A Nuffield Farming Scholarships Trust Report

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Soil health and fertility in grasslands: an essential component in improving upland beef and sheep productivity and sustainability

Richard Tudor

July 2018

NUFFIELD UK

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Date of report: July 2018

"Leading positive change in agriculture.
Inspiring passion and potential in people."

Title	Soil health and fertility in grasslands: an essential component in improving upland beef and sheep productivity and sustainability
Scholar	Richard Tudor
Sponsor	McDonald's Restaurants
Objectives of Study Tour	To gain a better understanding of soil in relation to upland farming systems To better develop healthy fertile soils capable of producing healthy forage and healthy animals whilst reducing our reliance on chemical fertilisers.
Countries Visited	Ireland, USA, Canada, UK, Sweden, Finland, Netherlands, Spain
Messages	• Soil, the greatest asset on our upland grassland farms, deserves greater attention • A chemical soil analysis needs to consider more than N, P and K • A soil assessment that considers all key indicators of a healthy soil needs to be promoted • Compaction needs to be taken seriously. • Rest periods are key to grassland productivity • Species diversity needs to be encouraged in grass leys

EXECUTIVE SUMMARY

2015 was declared the International Year of the Soils and December 5th has become our annual World Soils Day to raise awareness amongst us all of the importance of soils in our daily lives: from agriculture to food to mitigating climate change. ‘Soil’ has become a very fashionable topic but, as grassland farmers who are responsible for 70% of the UK agricultural land, do we really understand its role and how it functions?

In general, arable farmers have better recognition of their soils than livestock farmers: quite simply for the reason that they literally *see* it. Upland and hill farmers rarely actually *see* their soils, which leads to a lack of understanding of its vital role and importance in grass and forage production. As with arable yields, grass yields have also plateaued. From presenting at a recent roadshow I estimate that only an approximate one third of Welsh livestock farmers currently soil test (despite 80-100% financial assistance from the Welsh Assembly Governments Farming Connect programme to do so). Dr Sinclair Mayne, CEO of AFBI, Northern Ireland’s Agri-food and Bioscience Institute, delivered a message to Westminster in June calling for a renewed focus on grassland management, and reported that many of the constraints on grassland production were due in large part to under-investment in soil analysis with only 5% of UK grasslands analysed every year. There is an urgent need for our farmers to better appreciate the value of their soils.

Soil is every farm’s greatest asset, and most farmers believe that they are passing their land on to the next generation in a better state than they received it. Defining ‘better state’ is not easy, but we can only judge this belief if we understand the fundamentals of what constitutes a healthy soil.

The aim of my study was to gain a better understanding of soil in relation to upland farming systems in order to develop healthy fertile soils capable of producing healthy forage and healthy animals, whilst reducing our reliance on chemical fertilisers. I have learnt the value of grazing livestock to the ecosystem and their role in sustaining the biodiversity of flora and fauna and their positive effect on carbon sequestration but my study has focused on understanding the basics of a productive working soil. This is the base for everything that we do especially when attempting to defend agriculture’s contribution to climate change. Efficient, healthy livestock are key to reducing emissions and our footprint. The Carbon Navigator management template produced by Teagasc and Bord Bia measures the environmental benefits that can be provided by increasing efficiencies.

The barriers to implementation amongst farmers are always difficult to understand but effective communication and engagement has to be the starting point. Legislation has a role to play in setting the wheels in motion, and I welcome recent change in requirements in England to test soils every five years.

Key to farming sustainably in the uplands is an understanding of what constitutes a healthy fertile soil, and the management practices that are best suited to provide it.

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DISCLAIMER

The opinions expressed in this report are my own and not necessarily those of the Nuffield Farming Scholarships Trust, or of my sponsor, or of any other sponsoring body.

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1. Personal Introduction

I am a grass farmer from the uplands of mid Wales, producing lambs for Waitrose and ten-month-old store cattle from our suckler cows. The farm has evolved since I returned home to farm in 1998 with timely opportunities arising to expand the farm through the purchase of low value unimproved hill land, followed by an intensive period of reseeding and land improvement to raise the stock-carrying capacity of the land.

Figure 1: Richard Tudor, the author, on his farm

During my gap year from Aberystwyth University I lived in Oregon and worked on a sheep 'ranch' alongside a shepherd from New Zealand and a 'free-reins' type of owner. Upon reflection the lessons learnt and knowledge gained have been invaluable to my character and personal development. On completing my degree I was determined to experience life as a shepherd at Mount Linton Station, New Zealand, with its 58,000 ewes. The appreciation of scale and the logistics of the operation with its forage-focused approach was extremely motivating and inspiring to a young 21-year-old Welsh farmer and helped shape my ambitions.

Recognising the value of travelling to other countries to learn about their farming systems I have actively pursued opportunities to travel and study with various scholarships providing me with this platform. I travelled to South America to learn more about beef production through a Hybu Cig Cymru scholarship, to North America to look at ways of improving the efficiency of the suckler cow courtesy of ASDA and ABP, and also looked into foetal programming and epigenetics in the USA through a Moredun Research Institute bursary.

On the farm my focus has always been to improve the efficiency of my production systems through the use of selected genetics, better management techniques and better grass utilisation. I have been fortunate to farm alongside my father for 20 years and, with a shared vision, it has been extremely rewarding to develop the farm together.

I chair the local school governors' board and am currently vice chair of the NFU Cymru Livestock board.

2. Background to my study

Having studied agriculture at the University of Aberystwyth, and in particular at the 'Stapledon Building', my own agriculture system has been heavily influenced by **Sir George Stapledon**, the pioneer of the uplands grassland improvement revolution. He often quoted Jonathan Swift:

> *'whoever could get two ears of corn, or two blades of grass, to grow upon a spot of ground where only one grew before would deserve better of mankind, and do more essential service to his country, than the whole race of politicians put together'*

In line with these wise words is my own farming mantra of '*you have to become a grass farmer before you become a sheep farmer*', which was valuable advice given to me by an elderly New Zealand farmer 20 years ago.

When you combine these influences with results from the Farm Business Survey unit at Aberystwyth University that benchmarks the financial and physical performance of Welsh farms, it is no surprise that the common denominator for all the top one-third of farms, across all systems and farm types, is a stocking rate that's 10% above the average.

With the current uncertainty facing farming in the hills and uplands, the vital role of livestock production and the grazing of land only suitable for growing grass must be highlighted and valued. As Sir George Stapledon recognised over a hundred years ago, to sustain rural communities and the rural environment we must prevent the depopulation from the hill and upland farms, through securing prosperity by producing food and protecting our natural resources.

However, grass is not 'just grass' but, **as I learnt in Finland**, 'grass is king', and therefore learning the fundamentals of growing grass became the basis of my study; to focus on soil health and fertility in upland grasslands.

the common denominator for all the top one-third of farms, across all systems and farm types, is a stocking rate that's 10% above the average.

My study focused on two main areas:

- firstly understanding what constitutes a healthy fertile soil and the key indicators involved
- and secondly the management practices best suited to achieving healthier soils.

In farming it is important to determine your objectives, mine being to produce food (or nutrients) using all the resources available to me whilst recognising the need to balance immediate economic returns with longer term environmental returns. These questions must be considered in relation to the future prosperity of the whole ecosystem, and my own desire to reduce my usage of, and dependency on, chemical fertilisers.

> *"generally the type of soil management that gives the greatest immediate return leads to a deterioration of soil productivity, whereas the type that provides the highest income over the period of a generation leads to the maintenance or improvement of productivity".* Charles Kellogg, 1936

3. Countries visited

July 2017	**Spain – Basque region** With a surprisingly similar climate to the UK, in the mountainous regions of northern Spain livestock grazing and production is very important to the rural communities and I was interested in learning and seeing the results from their LifeRegen Farming project.
Sept/Oct 2017	**Canada – Manitoba and Saskatchewan** Improving soils through mob-grazing is popular in this region of Canada and, with a short growing season, the utilisation and conservation of grass was of interest. **USA – North and South Dakota, Iowa, Wisconsin, Michigan, NY State, Pennsylvania** Zero tillage and biological farming focuses on the health of the soil and, with increasing interest in the movement, key management practices have been identified.
November 2017	**Ireland** With a similar climate and an excellent farm knowledge exchange hub in Teagasc, communicating new research to farmers is key to moving the industry forward. Devenish Nutrition's 3-step Soil Improvement Plan was a big attraction.
February 2018	**UK – Wales, Devon and Cornwall** Visiting farmers practising soil improvement techniques and management and the latest research at Aberystwyth and Bangor University and North Wyke.
May 2018	**Finland** With a short growing season, cold winters and exceptional mid-summer grass growth, learning about the challenges and how they have adapted intrigued me.
June 2018	**Sweden** Sweden is focused on sustainable production, and how we define sustainability in the context of producing food was of interest.

4. Healthy soil and limiting factors

For healthy yields you need healthy plants which, on a large scale which exempts hydroponics, can only be achieved by healthy soils that allow roots to develop and function in synergy with the soil biology. A healthy yield should not only be measured by weight but also by its yield and supply of nutrients which will produce healthy livestock.

Photosynthesis is a topic that I have always been particularly intrigued with but little had I realised how everything that I produce on farm relies on this vital process.

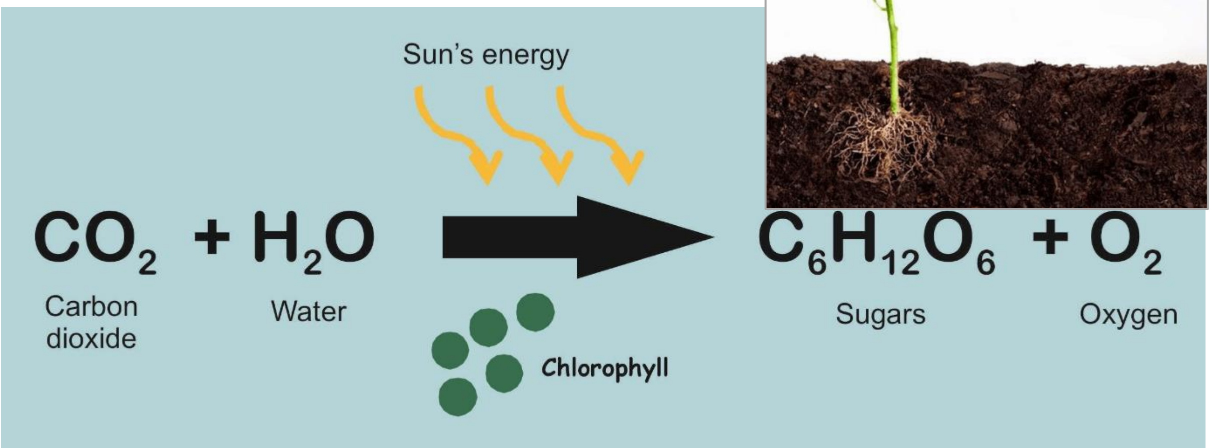

Figure 2: The above 2 slides were taken from a presentation by Mark Tripney, UK NSch

The sugar produced is the plant's energy store which is used by the plant for its own growth or gets exuded from the roots to feed the soil life in an incredible symbiotic relationship, that sees the soil microorganisms supply nutrients to the plant in exchange for food in the form of carbohydrates.

When considering how to influence the process of photosynthesis there are two things to consider:

1. Photosynthetic capacity, and
2. Photosynthetic rate

and as farmers we need to determine the limiting factors within our systems. Although environmental factors such as sunlight hours, rainfall and temperature, are beyond our direct control we have the ability to influence their effect; such as ensuring a greater leaf area for sunlight absorption and ensuring good water holding capacity within the soil.

The limiting factors below ground can be broken down into the following categories:

1. Soil chemistry
2. Soil physics
3. Soil biology
4. Grazing management

All of which directly influence root development and structure and I discuss them in the next 4 chapters in the light of knowledge gained on my Nuffield Farming study tour.

5. Soil chemistry

The chemistry of the soil is extremely complex and involves an extensive cocktail of chemical elements, some essential and beneficial, and others detrimental to soil and plant life. Plants require approximately twenty elements (or nutrients) with some required in large quantities and others in trace amounts. Therefore, thinking of applying only the primary essential nutrients of Nitrogen, Phosphorus and Potassium (NPK) to correct imbalance can prove costly. The secondary essential nutrients of Calcium, Magnesium and Sulphur must also be considered to achieve a balanced soil and healthy plants.

The soil is like a bank – outgoings must be matched by ingoings to avoid deficit.

Justus Von Liebig's law of the minimum states that growth is not dictated by the total resources available but by the scarcest resources (the limiting factor), a concept that found that adding more of an already plentiful nutrient did not increase plant growth.

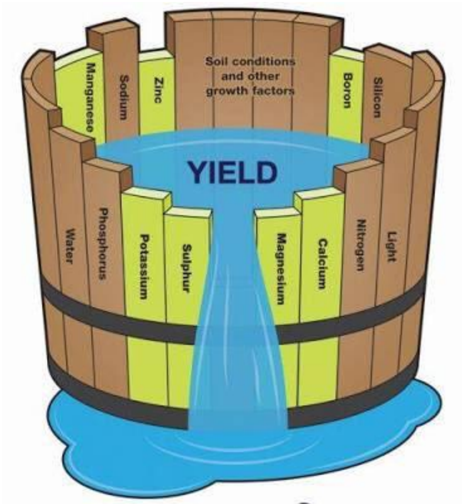

Figure 3: Liebig's barrel illustrating how crop growth is inhibited if one nutrient is in short supply. Source: *http://www.pda.org.uk/news/nf81-liebigs-barrel.htm*

The sufficiency-level approach to soil nutrients works on a similar basis to the law of diminishing returns where yields plateau despite higher fertilisation. It demonstrates that optimum is far more efficient than maximum amounts. However, the majority of UK farmers work to the "build-up and maintenance approach" with basic soil tests indicating the level of current fertility (P and K mostly); how much needs to be applied to reach the ideal level; and how much additional fertiliser is required to replace crop off-take. The soil is like a bank – outgoings must be matched by ingoings to avoid deficit.

