tonne of meat, and poor quality grass generates higher methane emissions.

Although extensive systems have greater environmental impacts, upland hill farms utilise difficult to exploit land resources with lower quality vegetation and forage producing valuable foodstuffs in the form of red meat from cattle and sheep. The grazing animals convert and concentrate nutrients not suitable for human needs into lamb and beef products that are a valuable source of energy, protein, vitamins and minerals in a balanced human diet *(Eblex. 2009).*

The correct balance of grazing on the uplands also benefits and maintains the character of the landscape and its biodiversity and increases the pastures potential as a carbon sink.

A study carried out by the SAC on a 457 hectare livestock farm in Scotland found that the farm was "in an approximate carbon balance*"(Topp et al. 2008).* The processes contributing to carbon release into the atmosphere were balanced by those that remove it. Plant growth was the main process credited with the removal of the carbon from the atmosphere and the farms large area of woodland was found to be significant in this carbon uptake.

Trees remove carbon from the atmosphere during the process of photosynthesis. A small amount of this carbon not used for growth or respiration is transferred to the soil were it builds up over a period of time. The forestry commission estimates that over a life cycle of a stand of trees between 100 – 200 tonnes of carbon per hectare is removed from the atmosphere.

Grasslands also capture and store a large amount of carbon in their soil and it is thought that they contribute more than 32% of the total carbon stored in British soils. The grassland trust estimates that the UK's grassland soils can hold up to 80 tonnes of stored carbon per hectare.

Peatland ecosystems which are most associated with the uplands represent the single largest carbon reserve in the UK holding over 300 million tonnes of stored carbon.

Although beef and lamb production on nutrient poor upland pastures creates emissions that contribute to global warming it is quite possible that the farm business that produce the meat may have a negative carbon footprint due to the vegetation and soil types found on the farm sequestrating and storing carbon.

This project aims to calculate AF carbon footprint and to find out if Neil's environmental approach through his various green schemes have created a farm business with a negative carbon footprint.

Methodology

The units used to express carbon footprints are CO_2 equivalents. The reason for this is that the impact each greenhouse gas has on the atmosphere over a 100 year time horizon is different. 1 kg of CH_4 has the equivalent impact of 23 kg of CO_2 and 1 kg of N_2O has the same effect of 296 kg of CO_2. The impact of the gases is known as the GWP and is a measure of how much heat a GHG can trap in the atmosphere relative to carbon dioxide.

The Intergovernmental Panel on Climate Change (IPCC) provide internationally agreed methodologies that can be used to calculate land-based businesses carbon emissions. These methodologies allow GHG emissions caused by farming processes to be determined using three tiers of complexity. Following the IPCC guidelines to calculate the carbon footprint of a farm is a complicated process as the methodology can be interpreted differently and the multifaceted equations can lead to significant levels of human error.

In order to overcome these hurdles there are several online carbon footprint calculators designed to be simple to use and specifically for land based business. Their methodologies used to calculate carbon emissions are based on the IPCC guidelines.

The Country, Land and Business Association developed the Carbon Accounting for Land Managers (CALM) calculator. If the relevant data is to hand it is straightforward to use, with sub-sections and a drop down menu format, data input and calculation takes less than an hour.

Its whole farm approach allows farmers to monitor and assess the carbon balance of their farm as the type and level of emissions attributed to different areas of the business are indicated. This means areas with particularly high GWP are identified and so they can become the focus for future improvements. As well as total annual emissions of CO_2 equivalents in tonnes the calculation results also give a breakdown of N_2O, CO_2 and CH_4 emissions which is useful.

The Cplan calculator was created by mixed hill farmers from central Scotland. With the relevant data to hand it take minutes to complete and get a calculation. The result table allocates emissions to each area of the farm. This calculator is very simplistic and does not break areas down so specific data cannot be included, meaning a larger number of assumptions are made by the tools calculations that can significantly affect the end results. The results provided by the calculator need to be multiplied by 3.67 in order to convert them to CO_2 equivalents.

Neither of these calculators includes Carbon sequestration by grassland of which there is 2023 hectares at AF. I feel it is important to include this in my overall findings so have decided to use an appropriate value from the literature and apply it.