During my study I have frequently questioned whether our current RB209[1] basic soil test is fit for purpose with its focus on Phosphorus(P), Potassium(K) and Magnesium(Mg) levels. When discussing this chemical soil test I was frequently answered with "*you need to know more than that*", and that **an approach based on balancing all the nutrient needs of the soil is far more beneficial than attempting to feed the plant's requirements for yield using only three chemical elements.**

However, I accept anything is better than nothing and that, if focusing only on quantitative yield, sufficient trials have demonstrated that this approach (RB209 basic soil test) works and is simple and easy to understand. Indices should always be considered alongside the actual concentrations of P, K, and Mg as the range within each index is significant. Following the trends within the concentrations allows a more dynamic response to these nutrients. High index 1 and Low index 2 are very close.

This law of minimum approach should also consider the law of maximum or the effect of excesses; and hence a more detailed analysis of soil nutrients allows a greater understanding of the interaction between the elements, and how the soil's properties affect their availability.

During my Nuffield Farming study tour it became obvious that the Cation Exchange Capacity and the base levels of the major cations in the soil are frequently discussed and acknowledged as being an important part of any soil chemical analysis.

5.1. Cation Exchange Capacity (CEC) and the Base Cation Saturation level (BCS)

The CEC is a good indicator of soil type and soil fertility and refers to the ability of a soil to hold onto cation nutrients (in particular Calcium, Potassium, and Magnesium) and is scored on a scale of 0 to 50. **In Finland** they explained the CEC of a soil as "the size of the fridge", and that basically the bigger the fridge the more nutrients the fridge could hold. Sandy soils, due to their free draining nature have a low CEC (0-8) whilst clay soils have a high CEC (30+).

The BCS refers to the balance of Calcium, Magnesium and Potassium at the cation exchange sites in the soil and many believe that a particular ratio is required for optimum yield. It is referred to as the **Albrecht method named after William Albrecht**, a Professor of Soils at the University of Missouri in the 1950s and 60s who discovered a link between the quality of the soil and ill-health in livestock. He developed base level guidelines for certain nutrients and acknowledged the interaction between them.

Depending upon the CEC of a soil it is recommended that Calcium should occupy 60-80% of the Cation Exchange sites, Magnesium 10-20% and Potassium 2-5%. Many farmers religiously follow the ideal ratios but scientists and researchers have since dismissed this idea of ideal ratios, due to very little experimental evidence to support the concept of improved yields. In deference to William Albrecht much of his work focused on correcting ill-health of plants and livestock by addressing soil imbalance and not necessarily on producing higher yields.

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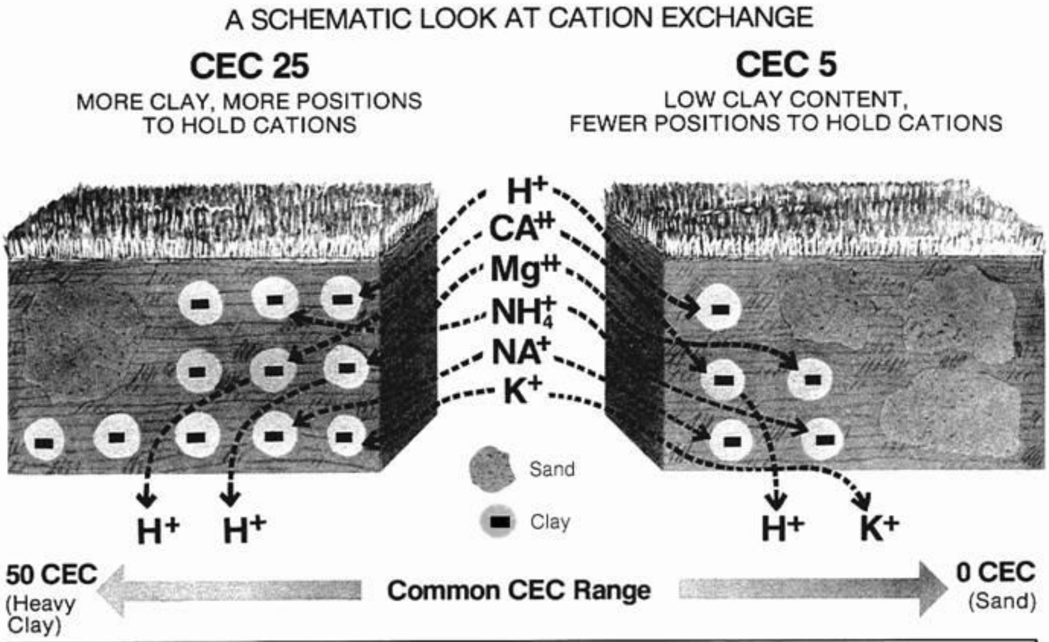
[1] RB209 was first published in 1973 and was the first comprehensive set of fertiliser recommendations from the Ministry of Agriculture, Fisheries and Food (MAFF). RB209 stands for Reference Book 209. It has been updated by AHDB many times since.



SOME PRACTICAL APPLICATIONS	
Soils with CEC 11-50 Range	Soils with CEC 1-10 Range
• High clay content • More lime required to correct a given pH • Greater capacity to hold nutrients in a given soil depth • Physical ramifications of a soil with a high clay content • High water-holding capacity	• High sand content • Nitrogen and potassium leaching more likely • Less lime required to correct a given pH • Physical ramifications of a soil with a high sand content • Low water-holding capacity

Figure 4: Illustration of CEC provided from a Cornell University soil guide handbook

(See next page for a table showing all the necessary metrics that I believe are required from a chemical soil test, with easy-to understand-recommendations)

pH				
For lime recommendations edit the crop and soil type from the drop down box		→	Consult your SSM advisor for lime guidence	
Active ph	6.10	0.0		
The following recommendatons are based on	Rec's for a soil depth of approx	General plough depth	with	an Ideal soil structure

Major Cations		Desired kg/ha	Found kg/ha	(+or-) kg/ha	SSM Target %	Calculated BCS%	Clay % / Sand %	soil particles not analysed
(Estimated CEC) 6.61								
Calculations for the Basic UK extraction methods.	Calcium (Ca)	1688	1452	-236	65.50	56.35	apply Soil Calcium in appropriate form	
	Magnesium (MgO)	370	516	146	14.50	19.88	Reduce Soil magnesium levels	
	Potassium (K2O)	351	217	-134	5.82	3.60	Question crop peak demands for K2O	
	Sodium (Na)	35	57	21	0.89	1.47		
	Hydrogen % (Calc)				5.29	15		
	Other Cations (Calc)				8	3.70		
Target Ca:Mg Ratio 4.52	result	2.84	Ca:Mg BS% 80%		80	76.23	Acceptable Ca:Mg saturation	

OM			
Organic Matter (LOI) min	>3%	8.01	Maintain Organic good matter levels
Active Carbon		0.00	0
Min required OM for structural integrity	3		CROSS 0.46 <0.5

Anions		Index	Found kg/ha	Target kg/ha	(+or-)	Treatment
Olsen P	Phosphate (P2O5)	2	71	112	-40.2	Apply available phosphate to the soil
		0		0	0.00	apply phosphate solubilising bacteria
	Sulphate (So3) below detectable levels		60.3	78	-17.7	Apply Sulphur

Trace Elements PPM	Availabile trace elements to roots		Guide range				Soil Treatments	Foliar treatment
Hot water	Boron (B)	mg/l	1.2	to	2.4	0.9	Apply Granular Boron	High Boron demanding crops only
M3	Iron (Fe)	mg/l	19	to	189	230	Apply products that create new roots	0
M3	Manganese (Mn)	mg/l	18	to	70	111		
M3	Copper (Cu)	mg/l	2.5	to	7	2.9	Consider maintenance levels of copper.	
M3	Zinc (Zn)	mg/l	4	to	10	3.1	apply granulated zinc	YES
	Chloride (Cl)	mg/l	20	to	50	0.9		0
Hot water	Iodine (I)	mg/l	1	to	1	0		0
M3	Molybdenum (M	mg/l	0.5	to	0.5	N/A	N/A	
M3	Cobalt (Co)	mg/l	0.5	to	2	0.64		0

RB209 mg/l		UK Index		RB209 av: yield crop recommendations		Advisor Comments
16	Phosphate	2	kg/ha	20	16.8	
					off take	
92.65	Potash	1	kg/ha	30	57.6	
0.6	K:Mg Ratio OK					
160.25	Magnesium	3	kg/ha	0		
						Ok k:mg ratio.

Figure 5: The table above is of a recent soil sample taken from my own farm that includes all the necessary metrics that I believe are required from a chemical soil test, with easy-to-understand recommendations

5.2. Soil pH

Correcting soil acidity is an essential first step in addressing soil fertility issues as it results in greater nutrient availability, better nutrient cycling, and increased microbial activity within the soil. The ideal or optimum PH of 6.3 or above for grasslands is rarely achieved with a target of PH 6.5 being beneficial to aim for. In 2016 **Farming Connect** sampled 4848 soils across Wales and showed the average pH to be 5.8, with 70% of soils below pH 6.0 and hence a severe limiting factor for quality grass production.

William Albrecht advised:

> *"Don't lime to fight acidity, use lime to feed the plant"*

Realising that lime is being continually removed from the soil is vitally important as high rainfall, drainage, crops, livestock and especially fertilisers are all guilty of removing lime and creating acid conditions. The acidifying effect of certain fertilisers can be extremely detrimental with Urea, for example, requiring 2kg of lime for each 1kg of Nitrogen applied to neutralise its acidifying effect. **Teasgasc** (Ireland) suggest that 250-625kg/ha of lime is lost each year in drainage water; and that 1 beef animal removes 25kg of lime, 1000 litres of milk removes 3kg of lime, in addition to offtake from silage.

The application of chemical fertilisers is a large contributor to Green House Gas (GHG) emissions, and a significant contributor to agriculture's overall footprint. According to recent figures from the **Welsh**

Assembly Government, agriculture in Wales accounted for 12% of total Welsh emissions in 2016, with fertiliser comprising 21% of agriculture's emissions and a 2.5% contribution to the national total.

Research at **Teagasc Johnstown Castle** on the fate of various nitrogen fertiliser sources demonstrated the benefits of applying protected Urea compared to Calcium Ammonium Nitrate (CAN), with fewer emissions and nitrate losses. **A key conclusion was that the weather, soil conditions and timing of applications had as much of an effect on wastage (nitrate leaching and nitrous oxide and ammonia emissions) as did the fertiliser type.**

The effect of soil acidity upon fertiliser and nutrient use efficiency, due to its effect on availability, is significant.

Soil acidity	Nitrogen	PHospHate	Potash	Fertiliser wasted
Extremely acid – pH4.5	30%	23%	33%	71.34%
Very strong acid – pH5.0	53%	34%	52%	53.67%
Strongly acidic – pH5.5	77%	48%	77%	32.69%
Medium acid – pH6.0	89%	52%	100%	19.67%
Neutral – pH7.0	100%	100%	100%	0%

Figure 6: Table to show relative efficiency of fertilizer at various pH levels.
Source: Dr C Snyder, Soil pH management

PH as a measure of soil acidity is based on a factored scale, which means that a soil with a pH of 5 is actually 100 times more acidic than a soil with a pH of 7.

Many have attempted to quantify the return on investment of applying lime to correct soil acidity. Figures range from 4 : 1 up to 7 t: 1, which then prompts the question:

> **Why is the optimum pH of 6.3 rarely achieved, let alone maintained, but fertiliser continues to be applied regardless of its poor utilisation?**

"*It's expensive to apply lime*", and "*it's close enough*" are answers I often received, which are both viewpoints that need to be addressed, and educated.

The ability of the plant to better uptake beneficial nutrients due to their higher availability at a pH of 6.3 also results in higher concentrations and availability of those minerals to livestock from grazing the plant. Likewise, the higher concentrations of undesirable elements can have a negative effect on the health of the plant and animals. For example, aluminium toxicity occurring at low pH levels is detrimental to animal health and also leads to a significant decrease in root growth and development.