'Grassland carbon sequestration on all farms. Permanent grassland sequesters carbon at a rate of 0.24tC/ha/year. This assumption was used in a recent beef carbon footprint study for the Countryside Council for Wales.' *(National Trust. 2012)*

Results

Table one shows that both the Cplan and CLAM calculators produced a positive carbon emission result for the farming business at AF. The Cplan total carbon emissions result is just over 3 times higher than the one produced by the CALM calculator. It is clear to see from Fig one and Fig two that there are some major differences between the figures calculated by the two different carbon tools for the CO_2 equivalent emissions for certain areas of the farm. The CALM calculator emissions result for fertilizer use is 726.6 tonnes larger than the result obtained by Cplan calculator. The Cplan calculator CO_2 equivalent emissions for the livestock at AF is 25463 tonnes greater than the result produced by the CALM calculator.

Both carbon calculators have produced a similar figure for CO_2e emissions arising from negative land change and apart from the Cplan livestock result they have the biggest impact on AF overall carbon budget.

As expected both the woodland and grassland on the farm have a net gain of carbon so have a negative emission result which goes in some way to reduce the carbon footprint of the activities at the farm.

The Cplan calculator results are not broken down into Methane and Nitrous oxide emissions so theses cannot be compare to those produced by the CALM calculator in tables two and three. Although they appear relatively small compared to the CO_2e results in Fig one and two we have to remember that CH_4 is a 23 times more powerful GHG gas compared to CO_2 and N_2O is 296 times more powerful so when converted to CO_2e the figures are high.

Table one – Total Carbon dioxide emissions arising from Auchencheyne farm using two different carbon calculators.

Carbon calculating tool	**CO_2 Equivalents (tonnes)**
Cplan	41098
CLAM	12713

Fig one – Comparison of low CO_2e emissions and sequestration at Auchencheyne farm using two different carbon calculators.

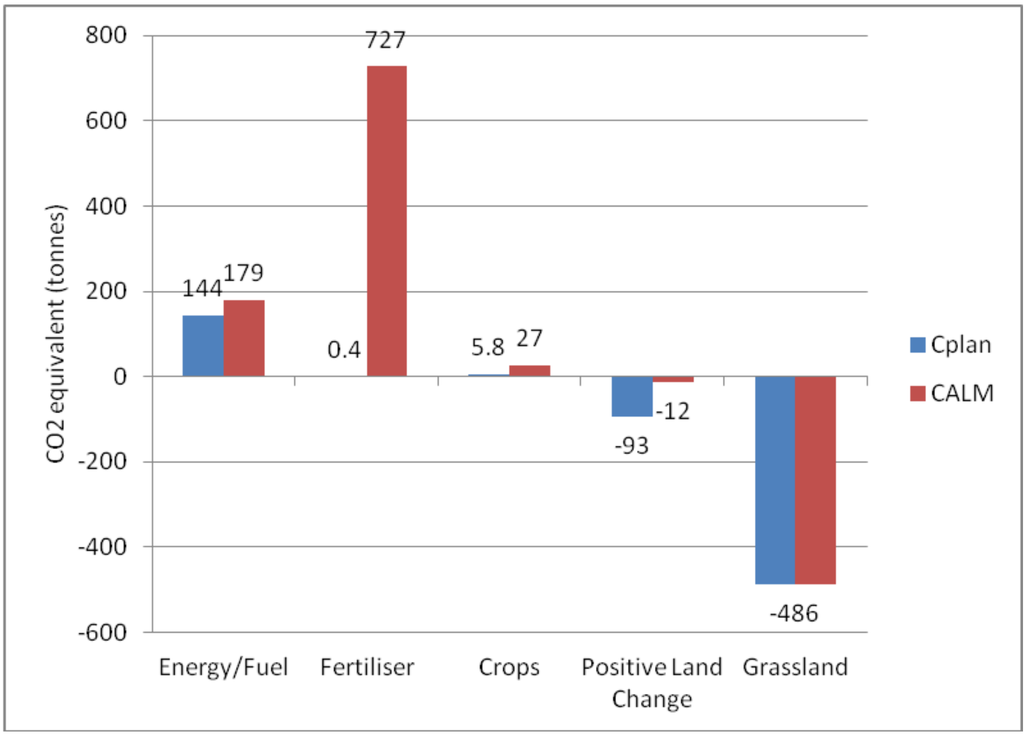

Fig two – Comparison of high CO_2e emissions and sequestration at Auchencheyne farm using two different carbon calculators.