See Nutrient availability chart on next page

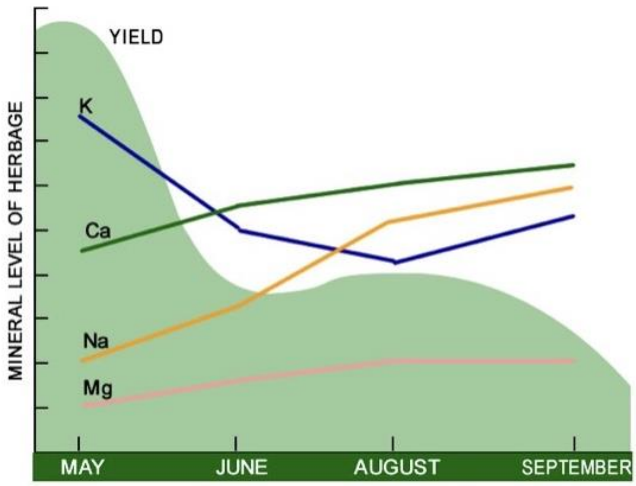
Nutrient availability chart

Nutrients	Soil pH 4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0
Nitrogen	NA	SA	MA	MA	HA	HA	HA	HA	MA	MA	SA
Phosphorus	NA	NA	SA	MA	HA	HA	HA	MA	MA	SA	MA
Potassium	NA	SA	MA	MA	HA	HA	HA	HA	MA	MA	MA
Sulphur	NA	SA	MA	MA	HA	HA	HA	HA	MA	MA	MA
Calcium	NA	NA	SA	MA	MA	MA	HA	HA	HA	HA	MA
Magnesium	NA	SA	SA	HA	HA	HA	HA	HA	MA	MA	MA
Iron	HA	HA	HA	HA	HA	MA	MA	SA	SA	SA	SA
Manganese	HA	HA	HA	HA	HA	MA	MA	SA	SA	SA	SA
Boron	MA	MA	HA	HA	HA	HA	HA	MA	SA	SA	MA
Copper	NA	SA	MA	HA	HA	HA	HA	MA	SA	SA	SA
Zinc	HA	HA	HA	HA	HA	MA	MA	SA	SA	SA	SA
Molybdenum	NA	NA	SA	SA	MA	MA	HA	HA	HA	HA	HA
	Acidic			← Optimum pH Zone for Soil →					Basic		

NA = Not available; SA = Slightly available; MA = Moderately available; HA = Highly available

Figure 7: Nutrient availability chart: *Source: www.Himachalfruits.com*

Forage mineral analyses provide a good insight into the balance of minerals and the acidity of the soil. Mineral deficiencies and excesses in the plant reflect the availability of those minerals in the soil. Timing of analysis is an important consideration as the makeup of the plant changes depending on growth stage and maturity, and also during the season. Silage mineral analyses offer a good indication, and as the winter diet of suckler cows is consistent and solely relies on silage, any imbalances can be corrected with supplementary minerals, bespoke to the analysis. A forage mineral analysis allows you to test the sick-looking parts of a field in comparison to the healthy areas.



Seasonal pattern of mineral uptake in grass swards

Figure 8: Chart courtesy of Potash Development Association

At the **University of Michigan Lake City research farm**, cows rotationally grazing rangeland were offered a mineral cafeteria to address imbalances. Cattle were apparently able to differentiate to match their own requirements and deficiencies. It was believed that the deficient minerals would be taken up by the cows and would then return to the land via the nutrient cycle to help balance the deficiency in the soil.

Figure 9: Mineral Cafeteria, Lake City research farm, University of Michigan. Photo: author's own

The choice of lime type and lime quality is an important issue for the industry and deserves greater attention. On a recent survey of bulk lime, 9 of 14 samples taken from quarries around the UK did not meet set industry regulation standards for sieve size for different grades to qualify as Aglime, with resultant reactivity ranging from 10 to 69%. The finer the lime the better.

5.3. Calcium

During my visits to soil-focused grass producers the importance of supplying sufficient calcium became evident. Our recognition and understanding of the role of calcium for the pastures of our uplands is often overlooked, and its absence from our basic soil test underlines this.

> *"one of our roles as farmers is to ensure plants receive sufficient calcium. Calcium is the key to building soil fertility*". Gary Zimmer, Wisconsin

Calcium improves soil structure, encourages root growth, increases the availability of necessary nutrients and is an important element in cell wall construction. However, calcium itself cannot move from one part of the plant to another which results in a need for adequate soil calcium throughout the growing season, especially for legumes.

Whilst visiting **Jon Wilson, farm manager for Yeo Valley's farms,** at Holt Farm, he explained the transformation in their soils after they had implemented a soil improvement plan working with consultant Jo Scammel NSch. Soils were heavy, poor draining and prone to water logging, and soil tests revealed high levels of magnesium in relation to calcium. To remedy the condition of the soil, calcareous lime and gypsum (up to 2 tonnes/acre) was applied which has led to a noticeable difference in soil structure, grass growth and, in particular, earthworm numbers.

5.4. Magnesium

Magnesium's presence is better recognised than calcium's. Again, it is needed in sufficient amounts with its important role in chlorophyll production and phosphorus uptake. Many upland areas, Wales in particular, have sufficient magnesium due to the soil's rock base material being dolomitic, and additional applications of magnesium results in heavier, stickier soils with poor water and nutrient transfer and availability.

5.5. Potassium

The potassium requirement of a plant is second only to that for nitrogen and is an essential plant nutrient, playing a role in all aspects of plant growth. **At Cornell University whilst meeting with Professor Harold Van Es,** I learnt that plants with higher potassium levels are more tolerant to cold and frost and can therefore help in extending the grazing season. It is widely understood that crop offtake must be replenished, with considerations and adjustments made based on yield, but excessive applications can have a negative effect on the soil and plants.

plants with higher potassium levels are more tolerant to cold and frost and can therefore help in extending the grazing season

Untimely and excessive applications of potassium can result in 'flattened', compacted soils and 'luxury uptake' leading to a dangerous antagonistic relationship with magnesium that can increase the risk of grass tetany (staggers) and hypocalcemia (a condition in which there are lower-than-average levels of calcium in the liquid part of the blood). This is because it interferes with the plant's ability to uptake magnesium and calcium. High levels of potassium also interfere with boron and manganese uptake. When magnesium levels are high it takes more potassium to grow the same crop.

Weeds, and in particular broad-leaved docks, like high potassium, low calcium soils. Correcting this balance can be an effective way to help reduce weed pressure.

Jo Scammell UK NSch is an advocate of high calcium soils to reduce weeds and has presented evidence on several occasions as to its benefits.

5.6. Phosphorus

Sir George Stapledon was a firm believer in the importance of phosphate and that it should be placed first, alongside lime, in order of priority when undertaking any of his upland grassland improvement projects.

The availability of phosphorus is significantly affected by acidity, and excessive applications to compensate for low pH can cause serious environmental damage, with eutrophication (the increase of vegetation in a particular area of water) of the watercourses. However, phosphorus does not leach but rather attaches itself to soil particles and can wash away with surface water, which is of a lesser concern in permanent grasslands as the soil is covered and undisturbed.

Insufficient phosphorus can severely affect plant yield, as was evident in trial plots visited at **Embrapa research facilities in Brazil**, where the absence of, or even low, phosphate levels resulted in total crop failure. Several researchers have observed that the biggest root networks are found on plants grown in phosphate-deficient soils.

High phosphate levels and availability can interfere with the uptake of copper and zinc, two essential trace elements for both the plant and the livestock grazing the plant. Therefore, additional applications should be avoided when soil levels are already sufficient.

The current phosphate quota system introduced in the **Netherlands,** which basically freezes their cow population, serves as a warning of the effects of excessive nutrients and its effect on water quality. Whilst I was visiting dairy farms in the country, Jaco de Groot, NSch explained that farmers in the Netherlands are required to maintain cow numbers as set on the 2nd of July 2015, or purchase extra quota, currently valued at roughly €8,550 euros for each additional cow. This has the basic effect of inhibiting the intensification of production. Each time quota is traded the government retains 8% of the volume and removes it from circulation, resulting in a shrinking of the national herd.

5.7. Nitrogen

Timing of application of any nutrients in any form is key to reducing losses from leaching.

Nitrogen is the only major nutrient required by plants that can be synthesised from the air. It is regarded as the most frequently applied chemical fertiliser nutrient as its application significantly boosts crop and grass yields. The benefits of applying nitrogen are well known but the losses associated with nitrogen are less well known and need to be better understood in upland grassland systems. Historically the price of bagged nitrogen was low so, based on the law of diminishing returns, optimum rates were encouraged, and maximum yields targeted; but as its price has increased the application rates on upland farms have decreased.

Nitrate, the form in which plants absorb nitrogen from the soil, is very mobile and can result in losses from leaching into groundwater and watercourses from drainage and high rainfall, plus denitrification from volatilisation, in the form of nitrous oxide, as a result of compaction and poor soil health. Timing of application of any nutrients in any form is key to reducing losses from leaching.

Volatilisation also occurs due to poor timing of application of chemical fertiliser nitrogen with regards to weather and soil conditions. The poor storage and application of farmyard manure, and especially slurry, contributes significant levels of GHG emissions, with volatilisation at each stage of handling causing significant nitrogen losses. The current incentives from government to purchase trailing shoe injectors for slurry applications, plus covering slurry and muck stores, are all positive steps in reducing emissions and, hence, saving money.

Case Study: The Baltic Slurry Acidification project

The Baltic Slurry Acidification project in Sweden was looking at reducing nitrogen losses from livestock reduction by promoting the use of slurry acidification techniques (SATs). The use of SATs reduced the pH of slurry from 7.5 to 6, reducing ammonia and nitrous oxide emissions and increasing the nitrogen use efficiency of slurry, thereby decreasing their dependency on chemical nitrogen. Results demonstrated that the application of 3.6 litres of sulphuric acid directly into the slurry tanker increased first-cut grass silage yield by 510kg of dry matter per hectare at a cost of 47p per cubic meter. Several different acids were trialled but sulphuric acid proved to be the best value for money and also supplied 29kg of sulphur per hectare at an application rate of 25 cubic meters per hectare.

In Northern Ireland and the Republic of Ireland, Devenish Nutrition's 3-step soil health plan involves the use of **BioAg's Digest-it** slurry additive that aerobically composts slurry. It has been proven to increase nitrogen levels by 33% whilst reducing volatile ammonia emissions. On-farm trials demonstrated that, over two silage cuts, a 12% (1.42t DM/ha) increase in grass yield in 2017 and a 15% (1.39t DM/ha) increase in 2018 was achieved from the application of Digest-it treated slurry (at a rate of 25,000 litres per hectare) - compared to untreated slurry. The increase in yield was calculated by **Teagasc** to be worth an extra £168 per hectare.

5.8. Sulphur

Awareness of sulphur deficiencies has increased considerably over the past 10 years with most compound and blended fertilisers available in the UK now including sulphur. This inclusion requirement is due to its absence from atmospheric deposition (due to cleaner heavy industry) and, as sulphur is mobile in soils, it needs applying annually. According to **Yara figures** approximately 90% of the grasslands in Wales are deficient in sulphur, resulting in compromised protein synthesis that affects yield and quality.

The plant's requirement for sulphur is greater than the requirement for phosphorus but is certainly not given the same recognition within nutrient management plans. Sulphur has the ability to improve soil structure by reducing high soil magnesium levels, but most importantly it is present in all amino acids and is key in improving protein quality through better utilisation of nitrogen.

Thomson and Joseph silage forage analyses in the UK show an increase in grass silage sulphur levels of 26% since 2010, equivalent to a 4% unit increase in grass protein levels. This represents a significant reduction in the requirement for imported protein feeds.

Manure, slurry and digestate are all good sources of sulphur and within the soil its presence is mostly in organic matter. Therefore, maintaining or increasing soil organic matter levels is beneficial.

On soils low in calcium and sulphur the application of gypsum can be beneficial, it being a good source of both.

5.9. Feeding and correcting the soil

For building soil fertility the ultimate soil food that balances the whole nutrient cycle is livestock manure or compost. The key words are "feeding the soil" as opposed to "feeding the plant". If soil tests indicate sufficiently high levels of potassium and phosphates then large additions of extra manure can have a detrimental effect on the uptake of other nutrients (copper and zinc under high phosphate and boron and magnesium with potassium).

For building soil fertility the ultimate soil food that balances the whole nutrient cycle is livestock manure or compost.

When applying manure in ideal conditions it feeds the soil on a slow release basis with the release of nutrients better matching the needs of the plant over the course of the season. This results in less pollution risk from nutrients and a constant food source for the soil biology.

Summary: Chapter 5: Soil Chemistry

1. **The soil is like a bank – outgoings must be matched by ingoings to avoid deficit.**
2. **Addressing soil chemistry requires a balancing of several minerals.**
3. **A chemical soil analysis needs to consider more than N, P and K.**
4. **Lime consideration is the first step in correcting soil fertility.**
5. **Livestock manure and compost is the ultimate soil food.**

6. Soil physics

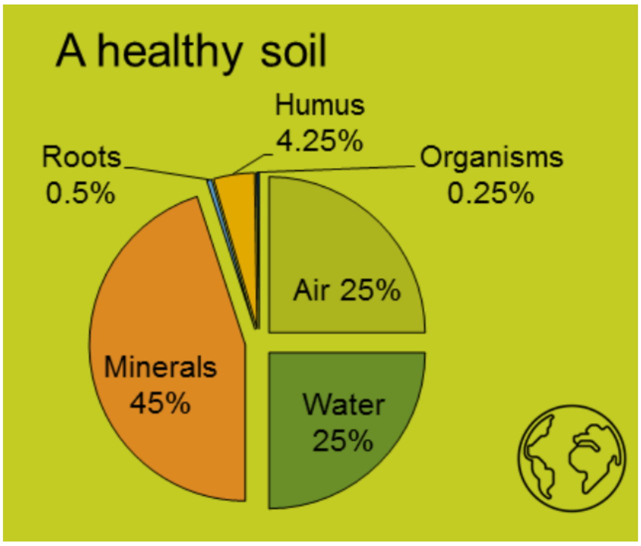


Figure 10: 20 things you didn't know about soils. *Chart courtesy of Yara*

The solids within the soil are what we physically see and are made up of fragments of stone, sand, silt and clay. These are defined by their size, and their percentages determine the soil type.

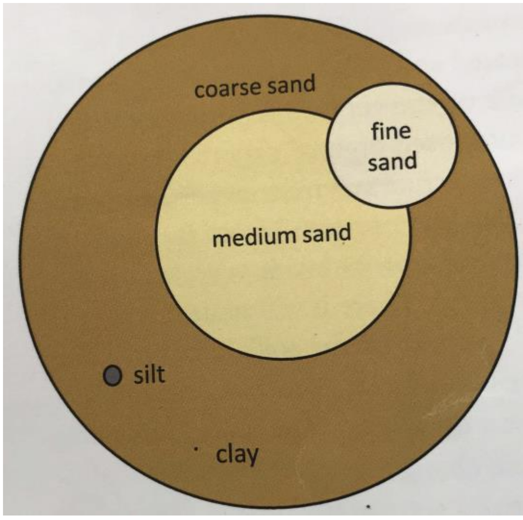


Figure 11: Chart to demonstrate relative size of soil particles. *Taken from: Cornell Comprehensive Assessment of soil health manual.*

Your soil type influences its ability to hold water, nutrients and organic matter: with a high sand content resulting in poor retention, and high clay resulting in good retention. When assessing soils, the soil type must be considered.

The pore spaces within the soil refer to the spaces between the solid particles and are filled with air, water and living organisms. Air, or more specifically oxygen, is essential for root development, and soil organisms and water are essential for the dissolving and transport of nutrients to the plant roots. Water drainage issues are often overlooked today but need to be addressed, with the return on drainage investment always making economic sense. This balance of air and water depends upon your soil structure and your soil management, and to achieve good physical structure the soil chemistry must be addressed first.

Key health indicators for the physical properties of the soil include:

1. Aggregate stability and soil structure
2. Bulk density and soil porosity
3. Water holding capacity and water infiltration

6.1. Compaction

Compaction is one of the major factors limiting grass yields on upland farms. An estimated 70% of grassland soils is compacted. A recent trial at **SRUC (Scotland's Rural College)** looked at the effect of machinery (tractor) and cattle on soil structure and grass yield. Over a two-year period the average yield loss was 14% on land poached by cattle, and 22% on land damaged by machinery.

The soil's bulk density on most livestock farms is higher due to the hoof pressure from livestock whilst grazing year-round, especially when soils are wet, but is compounded by the use of heavy machinery and equipment. Clay soils are more vulnerable to compaction than sandy soils due to their smaller particle size. Compaction destroys all the above key indicators (*see points 1, 2 and 3 two paragraphs above)* and therefore requires urgent recognition for improved soil health. The soil pores get compressed, expelling air and reducing the space for water to flow, resulting in waterlogged soils that are slower to warm up in the spring, and the absence of air in the soil creates unfavourable anaerobic conditions.

These anaerobic soils prevent the roots from accessing oxygen, reduces biological activity and increases the availability of undesirable minerals, such as iron and molybdenum. The inability of roots and water to penetrate compacted layers results in poor fertiliser utilisation and creates a greater pollution risk from leaching, run-off and emissions.

Compaction is a growing problem on grassland farms with forage mineral analyses of silage samples highlighting why this is a worrying trend. **Thompson and Joseph** samples (https://www.tandj.co.uk/) show that, since 2010, iron concentrations have increased by 8% and molybdenum by 33%, largely due to compaction creating anaerobic conditions. In well aerated soils molybdenum is oxidised making it difficult for the plant to absorb through the roots. These levels of iron and molybdenum are far in excess of animals' needs and pose a risk to the animals' health through reducing their ability to absorb copper and zinc - resulting in necessary supplementation. Thiomolybdate toxicity is caused when molybdenum seeks copper to bind to in the rumen, but if in excessive amounts it enters the blood stream in search of copper. This results in clinical signs of copper deficiency despite sufficient copper. Supplementary ionic copper is required to prevent molybdenum entering the blood stream.

So the need for copper supplementation is often as of a direct result of soil compaction and could be reduced or eliminated by addressing soil compaction.

6.2. Alleviating compaction

Root growth with soil bulk density at 1.0 g/cm^2	Root growth with soil bulk density at 1.3 g/cm^2	Root growth with soil bulk density at 1.3 $g/cm^{2.}$ Compaction layer is at 15.2 cm (6") depth	Root growth with soil bulk density at 1.6g/cm2. but compaction layer is at 15.2 cm (6") depth

Figure 12: Photo shows the effect of the soil bulk density. It illustrates that a dense soil with no compaction layer is as damaging as a less dense soil that has a compaction layer. Soil bulk density must always be considered. Photo source: Iowa State University.

The first step in alleviating compaction is to determine the physical depth of the compaction problem, with several options available. Digging a hole with a spade is a good starting point as it will give you an insight into the soil structure, its bulk density and aggregate size and stability along with root depth, development and direction. Visiting **Joe Breker in Havana, North Dakota**, who had been practising zero tillage for 30 years, he commented that:

> *"the ideal soil should have aggregates like cottage cheese"*

A simple "drop-test" of the sod of soil will highlight compaction in the upper layers if the soil breaks up horizontally as opposed to vertically. A water infiltration test will give an insight into the soil's bulk density. Penetrometers are also available to measure the density of compaction but **Tuomas Mattila,**

a soil specialist in Finland, used a 'tile/drain probe' to discover if there was a compaction problem and its depth. The simple steel probe allows you to feel and sense your way through the soil profile and identifying the depth of compaction.

Figure 13: Tuomas Mattila, a soil specialist in Finland uses a 'tile/drain probe' to discover if there was a compaction problem and its depth.

Livestock compaction will generally be found at a depth of 5-15cm, with compaction from heavy machinery found deeper at 15-30cm. The depth of the problem affects treatment choice. Deep rooting forages such as radishes have the ability to penetrate compacted layers, allowing earthworms access to aid in its alleviation. Rest periods also have the ability to allow the soil to "breathe" back into shape with the benefit of improved root structure to aid the soil's resilience to compaction.

Mechanical treatments can be categorised as:

A. Aerators or slitters, for shallower compaction, and
B. Sward lifters or subsoilers, for deeper compaction.
C. Mole ploughs for improved drainage to reduce poaching of wet areas.

Timing and frequency of operations are key to the success of any treatment with the soil needing to be dry enough to create a shatter effect to break compaction layers. I was **advised in the US** that the correct timing was similar to testing a baked cake – if you pierce a cake with a needle and the needle comes out clean with no residue, then it's cooked. Similarly with an aerator the blades need to come out of the soil clean.

Aerators are excellent at breaking surface compaction and allowing air, water and nutrients into the **Devenish Nutrition's** 3-step soil health plan involves the use of aerators to correct compaction. It is estimated that compaction can reduce grass yields by about 40%. My personal experience on farm also confirms the benefits of aeration.

Awareness of tyre pressure and tyre load deserves greater attention from farmers and contractors

Martin Howard of Launceston, Cornwall, believed that managing soil compaction was crucial to his future farming system. Martin related his animal health issues to his soil health and focused on improving soil health by subsoiling to reduce compaction and produce deeper soils. His aim of getting a perfect soil structure involved getting roots to go down further, which could only be achieved by getting oxygen deeper into the soil to unlock nutrients. His early results were clearly evident in mid-winter with grass and forage growth visually demonstrating an extended growing season on his farm.

Preventing compaction is as important as *alleviating* it as, once alleviated, the challenge is to prevent future compaction. Awareness of tyre pressure and tyre load deserves greater attention from farmers and contractors, with a need for better information and an understanding of its consequences on soil. Our choice of the type of tyres needs more investigation than basing the decision solely on price.

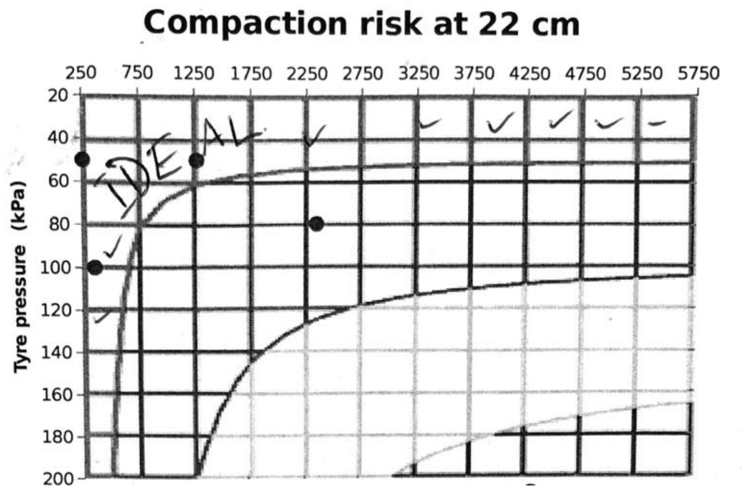


Figure 14: The above chart was part of a soil structure presentation by Tuomas Mattila in Finland

Tyre load (kg)

A visit to Sweden demonstrated how, for a focused approach to soil health, everyone involved on the farm must understand and believe in the end goal.

This was the case with **Lars Svensson at Mariestad** where eight organic farmers collaborated to build a 1200 cow dairy as a solution to feeding their tired soils. The addition of livestock manure had rejuvenated their soil biology, and fertility and crop yields had responded positively. Applying manure, slurry, and harvesting silage and crops was creating a compaction issue and the decision was made to adopt a controlled traffic system on all operations. Staff were trained and equipment purchased to enable the new system to be operated. Within only 2 years a visible improvement was to be seen in soil structure and earthworm numbers.

Figure 15: Silaging on a controlled traffic system with Lars Svensson.
All field operations were carried out on a controlled traffic system.

Summary: Chapter 6: Soil physics

1. **Soil bulk density on livestock farms is greater due to hoof pressure.**
2. **Identifying and consequently alleviating soil compaction is essential.**
3. **Ensure that roots have the ability to explore deeper for nutrients.**
4. **Awareness of tyre pressure and tyre load deserves greater attention from farmers and contractors**

7. Soil biology

"We know more about the movement of celestial bodies than about the soil underfoot"

Leonardo DaVinci, circa 1500s

For many of us the quote above resonates as being as true today as it was 500 years ago - but why? Soil more often than not is seen as a commodity and a medium that grows grass and is considered solely on a chemical basis, with a belief that we only need to add something to it to correct any deficiency. If we were all to consider the soil as a living ecosystem it would gain far more respect, and as health infers something that is living, *the life in the soil* is of paramount importance for all that we aim to produce.

To gain a better understanding of soil biology I attended an **ARTIS Improving Soil Biology for Better Yields course**, held near Hereford, at the beginning of my study. It provided an excellent base for understanding, and I would encourage every farmer to attend such training courses.

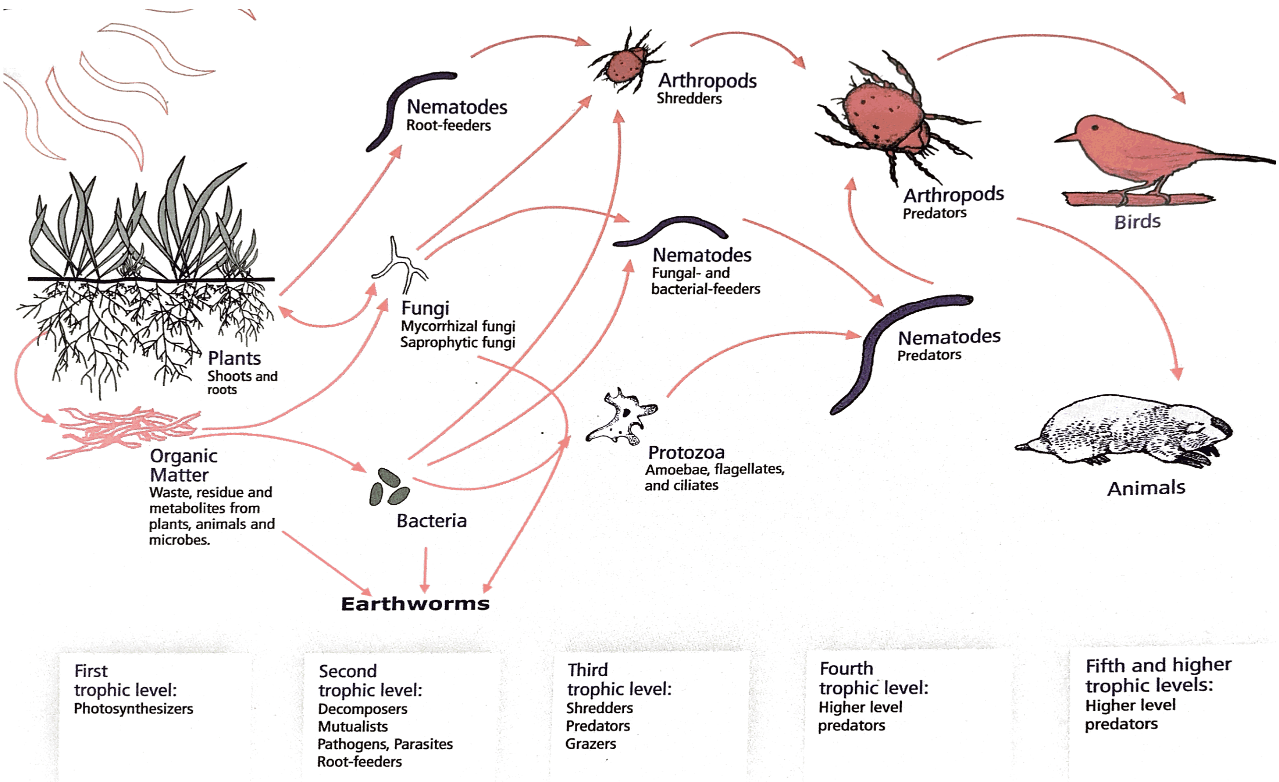


Figure 16: The Soil Food Web. Chart taken from Cornell University's Soil Framework Manual https://soilhealth.cals.cornell.edu/training-manual/

The soil is full of life as the soil food web (above) illustrates, with each link in the soil food chain and pyramid being vital. Food and energy sources are required for all living organisms, with the soil's food source coming from sugars from photosynthesis, and organic matter from plants and animals, to provide the ideal habitat and conditions for the soil biology to thrive.