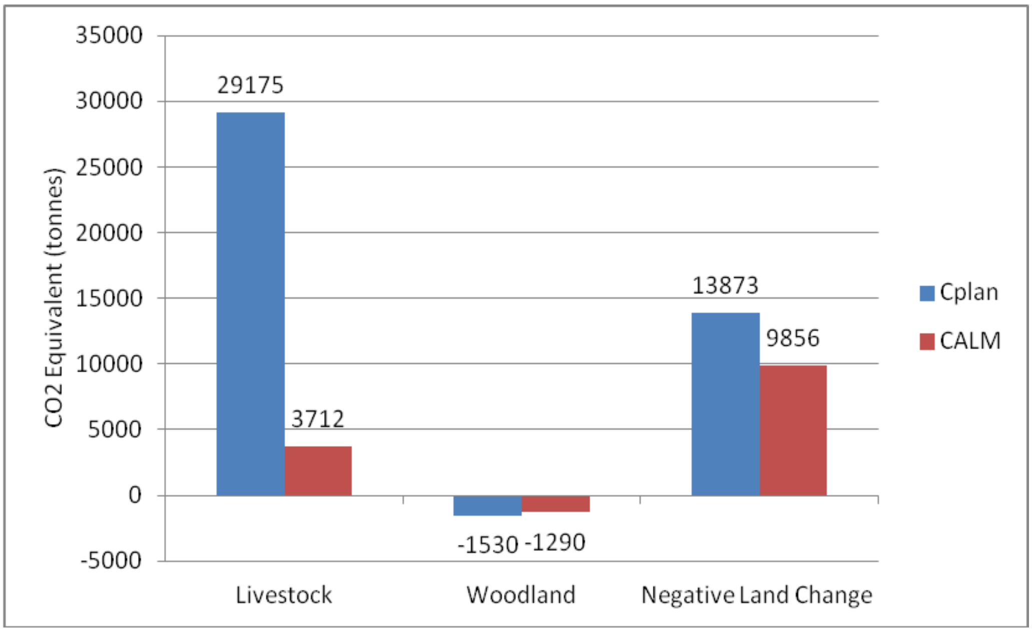

Table two – Methane emissions arising from the livestock at Auchencheyne farm using the CALM calculator.

Release mechanism	**Methane (tonnes)**
Enteric emission	87.536
Storage	3.842

Table three – Nitrous Oxide emissions arising from fertiliser use at Auchencheyne farm using the CALM calculator.

Release mechanism	**Nitrous Oxide (tonnes)**
Fertiliser use	1.885

Discussion

The results obtained from the two different calculators are quite surprising and not what I was predicting. The overall carbon footprint total for AF from both the calculators is a lot higher than I was expecting and there is a marked difference between the two different calculators' outcomes.

The major differences between the Cplan and CALM calculations are for the emissions from fertiliser use and livestock. This could be because the CALM calculator brakes down these sections into greater detail than the Cplan which therefore makes more assumptions in its calculations resulting in a less reliable output.

The CALM calculator requires details on various age groups of livestock, numbers of days housed and grazed and manure produce compared to the Cplan tool that only asks for numbers of livestock. Each tool makes its own assumptions when calculating the emission conversion factor to be used within the carbon calculation. Factors such as weight, gross energy consumption, energy used for maintenance, activity and lactation, daily weight gain and many more all directly or indirectly affect enteric fermentation and therefore the level of methane released by the livestock *(Soil Association).*

The CALM calculator also divides fertiliser use down in to different compounds and allows the percentage nitrogen in each product to be recorded and has a separate section for use of lime unlike the Cplan that only takes into account total usage.

Both calculators have their limitations, in order to provide a service that can assess farms carbon balances they have to find a balance between being user friendly whilst using complex calculations that require lots of detailed farm data. In order to achieve this they have to use standard emissions data and make assumptions throughout the calculation process.

This can explain the differences between the results produced by the two different calculators but does it also explain the higher than expected overall carbon footprint of AF.

A study carried out by Harper Adams University College evaluating the methodologies available for measuring and reducing carbon emissions found that 'Overall the carbon dioxide emissions calculated using the CALM calculator were 84% higher than when the carbon dioxide emissions were calculated by hand using the IPCC guidelines.' *(Harper Adams University. 2011).*

This would suggest that although very time consuming and open to human error calculating a farms business carbon footprint by hand using the IPCC guidelines would give you a more accurate and reliable result. The same study found that another carbon calculating tool The Cool Farm Tool provided very similar results to those obtain by hand using the IPCC guidelines. Using this tool is a good compromise as although more complex and time consuming than the Cplan and CALM calculators it provides a more realistic result but cuts out a lot of the human error and the time associated with doing the calculations yourself by hand.