When assessing soil biology and soil health the key indicator is earthworm numbers. They are the ecosystem engineers that burrow through the soil to provide the infrastructure that all other biology relies on, eating damaging nematodes and pests, whilst dragging organic material down from the surface to feed themselves and other biota.

When assessing soil biology and soil health the key indicator is earthworm numbers

There are several different types of earthworms, all with a different function, some working near the surface and others being deep burrowers. Casts excreted from the worms are rich in nutrients in plant-available form, with concentrations of N, P and K up to ten times higher in soils that contain worms. The casts also contain substances that aid in forming aggregates. The pores created by deep burrowing worms provide channels for water, air, and roots to grow and access nutrients, thus taking life deeper into the soil profile. A general rule of thumb suggests that a cubic foot of healthy soil should contain 25 earthworms during the growing season.

The role of bacteria and fungi within the soil and their symbiotic relationship with the plant is a vitally important consideration when discussing soil biology. It was put to me that if the plant is the diner at a restaurant, then the mycorrhizal fungi would be the waiter and the bacteria the chef in the kitchen: which demonstrates the communication pathway that exists between the plant and its food source.

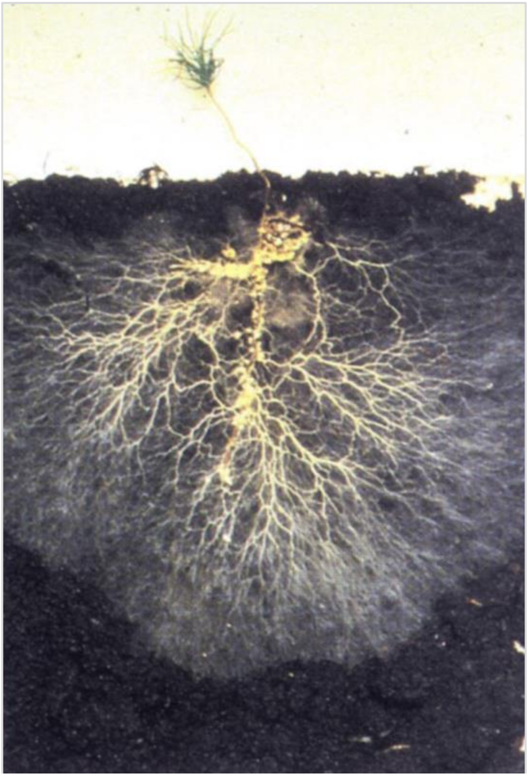


Figure 17: Showing the vast hyphae network that extends the plant's reach for absorption of water and minerals. Source: www.rootrescue.com

The extensive root biome is created by the bacteria and mycorrhizal fungi to feed the plant. The mycorrhizal fungi attach to the plant's roots and are fed sugar by the plant in exchange for nutrients in available form. The more food received by the fungi the more extensive its vast hyphae (cells) structure grows, which increases its nutrient-supplying capacity.

When chemical fertiliser is applied, plants can extract nutrients from the soil, but the soil biology can provide those nutrients more efficiently by supplying them in a more available form. I learnt, at the **Groundswell** event (www.groundswellag.com), that up to 20% of plant nitrogen comes from nitrogen-fixing bacteria and that 75% of plant phosphate is supplied by mycorrhizal fungi. That highlights the need to feed the soil microbes and focus less on attempting to supply all of the plant's nutrients by applying chemical fertiliser.

According to an article in the **Holistic** management newsletter it is estimated that only half of applied fertiliser is actually absorbed by the plant itself, with the rest polluting both air and water resources. In 2015, US farmers spent $25.5 billion dollars on fertilisers and pesticides, a 7% increase from 2014, which highlights the actual financial cost of the losses.

Glomalin is produced by the mycorrhizal fungi hyphae. It is best described as the glue that binds aggregates together with the fine thread-like roots, with hyphae helping to create crumbly cottage cheese-like soil structure and ensure aggregate stability.

7.1. Testing the biology

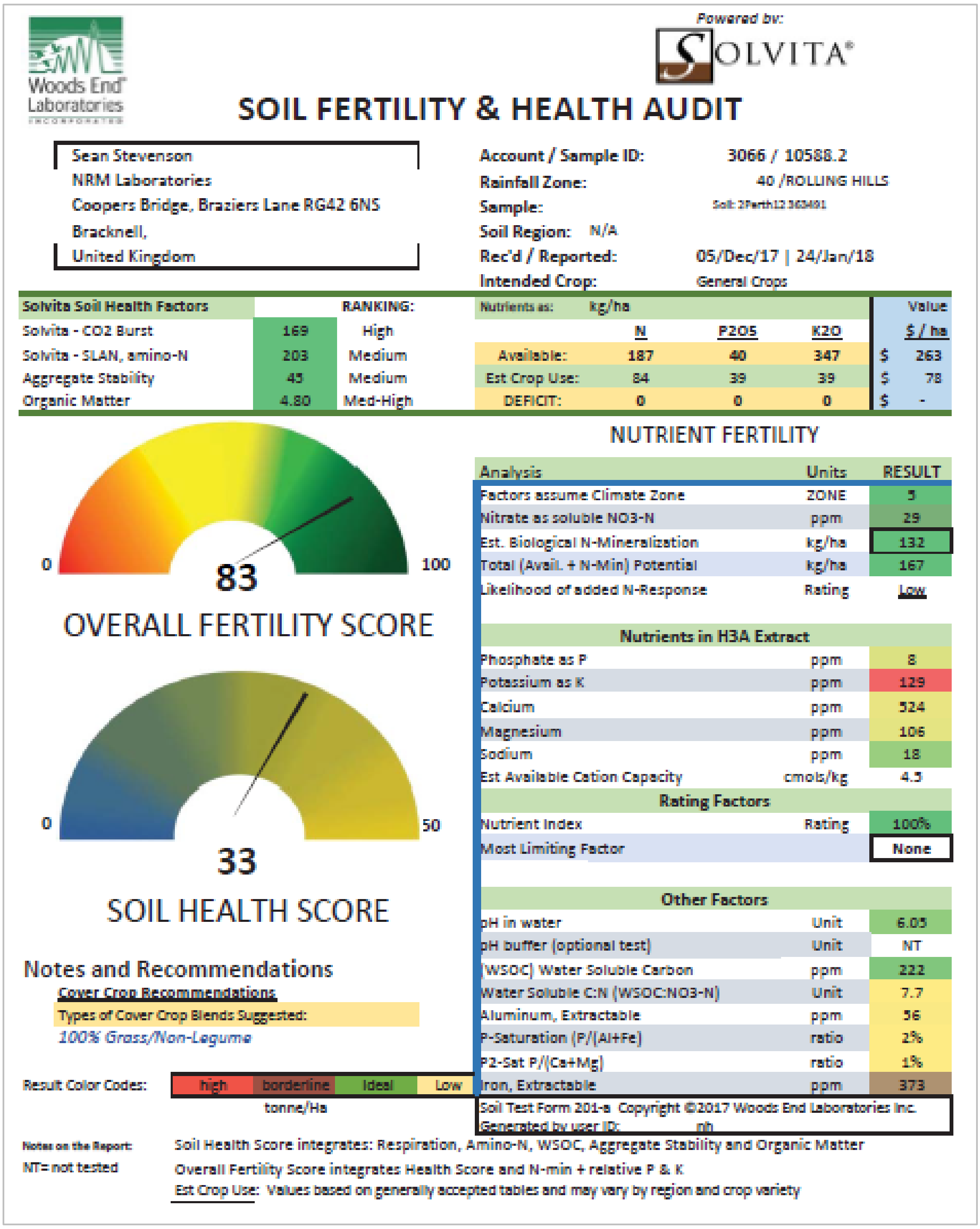
There are several soil tests that attempt to measure and analyse soil biological health but, due to constantly changing climate within the soil ecosystem, results can be variable and are not repeatable. However, as with any soil test, sampling at the same time of year, same time of day and in similar weather conditions, can improve reliability and allow fair assessment of change over a given period. Acting upon a biological analysis is difficult compared to a chemical or physical test. The latter can result in direct action and recommendations that can remedy the issues.

Biological additives to feed the soil **have become extremely popular in the US** with an array of products marketed to farmers who are convinced their soils will be healthier by adding them. Most are molasses-based to provide the soil microbes with a sugar feed source to increase their activity and action.

An increasingly popular way of assessing crop health, and consequently soil health, is the Brix test (refractometer) that measures the amount of crude sugar in the plant tissue. With sugar levels relating to the health of a plant, the Brix is an easy, inexpensive way to test.

The Solvita CO_2 burst test (https://solvita.com/soil/) measures the respiration from the soil of all the microbial activity, as they breathe in oxygen and breathe out carbon dioxide (CO_2). The test scores CO_2 from 0 to 5 with 5 indicating high biological activity.

The **#soilyourundies** video relates to burying a pair of cotton underpants in the soil and leaving them for a set period of time to assess the biological activity of your soils reflected by the level of decomposition that occurs. The campaign has been very successful worldwide - and on social media - by raising awareness of soils in a very visual, simple and light hearted test. Clayton Robbins, Canadian NSch, handed out cotton facecloths at the 4-H Global Summit, for delegates to bury so as to raise the awareness of soil biology at work. Whilst visiting **farmers across the US** it became evident that the **Haney soil test** created by Rick Haney of USDA-ARS was increasing in popularity especially on grass-based and regenerative type farms. The test involves the use of a specially designed acid that mimics root-released acids to discover the nutrients available to the plant, and potential availability based on the level of biological activity. A soil health score and overall fertile score is then generated from the results along with appropriate recommendations. I am a member of a soils group that has sent soil samples over to the US for analysis under the Haney method, and the photo below is a copy of the



Woods End Laboratories Incorporated

Powered by: SOLVITA®

SOIL FERTILITY & HEALTH AUDIT

Sean Stevenson
NRM Laboratories
Coopers Bridge, Braziers Lane RG42 6NS
Bracknell,
United Kingdom

Account / Sample ID: 3066 / 10588.2
Rainfall Zone: 40 /ROLLING HILLS
Sample: Soil: 2Perth12 363491
Soil Region: N/A
Rec'd / Reported: 05/Dec/17 | 24/Jan/18
Intended Crop: General Crops

Solvita Soil Health Factors		RANKING:
Solvita - CO2 Burst	169	High
Solvita - SLAN, amino-N	203	Medium
Aggregate Stability	45	Medium
Organic Matter	4.80	Med-High

Nutrients as: kg/ha	N	P2O5	K2O	Value $ / ha
Available:	187	40	347	$ 263
Est Crop Use:	84	39	39	$ 78
DEFICIT:	0	0	0	$ -

0 83 100
OVERALL FERTILITY SCORE

0 33 50
SOIL HEALTH SCORE

NUTRIENT FERTILITY

Analysis	Units	RESULT
Factors assume Climate Zone	ZONE	5
Nitrate as soluble NO3-N	ppm	29
Est. Biological N-Mineralization	kg/ha	132
Total (Avail. + N-Min) Potential	kg/ha	167
Likelihood of added N-Response	Rating	Low
Nutrients in H3A Extract		
Phosphate as P	ppm	8
Potassium as K	ppm	129
Calcium	ppm	524
Magnesium	ppm	106
Sodium	ppm	18
Est Available Cation Capacity	cmols/kg	4.5
Rating Factors		
Nutrient Index	Rating	100%
Most Limiting Factor		None
Other Factors		
pH in water	Unit	6.05
pH buffer (optional test)	Unit	NT
(WSOC) Water Soluble Carbon	ppm	222
Water Soluble C:N (WSOC:NO3-N)	Unit	7.7
Aluminum, Extractable	ppm	56
P-Saturation (P/(Al+Fe)	ratio	2%
P2-Sat P/(Ca+Mg)	ratio	1%
Iron, Extractable	ppm	373

Soil Test Form 201-a Copyright ©2017 Woods End Laboratories Inc.
Generated by user ID: nh

Notes and Recommendations
Cover Crop Recommendations
Types of Cover Crop Blends Suggested:
100% Grass/Non-Legume

Result Color Codes: high | borderline | ideal | Low
tonne/Ha

Notes on the Report: Soil Health Score integrates: Respiration, Amino-N, WSOC, Aggregate Stability and Organic Matter
NT= not tested Overall Fertility Score integrates Health Score and N-min + relative P & K
Est Crop Use: Values based on generally accepted tables and may vary by region and crop variety

Figure 18: Results of a Haney test taken on soils from my own farm. Source: author's own

7.2. Organic matter (OM)

Soil organic matter plays a major role in defining soil health because of its effect on all the chemical, physical and biological properties of the soil. F.E Allison described it as:

> *"the key to soil fertility and productivity"*

7.2.1. Role of OM

1. Provides nutrients and food for plants and soil biology
2. Conserves soil nutrients in their organic form to be released slowly as conditions became ideal
3. Binds soil particles into aggregates that improve soil structure
4. Improves the water-holding capacity of the soil
5. Increases Cation Exchange Capacity

Arable farmers have long recognised the importance of maintaining the OM content of their soils with low levels making it difficult to grow plants due to fertility issues, water retention issues, compaction and erosion, that all result in a need for greater fertilisation, irrigation and machinery to maintain yields.