The Cool Farm Tool requires much more detailed data including information on climatic and weather conditions and soil types as these can affect emissions. When soils become wet and water logged oxygen is in short supply and nitrogen form fertiliser is converted into N_2O through denitrification which can produce large although sort lived peaks of the harmful GHG. Emissions of nitrous oxide are therefore highly variable depending upon weather conditions at the time of fertiliser use and without this data other calculators are relying on more assumptions.

Although the Harper Adams study found the results differed for the various different carbon calculator tools suggesting some are more accurate and reliable than others it did find that 'for the different types of emissions occurring on the farm, the pattern of the main emissions was similar across all the calculators' *(Harper Adams University. 2011)*. So even if the data from AF had been inputted into The Cool Farm Tool or used by hand following the IPCC guidelines to get an overall different result the main sources of GHG emissions would still have been shown to originate from enteric methane emissions from livestock and through negative land change.

Neil Gourley has a very green approach to his farming business. All the electricity used is in the form of renewable energy generated by the two hydro schemes he has implemented on his land making use of the natural resources available to him. He uses low revving eco friendly tractors that have better fuel economy than conventional machinery. He has converted his all terrain vehicles to run on LPG that has a lower carbon content compared with petrol and diesel so helps reduce the amount of carbon dioxide being emitted into the atmosphere.

All this coupled with the 2023 hectares of permanent grassland and 111.5 hectares of woodland that act as carbon sequesters and stores I was expecting the carbon footprint of AF to be negative or at least balanced. This would have been in line with the findings carried out by SAC in a study on a mixed farm in North East Scotland. They found 'that the farm is in an approximate carbon balance, with the processes releasing carbon into the atmosphere roughly balanced by processes that remove carbon and store it in the soil and vegetation' *(Topp et al. 2008)*.The actual results obtained showed the farm to have a small net up take of carbon of 5 tonnes per year.

The main reason this 457 hectare farm achieved a carbon balance is because around a 1/3 (142 ha) of the land is covered in woodland. This was seen to be an important factor contributing in carbon up take and having a significant effect on the overall result for the farm. Trees have a large biomass per unit area of land and because of this they play a vital role in the carbon cycle on a global scale. Through the process of photosynthesis tress assimilate CO_2 from the atmosphere and although some is released through respiration the rest is stored in the plants material or transferred to the soil. 'The maximum rate of carbon accumulation during the full-vigour phase of fast growing stands in the UK is about 10 tC ha-1 yr-1.' *(Broadmeadow et al. 2003)* A stand of trees in the UK has the maximum potential to remove 200 tonnes of carbon per hectare from the atmosphere over its life cycle.

Only around 5.5% of AF is woodland and this only produces a net CO_2e emissions uptake of around 10% of the farm business carbon budget. In order to reduce the carbon footprint of AF carbon uptake needs to be maximised. The best way to do this to obtain large reductions would be to plant more trees. This process has been happening on the farm over the last 20 years on a small scale with 14 hectares of grassland being converted to woodland. This land use change has a positive effect on the overall carbon footprint with an up take of 93 (Cplan) or 12 (CALM) tonnes of CO_2e a year.

There has been other land use change occurring at AF with 210 hectares of thick peat over one meter deep being drained. This has had a very significant impact on the carbon footprint of the business. The results obtain by the CALM calculator show it to be the biggest source of CO_2e emissions for the farm at 9856 tonnes a year and the Cplan results have it as the second biggest contributor to emissions after livestock at 13873 CO_2e tonnes annually.

Peatland ecosystems are the single largest carbon reserve in the UK holding over 300 million tonnes of stored carbon. It has been estimated that Scottish peatland contain 75% of the soil carbon in Great Britain *(Milne et al. 1995)*. Draining peat by lowering the water table exposes the organic carbon that has built up over thousands of years to the air. This causes decomposition and increased oxidation of the peat resulting in considerable quantities of carbon and nitrogen being lost to the atmosphere as CO_2 and N_2O. It is estimated that peatland being managed as improved grassed land can emit between 8.68 to 20.58 tonnes of CO_2e per hectare per year *(Natural England. 2011)*.