The Natural Resources Conservation Service in America quotes that a 1% increase in the OM level of a soil increases the water holding capacity of a soil by 310,000 litres per hectare.

In extensively managed grasslands OM levels are high and generally maintained due to grazing practices and the carbon cycle. Bur intensively managed grazing systems can deplete OM levels due to higher usage of nitrogen fertiliser and liming. This encourages soil biology which feeds on OM. There is also an effect from harvesting grass (off-take).

In its simplest form organic matter is made up of

1. Living material (3-9%) - roots, earthworms, microorganisms, bacteria, fungi
2. Recently dead material (7-21%) - dead roots, dead biota, crop residues
3. Decomposed dead material (70-90%) - manures, humus

Humus, or soil organic carbon, is the real store of plant nutrients, rich in humic substances that increase nutrient availability.

The range of typical OM levels varies according to soil type, with sandy soils having low OM levels of 1-2%, grassland clays in the 5-12% range and peaty soils reaching 20%. Replenishing OM is vital with livestock manure an excellent source.

Summary: Chapter 7: Soil biology

1. **The soil is teeming with life**
2. **The earthworm is a great indicator of soil health**
3. **Organic matter is the key for soil health and fertility**
4. **We must feed the soil biology to create ideal conditions for them to thrive**

8. Grazing management

8.1. Occupation length and rest period

A large, healthy root system is vital for grass as it provides nutrients and water to the plant. Several trials show a direct relationship between yield and root mass. Earthworm populations are also higher in crops with large root systems.

> *The breeding of grasses under nutrient-limiting conditions would prove far more beneficial to grassland farmers in the long term.*

Root development is often a low priority when it comes to grass breeding and, with trial plots ensuring sufficient nutrients are always available, the reliance on root function is reduced. Perennial ryegrasses for example have been bred to be highly responsive to nitrogen. The breeding of grasses under nutrient-limiting conditions would prove far more beneficial to grassland farmers in the long term. The development of Festuloliums (ryegrass fescue hybrids) under **Professor Mike Humphreys at the University of Aberystwyth** along with their Sureroot project (http://www.sureroot.uk/) has concentrated on the benefits of rooting depth, with encouraging results for drought resistance and nutrient uptake.

Correct management has the ability to encourage greater root development by providing the ideal soil conditions and better grazing management. As we rarely view or consider the root structure of grass plants the impact of our management on roots is unknown.

In **Andre Voisin and A. Lecomte's book** "Grass Productivity" (first published in 1962) the importance of the rest period or 'time factor' is emphasised alongside their belief that grass should not be "sheared" by animals' teeth more than once during the occupation of a field, in order to ensure sufficient reserves are left to allow maximum new growth. The period of stay in each field, along with sufficient rest periods, is key; with a maximum of three days the accepted norm for occupation and 21 days a minimum for rest. The added benefit of shorter grazing periods is the positive effect on daily intakes, with increased consumption linked to higher growth rates and higher milk production.

In an article in the spring 2017 edition of the Forager magazine an interview with **international dairy farmer and specialist Michael Murphy** mentioned that cows will eat 95% of their grass intake in the first three hours after milking and that work at **Moorepark, Ireland**, had shown that when grazing time is limited the cows will take more bites per minute.

At the **Grassfed Exchange Conference in Albany, New York State,** I learnt of the above results from a 1954 trial that looked at root growth stoppage resulting from defoliation in grass. The results are consistent with the advice given by both **Voisin and Lecomte** and the on-farm practices and beliefs of many Canadian and US tall-grass graziers. On some farms a compromise between the need to increase organic matter and soil carbon as opposed to livestock performance is sometimes deemed necessary.

See diagram on next page

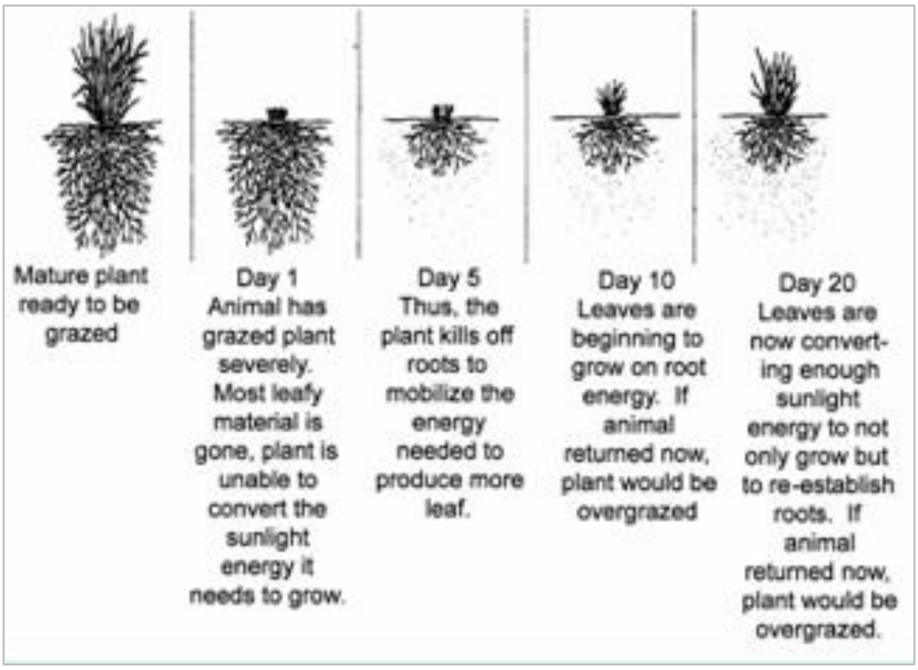


Figure 19: Root Growth Stoppage, resulting from defoliation of grass
Diagram by Franklin J Crider, Soil Conservation Service, USDA, February 1955.

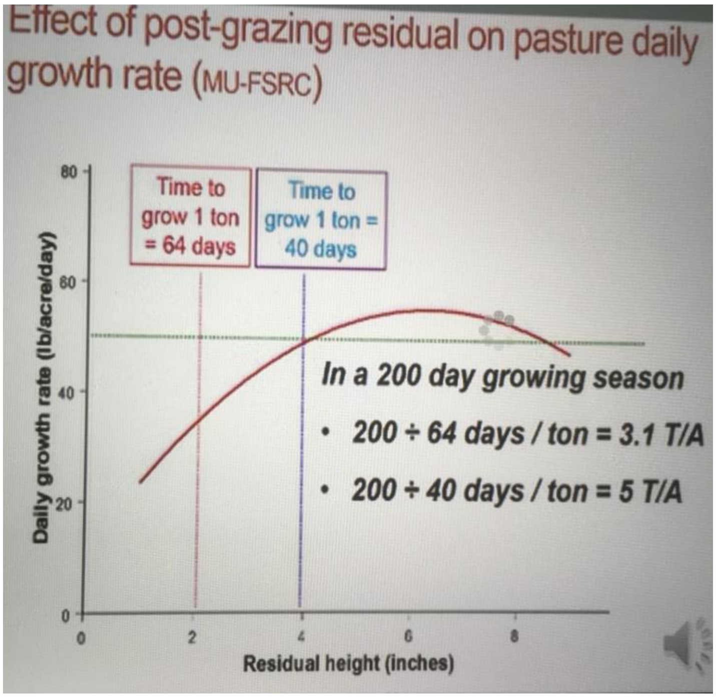


Figure 20: Slide courtesy of the Grassfed Exchange, showing results from the University of Missouri that highlights the importance of residual height

Set stocking and continuous grazing has an obvious negative effect on root development with root energy reserves exhausted, which consequently affects grass growth potential. Grass residuals must also be questioned with evidence from **Missouri State University** demonstrating the importance of leaving sufficient residuals for increased grass growth. The effect of leaf surface area for photosynthesis and encouraging faster recovery periods must be considered, with aesthetically pleasing bowling-green like fields not necessarily ideal for optimum grass growth.

During my study I visited several impressive mob-grazing and long/tall-grass graziers who had transformed their systems because of the need to raise the OM levels of their depleted and impoverished soils. Their motto was to graze a third, leave a third, and trample a third and they were all unanimous in their belief that there was no such thing as wasting grass, which I can accept. The idea was to feed the animal, feed the plant (by the residual leaf area for solar capture) and feed the soil and its biology, through greater nutrient cycling with more plant and animal material returned.

However, the context of climate was key to these systems and adopting similar practices on an upland farm in Wales with 1500mm annual rainfall is difficult, especially using our current grass species and native grasses that have evolved over centuries of sheep grazing to remain short and fine.

Case Study: Russ Wilson of Wilson Land and Cattle in Tionesta, Pennsylvania

Of all the farms visited which practised high intensity adaptive grazing, Russ Wilson of Wilson Land and Cattle in Tionesta, Pennsylvania, at 1600 feet above sea level and 1090mm rainfall, had the climate that was most comparable to the Welsh uplands, and had transformed the productivity of his soils and farm. After applying significant amounts of lime to correct acidity, and subdividing the farm into 30 permanent fields with an electric perimeter fence for further subdivision, the stocking density of the farm increased significantly. Cows were moved once a week in 2010, but up to between two and ten times a day in 2017. The increased intensity resulted in an even distribution of nutrients from manure.

Grazing season length also dramatically increased from 150 days in 2010 to 350 days in 2017, resulting in a significant cost saving from the reduced requirement for hay and housing. Russ emphasised that every time you put a machine between a cow and her feed, it adds cost.

Rest periods varied from the 30 days at peak growth to 180 days in winter, with the extended rest period seen as key to breaking the worm cycle, completely removing the need for any anthelmintic treatment. Diversity of forage species was very important to Russ with over 70 different species used, combining cool season and warm season annuals and perennials to provide a grazing platform capable of year-round grazing. Compaction was reduced by the short period of occupancy in each grazing and the long rest period allowed optimum root development which generated natural alleviation of any shallow compaction.

The health of his soil was strikingly obvious with its smell, earthworm numbers, root mass, moisture retention, aggregates and a low bulk density all combining to produce healthy crops and content livestock.

8.2. Grass species and variety selection

The context of climate and function is crucial when deciding what to sow, but as I have been repeatedly told:

> *"the greater the diversity above ground, the greater the diversity below ground"*

Many of the "off the shelf" grass mixtures available in the UK are perennial ryegrass-dominant. According to **Cotswolds Seeds,** 1200 tonnes of ryegrass are sown in the UK each year, accounting for 95% of all forage grass seed sales and highlighting the insignificance of other species.

Multi-species swards have become a fashionable option and, despite a need for greater understanding of their performance potential over a longer period, they have an important role to play in the future of upland grassland systems. Along with the inclusion of herbs, such as chicory and plantain, these mixes offer an improved root profile leading to better nutrient utilisation, an improved soil structure, increased earthworm numbers and better mineral profile for livestock.

The benefits of including nitrogen-fixing legumes into new leys are well established, and at the **University of Wisconsin, Madison, Chelsea Zegler** presented some of the initial findings from their ongoing soil health and grazing management research. The inclusion of clover was proving to be very beneficial. The final results are expected next year.

Plantain is particularly promising for its role in climate change mitigation with new varieties (Ecotain) developed in New Zealand proving to reduce nitrogen leaching from a urine patch by up to 89%,

Plantain is particularly promising for its role in climate change mitigation with new varieties (Ecotain) developed in New Zealand proving to reduce nitrogen leaching from a urine patch by up to 89%, through better utilisation of protein and nitrogen in the rumen.

Cocksfoot merits consideration for inclusion in a grazing or cutting ley, especially in drought-prone areas, due to its superior root structure. It also offers good spring growth and good regrowth after cutting. Timothy is ideally suited to upland grasslands due its hardiness and persistence, and also its ability to provide high quality early spring growth even on shallower soils.

The range of heading dates amongst the different species also complements the grazing season to ensure quality and yield is maintained throughout.

All these combined benefits make the richness of these species an essential requirement for upland grass swards.

See slide from Finland on next page

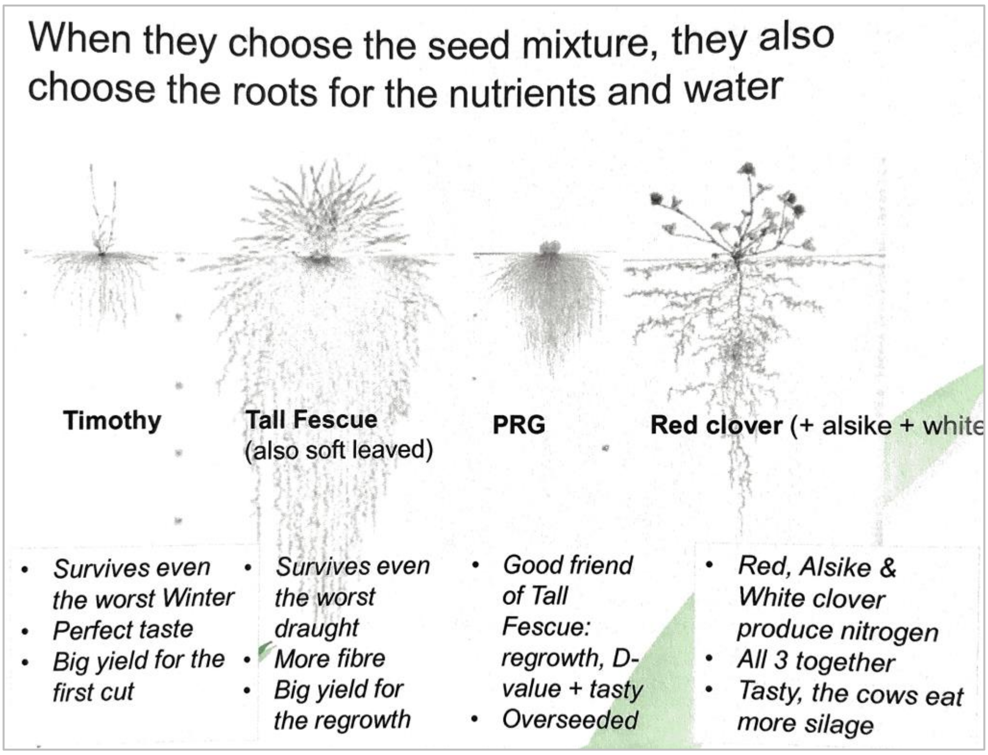


Figure 21: The above slide from Finland demonstrates the merits of their most popular species. Taken from a presentation by Anu Ella.

Case study : Finland

In Finland sward density was of upmost importance, with a focus on developing a dense canopy and a dense root mass capable of being winter-hardy to survive their harsh long winters. As the average field is reseeded every 3 years due to persistence and resilience issues, the correct selection of grass species was vital. Timothy was the grass species of choice in Finland, and most of Scandinavia apparently, on account of its winter hardiness and its early spring growth under challenging conditions. By ensuring sufficient covers of grass, the dormant period of winter was not the difficult part of the season but the spring was incredibly challenging for young grass shoots. Day temperatures in their springs can reach up to 20 degrees centigrade, followed by days and nights at -10 degrees centigrade. Day length also affected the shape of the growth curve with daily growth rates exceeding 350kg/day/hectare just before first cut in late May. The **Canopeo App** was used as a crude guide to canopy density and could be downloaded for free onto your smartphone (https://download.cnet.com/Canopeo/3000-2094_4-77203557.html. By taking a photograph of the canopy with your smartphone it would calculate the percentage of canopy cover and its density.

8.3. Soil assessments

When mentioning soil tests most people immediately think of a chemical or nutrient test, but to fully evaluate the health of your soils there are several indicators to consider beyond the constraints of chemical balance.

Any assessment should start with a spade for a Visual Examination of Soil Structure (VESS). Dig a hole and use your senses to give a first impression. Whilst walking through the field the weed content and grass composition and growth should be noted. Things to look out for at the soil pit include:

1. Earthworm numbers and their activity and sizes (ideally a mixture of sizes)
2. Bulk density, soil aggregation and aggregate size and their stability (cottage cheese)
3. Compaction, with horizontal cracks, pan layer, root structure and direction, colour
4. Colour, with darker better signifying more carbon, clay colour and rust from waterlogged soil
5. Smell, with putrid indicating unhealthy anaerobic conditions.

Simple and cheap though the spade method is, on most livestock farms this basic starting point is rarely practised, with the majority of decisions based on a chemical soil test and the fertiliser required.

The Smartgrass project at the University College of Dublin

This carries the caption "biodiversity for production" and is looking at the production potential of multi-species swards as a viable alternative to conventional high input perennial ryegrass monocultures.

Dr Helen Sheridan, project leader, explained the results of the three years from the simulated grazing experiment and their **Farmlet** experiment that used twin suckling ewes to compare four sward types:

Perennial ryegrass (PRG)	@ 163kg Nitrogen/ha/year
Perennial ryegrass + White clover	@ 90kg Nitrogen/ha/year
6 species (2 grass, 2 legumes, 2 herbs)	@ 90kg Nitrogen/ha/year
9 species (3 grass, 3 legumes, 3 herbs)	@90kg Nitrogen/ha/year

The results were hugely positive with all metrics (lamb 6-week weight, weaning weight, ewe weight, faecal egg counts and anthelmintic use) showing a benefit from containing more species in the sward.

The seasonal production curve also showed significant benefits in sustaining growth evenly throughout the growth period with less peaks and troughs than the PRG swards, allowing far better utilisation under grazing.

The SQUARE project (soil quality research assessment) in Ireland that involves several industry partners, has developed a "**GrassVess**" (https://onlinelibrary.wiley.com/doi/full/10.1111/sum.123) to score grassland soils, featuring scores for root mass and penetration, along with the standard scoring for earthworm numbers and structure.

Whilst in Finland I attended several grassland discussion group meetings and every meeting started with digging a hole and assessing the soil visually. Their recognition of soil being the starting point for improving forage yields was evident with all farmers visited and in attendance having a very good understanding of the health of their soils and how to assess it.

The best and most valuable examples of soil testing that I came across were assessments that encompassed all aspects of the soil from its function to its requirements, and these were:

1. **LifeRegen project in the Basque, Spain**
2. Comprehensive assessment of soil health at **Cornell University**

Case Study Nerea Mandaluniz, Basque region of Spain

Figure 22: Discussing the sub-division of paddocks with Aitor Azkarate and Josepe Saez on their organic dairy farm, Aniz, Spain

The **LifeRegen farming project** investigated the viability of regenerative practices and their beneficial effect on the quality of soil and the environment. This included developing simple inexpensive methods of evaluating soil quality and raising awareness amongst farmers of the importance of soil. The Basque region of Spain has a very similar climate to Wales, and along with similarly difficult terrain and sheep (milked for cheese production) the resemblance made the project very relevant. Traditional production systems based on grazing were the norm, but through rotationally grazing and allowing sufficient rest periods and measuring grass growth, the project had seen a positive effect on soil health whilst also improving production and output. Both sheep and cattle dairy farms and beef farms were involved in the project. Methods used included **SoilMontana Agro-ecosystem Health Cards** (AHCs) and soil chromatography (www.soilmontana.com

See overleaf for a copied sample of an AHC (SoilMontana Agro-ecosystem Health Card.

25.

BASIC Health Diagnosis

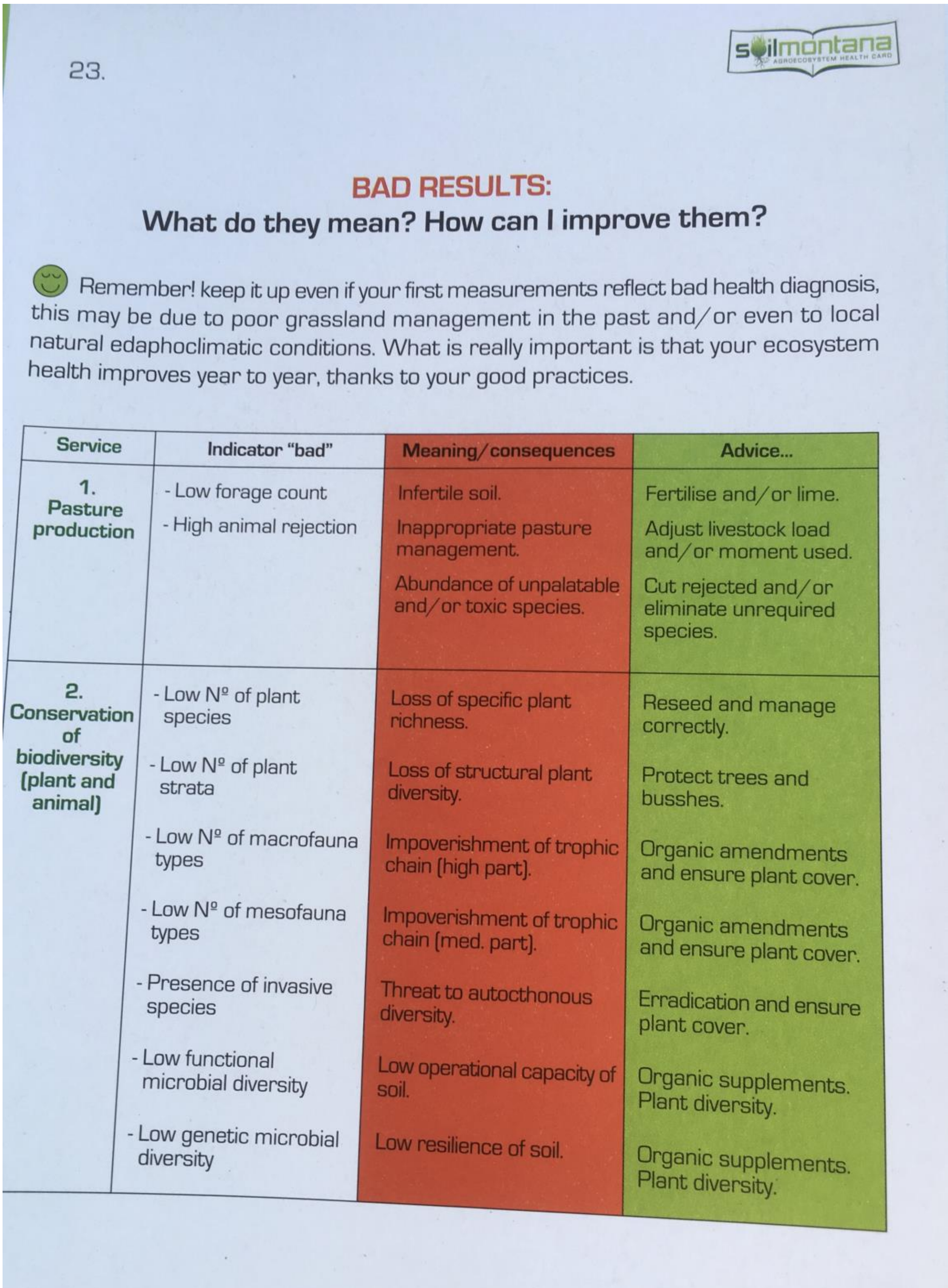
Plot name: ____________________ Date: ____________

Land registry code (SIGPAC): ____________________

Service	Basic indicators	Bad 1..2..3	Average 4..5..6	Good 7..8..9	Indicator value (1-9)	Service value (1-9)
1. Pasture production	1.1. Fresh weight (kg/m² per year): - mountain - valley	<0,8 <2	0,8-1,1 2-2,8	>1,1 >2,8		
	1.2. Animal rejection (%)	>25	5-25	<5		
2. Conservation of biodiversity (plant and animal)	2.1. Plant species (nº) - mountain - valley	<15 <15	16-30 16-25	>30 >25		
	2.2. Plant strata (nº)	1	2	3		
	2.3. Types of macrofauna (nº)	<3	3-6	>6		
	2.4. Invasive species (animal/plant) (nº)	>1	1	0		
3. Soil conservation	3.1. Worms (nº/m²)	<16	17-64	>65		
	3.2. Compaction- penetrability (cm)	<3	3-15	>15		
	3.2'. Compaction- root depth (cm)	<15	15-30	>30		
	3.3. Erosion risk (% bare soil)	>15	5-15	<5		
	3.4. Infiltration capacity (min)	>30	10-30	<10		
	3.5. Plant colour	pale	patchy	dark		
4. Combatting climate change	4.1. Root abundance	low	average	high		
	4.2. Soil colour	light	average	dark		

Figure 23: A sample of an *AHC (SoilMontana Agro-ecosystem Health Card)*, copied by the author

(See next page for an explanation of an AHC, copied by the author)



23.

soilmontana AGROECOSYSTEM HEALTH CARD

BAD RESULTS:
What do they mean? How can I improve them?

Remember! keep it up even if your first measurements reflect bad health diagnosis, this may be due to poor grassland management in the past and/or even to local natural edaphoclimatic conditions. What is really important is that your ecosystem health improves year to year, thanks to your good practices.

Service	Indicator "bad"	Meaning/consequences	Advice...
1. Pasture production	- Low forage count	Infertile soil.	Fertilise and/or lime.
	- High animal rejection	Inappropriate pasture management.	Adjust livestock load and/or moment used.
		Abundance of unpalatable and/or toxic species.	Cut rejected and/or eliminate unrequired species.
2. Conservation of biodiversity (plant and animal)	- Low Nº of plant species	Loss of specific plant richness.	Reseed and manage correctly.
	- Low Nº of plant strata	Loss of structural plant diversity.	Protect trees and busshes.
	- Low Nº of macrofauna types	Impoverishment of trophic chain (high part).	Organic amendments and ensure plant cover.
	- Low Nº of mesofauna types	Impoverishment of trophic chain (med. part).	Organic amendments and ensure plant cover.
	- Presence of invasive species	Threat to autocthonous diversity.	Erradication and ensure plant cover.
	- Low functional microbial diversity	Low operational capacity of soil.	Organic supplements. Plant diversity.
	- Low genetic microbial diversity	Low resilience of soil.	Organic supplements. Plant diversity.

Figure 24: An explanation of an AHC, copied by author

The AHCs have been adapted to grassland grazing systems and their simplicity was key to the excellent farmer participation in the project with the key indicators easily evaluated. The visual effectiveness of soil chromatography and its ability to highlight soil biological activity was fascinating and would be beneficial to introduce to grassland discussion groups in the UK.