One way to reverse this situation and reduce the impact of this land change has on AF carbon footprint would be to re-wet part or all of the drained area. When a drained peatland is re-wetted CO_2 emissions from decomposition of the peat are usually significantly reduced due to the return to anaerobic conditions. Restoration should also eventually result in a return to active peat formation, and ongoing sequestration of atmospheric carbon. This process is extremely slow with re-growth rates recorded at 1mm per year and that this only occurs at around 30-40% of re-wetted peatland sites. Restoration of peatland can also increase methane emissions resulting in an overall increase of GHG if vegetation type is not controlled so this may not be the solution. Some studies have found that tree planting could be beneficial in terms of GHG balance of peat so this could be an alternative option to reduce the CO_2e emissions and increase uptake.

The next biggest impact on AF carbon footprint is caused by the livestock. Around 88 tonnes of methane is emitted from the animals directly a year through enteric fermentation and about 4 tonnes of methane is released from the storage of their waste in the form of manure.

The way manure is managed and stored could reduce the amount of GHG are emitted from it. Methane is emitted from manure during anaerobic decomposition. Liquid storage such as slurry pits create these anaerobic conditions that emit up to 80 percent of manure based methane emissions. *(Alberta Agriculture and Rural Development. 2005)* Changing to a solid storage system would dramatically reduce this as solid manure emits little methane. Were possible straw should be prevented in getting into the slurry pits as it acts as a food source for the anaerobic bacteria causing an increase in emissions. The manure should be applied to the soil as soon as possible (unless the soil is extremely wet) to reduce storage time and discourage anaerobic conditions. Slurry pits could be covered to trap methane that is then treated or used to produce heat or electricity. The cover also reduces water content and controls odours. The slurry pits could be aerated increasing aerobic decomposition of manure that lowers the methane emissions but can increase nitrous oxide emissions. Anaerobic digesters could be used to produce methane that then could be used as a biogas to generate heat or electricity.

The easiest way to reduce the amount of methane emitted from the livestock at AF would be to reduce the numbers. Apart from the direct affect of immediately lowering the carbon footprint it would also have a positive knock on impact as low productivity pasture with moderate grassing stores 53.3 tonnes of carbon per hectare opposed to over grazed pasture which only stores 37.4 tonnes *(National Trust. 2012)*.

The way cattle are feed when housed could be used to reduce the amount of methane they emit. Feed digestibility is already maximised at AF by using mixed wagons to chop silage and straw but ionophores additives or coconut oil could be added to reduce methane emissions by rumen bacteria. A higher amount of concentrates could be fed to the finishing cattle which would improve their performance growing faster and taking less time to reach the desired slaughter weights. Replacing roughage with concentrate feeds also reduces the amount of dietary energy converted in to methane by reducing the pH in the rumen. Feeding greater amounts of concentrates can have the knock on effect of permanent pasture or woodland being converted to grow cereal crops reducing the area of lands ability to sequester and store carbon from the atmosphere.

An alternative method would be to move away from a more intensive cattle production system to a less intensive. Although the modern breeds such as the Charolasis crosses at AF when feed a low fibre high cereal diet have good growth weights and emit lower GHG emissions per kg of meat produced they do have negative impacts on the carbon footprint. Manure stored as slurry gives of methane, cereal production results in soil carbon loss through cultivation and crops sequester low amounts of carbon than grassland. The cattle are poor converters of low quality forage so large amounts of fertilizers are required to improve pasture that results in more N_2O being released into the atmosphere.

In a less intensive system using native breeds the pasture would not need improvement using fertiliser as they are efficient converters of poor forage. The use of fertiliser on AF amounts to 1.9 tonnes of N_2O emissions a year. They would not need to be housed so their manure would break down aerobically as cow pats so not emitting methane. The more species rich grassland they create would sequester more carbon. Although you would have to keep fewer animals and they would grow slower they would cost less to keep and if sold through a native breed meat scheme could bring the same level of profits.

Whichever system of livestock production is used breeding for good genetics would help to reduce the GWP of livestock. Breeding fertile animals would prevent unproductive baron animals releasing methane. Breeding for efficient forage conversion and fast growth rates would reduce the GHG emissions per kg of meat produced.

Recommendations

In order to get AF carbon footprint to be zero I would first put the farms data into the Cool Farm Tool to get a more accurate set of results closer to ones that would be obtained using the IPCC guidelines.

I would then look at the land use changes that have occurred at the farm and look to plant more trees and possibly return areas of land back to peatland. I would review the livestock systems and look into the possibility of using a less intensive system that would reduce fertiliser use and improve on manure storage systems.

These improvements coupled with Neil's on going green energy revolution at the AF should mean his business will become carbon neutral or even negative.

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