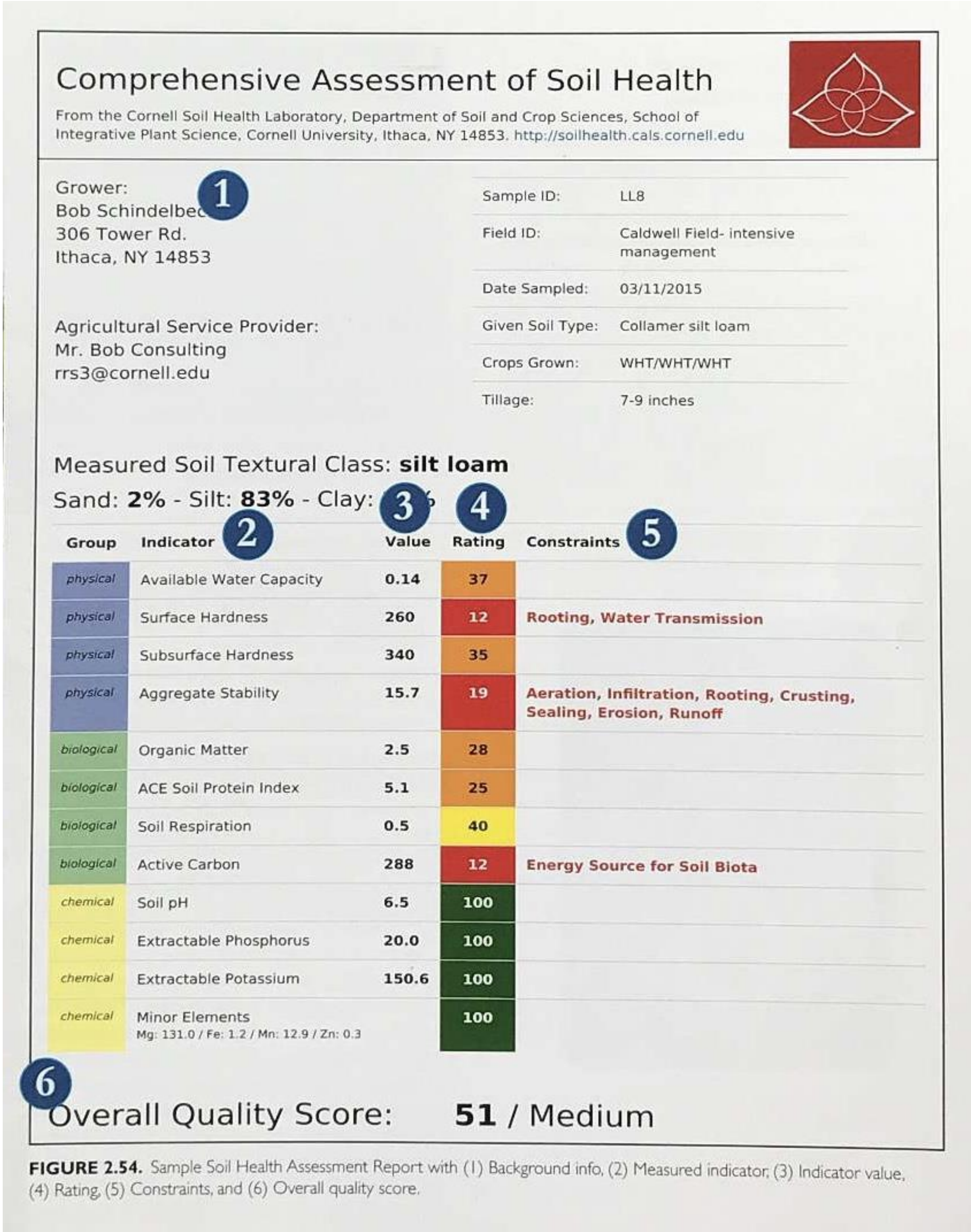
Wil Armitage NSch discussed chromatography in his report [Sustainable Milk Production: the vital role of Soil for Feed Integrity](). See www.nuffieldinternational.org/reports and search for UK 2013 reports.

Figure 25: Chromatography samples taken by Nerea Mandaluiz for the LifeRegen farming project, Spain

The results were very encouraging in demonstrating that the regenerative practices implemented:

- maintained livestock production;
- reduced carbon footprint per unit of output by 10%;
- improved soil fertility;
- and increased grass production by between 10% and 15%.

Cornell University's model combined the biological, chemical and physical elements, gave them all a rating score, and included the effect of different management practices on each of these elements. Ease of interpretation for the users was a key consideration alongside recognising constraints, in order to identify priorities, and the consistency and repeatability of the test (www.soilhealth.cals.cornell.edu).



Comprehensive Assessment of Soil Health

From the Cornell Soil Health Laboratory, Department of Soil and Crop Sciences, School of Integrative Plant Science, Cornell University, Ithaca, NY 14853. http://soilhealth.cals.cornell.edu

1 Grower:
Bob Schindelbec
306 Tower Rd.
Ithaca, NY 14853

Agricultural Service Provider:
Mr. Bob Consulting
rrs3@cornell.edu

Sample ID:	LL8
Field ID:	Caldwell Field- intensive management
Date Sampled:	03/11/2015
Given Soil Type:	Collamer silt loam
Crops Grown:	WHT/WHT/WHT
Tillage:	7-9 inches

Measured Soil Textural Class: **silt loam**

Sand: **2%** - Silt: **83%** - Clay: 3

Group	Indicator 2	Value 3	Rating 4	Constraints 5
physical	Available Water Capacity	0.14	37	
physical	Surface Hardness	260	12	Rooting, Water Transmission
physical	Subsurface Hardness	340	35	
physical	Aggregate Stability	15.7	19	Aeration, Infiltration, Rooting, Crusting, Sealing, Erosion, Runoff
biological	Organic Matter	2.5	28	
biological	ACE Soil Protein Index	5.1	25	
biological	Soil Respiration	0.5	40	
biological	Active Carbon	288	12	Energy Source for Soil Biota
chemical	Soil pH	6.5	100	
chemical	Extractable Phosphorus	20.0	100	
chemical	Extractable Potassium	150.6	100	
chemical	Minor Elements Mg: 131.0 / Fe: 1.2 / Mn: 12.9 / Zn: 0.3		100	

6 Overall Quality Score: **51** / Medium

FIGURE 2.54. Sample Soil Health Assessment Report with (1) Background info, (2) Measured indicator, (3) Indicator value, (4) Rating, (5) Constraints, and (6) Overall quality score.

Figure 26: Sample soil health assessment report. Source: (www.soilhealth.cals.cornell.edu).

A soil assessment is a far better way to look at soil than a chemical test. That tells you very little about the health of your soil, and if we are to improve our farmers' understanding of soil, we must start introducing more complete assessments, and score the key indicators.

See next page for Chapter Summary

Summary: Chapter 8: Grazing management

1. **Rest periods between grazings are essential**
2. **Grazing duration should not exceed 3 days**
3. **Species diversity must be encouraged**
4. **The breeding of grasses under nutrient-limiting conditions would prove far more beneficial to grassland farmers in the long term.**
5. **Soil assessments allow better understanding and reading of a soil than chemical analyses alone.**

9. Discussion

Why do upland livestock farmers not look at their soils? Why is our greatest asset given such low attention and priority? Why do we apply fertiliser in such quantities when we are actually wasting half of it on low pH soils because lime and correcting pH is "too expensive"?

All farmers and soil specialists whom I visited were surprised at the UK's narrow focus on N, P and K

Recognising the importance of the secondary essential plant nutrients of calcium, magnesium and sulphur, along with trace elements, is essential when attempting to create a healthy balanced soil. For this to occur, our basic soil test needs to become less basic: not necessarily more complicated but certainly more comprehensive. All farmers and soil specialists whom I visited were surprised at the UK's narrow focus on N, P and K.

The benefits of lime are well known yet we constantly fail to deliver when it comes to correcting acidity, which leads me to suggest we move the goal posts and raise the target of pH from 6.5 to 7.0 and attempt to slide the whole bell curve to the right. If a fertiliser purchase required a soil analysis to demonstrate efficient use possibly our industry would wake up. We are already required to use antibiotics responsibly for the benefit of all; then in the same way the responsible use of fertiliser should also come in for attention and scrutiny.

The damaging effect of compaction is apparently detected over 30 years later, and with machinery becoming heavier the damage inflicted today will affect the next generation's soil. The great hope is that the use of technology will result in machinery becoming smaller and lighter, but in the meantime greater awareness is required amongst farmers, and especially contractors, about the damage created by compaction, and how to reduce weight load and alleviate damage.

I welcome **Farming Connect's** latest training course "Pasture for Profit" that has been fully subscribed weeks ahead of the course date by young farmers eager to become more grass-focused. The content of the course includes all the fundamentals of growing and utilising grass and its role in making farms economically viable even in the current uncertain times.

The role of livestock in upland and hill grazing is essential to maintain productivity, biodiversity, carbon sequestration and the sustainability of rural marginal areas. The exodus of grazing livestock from these areas would be an environmental disaster.

Making soil "sexy" and exciting to upland livestock farmers is not an easy task, but through greater attention and focusing on area or group projects to get the dialogue started, and introducing novel ways of looking at soil, such as the chromatography, there is potential for soil to become a topic of discussion.

We have a duty of care to our next generations to ensure that they also have the resources available to farm and produce food, and care for our environment.

10. Conclusions

1. Soil, the greatest asset on our upland grassland farms, deserves our attention.
2. A chemical soil analysis needs to consider more than N, P and K
3. A soil assessment that considers all key indicators of a healthy soil needs to be promoted
4. Compaction needs to be taken seriously
5. Rest periods are key to grassland productivity
6. Species diversity needs to be encouraged in grass leys.
7. With soil the focus must be on creating the optimum conditions for the soil biology to thrive

11. Recommendations

1. For upland farmers, and their contractors, to better recognise the chemical, physical and biological aspects of the soil it is necessary to create a framework capable of delivering change. A minimum requirement should entail carrying out a comprehensive assessment of your soils every 5 years to allow better monitoring of trends in deficiencies and excesses, and should become a Key Performance Indicator (KPI). A Soil Health Plan should be formulated from the assessment to set out necessary amendments and actions.

2. A professional qualification or training course for the basic understanding of soil would allow for responsible use of fertiliser and manures and provide a good starting point for all farmers.

3. There is an urgent need for a renewed focus on lime on the grasslands of the hills and uplands, and a better appreciation of the calcium requirement of our soils.

4. Future support in the uplands should include livestock grazing incentives.

5. Grass breeding should reconsider the metrics used for evaluating grasses, with the current focus on yield under nitrogen fertilisation and cutting of questionable relevance to many upland and hill situations. The over-reliance on ryegrass breeding at the expense of other species should also be rebalanced.

12. After my study tour

My study and time away from the farm has allowed me the opportunity to look at my current business and consider the future direction of the farm. Having addressed succession issues, having a son leaving school and eager to farm, and having finished my term on the board of Hybu Cig Cymru, I have a renewed focus and appetite for concentrating on my own business.

With the uncertainties of trade following Brexit and the ever-declining trend in red meat consumption the decision has been made to sell the suckler cows and the majority of the sheep in favour of a spring calving, grazing-based dairy system, with calves already purchased and planning application submitted for the parlour. A contract has been signed and milking is due to commence on the 1st of April 2020. The lessons learnt whilst travelling and studying my topic has provided me with the necessary tools to increase grass production, utilise it more efficiently and convert it into money in the best possible way for our farm.

Recently there are several national initiatives and projects underway to focus on soil, and two such projects that I have become involved with are the Soil Biology and Soil Health partnership, funded by AHDB and NIAB and other industry partners, and also the Grass and Herbal Leys farm network run by DEFRA, AHDB and ADAS. Both projects are looking at ways of evaluating soils and improving soil health.

I welcome the Welsh Assembly government's approach to tackling water quality issues by setting up a task group involving all interested parties. I attend the NFU Cymru Water Quality Group, and the blue flag scheme proposed by NFU Cymru will allow farmers to input their own data and monitor their pollution risk, and not have the burden of imposed legislation.

We have a duty of care to our next generations to ensure that they also have the opportunity to farm and produce food and care for our natural resources.

Richard Tudor

13. Acknowledgements

My travel schedule was interrupted due to my father's illness and consequently more responsibility and pressure was placed on my family and staff in my absence. I would like to acknowledge the support and encouragement of my wife Catrin, and children, Morgan and Lois, and for accepting that I "had to go" and leave them to it. I would also like to thank Thomos Howells, Des Owen and Morgan for their excellent husbandry and care of the stock in my absence, and for being conscientious at all times.

Both my parents deserve acknowledgement for encouraging me to apply for a Nuffield Farming Scholarship and for their understanding despite the pressures during my father's illness. I would like to thank my father for his role in mentoring and supporting all my ambitions and allowing me the opportunity to express my influence on the farming system from an early age.

The Nuffield Farming experience has been greater than I ever imagined it would be, from the Contemporary Scholars' Conference in Brazil to my personal travel, to the network of friends that I have made along the journey, and the opportunities it has created. For this opportunity and experience I give a special thanks to the Nuffield Farming Scholarship Trust and my sponsor McDonalds, and to Mike and Poey Vacher and the team that were always there to listen and assist in any way possible.

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"We travel because we need to: because distance and difference are the secret tonics to creativity. When we get home, home is still the same, but something in our minds has changed, and that changes everything."

Jonah Leher, The Observer

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