PRIFYSGOL ABERYSTWYTH UNIVERSITY

IBERS
Athrofa y Gwyddorau Biolegol, Amgylcheddol a Gwledig
Institute of Biological, Environmental and Rural Sciences

Cronfa Amaethyddol Ewrop ar gyfer Datblygu Gwledig: Ewrop yn Buddsoddi mewn Ardaloedd Gwledig
The European Agricultural Fund for Rural Development: Europe Investing in Rural Areas

Llywodraeth Cymru
Welsh Government

Gweithio gyda ffermwyr
i wella iechyd pridd

Cynllun
PROSOIL
Project

Working with farmers
to improve soil health

www.prosoilproject.uk

Contents

Introduction

Healthy soil is vital for profitable livestock farming. It supports livestock production from grass, the most important crop in Wales, playing a fundamental role in Welsh food production.

It has key roles in improving the resilience of food production and environmental protection and enhancement.

In 2013 agricultural production from Welsh soils was worth £1,484 million per annum (Welsh Government, 2013).

Good farming and food production begins with the soil, and its impact is felt right through to the eating quality of the final product by the consumer.

Better soil management can help improve the quality and quantity of grass and forage produced, the carrying capacity of the land, nutrient use efficiency, water and flood management, product quality and financial efficiency.

This booklet aims to provide an insight into the PROSOIL project, developed through collaboration between farmers and IBERS scientists to promote the importance of healthy soils on livestock farms in Wales. It highlights opportunities to manage soil for improved grass and livestock production and positive environmental impact.

Acknowledgement

The IBERS PROSOIL Project team wish to thank the farmers and stakeholders for their collaboration in developing innovative ideas at farm and plot level and for their continued commitment to measuring, recording and sharing ideas throughout the project.

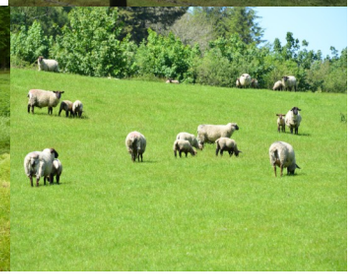
We would also like to thank and acknowledge the funding received through the Rural Development Plan for Wales 2007-2013, which is supported by the Welsh Government and the European Agricultural Fund for Rural Development.

Contact us:

email: prosoil@aber.ac.uk

@ibers_prosoil

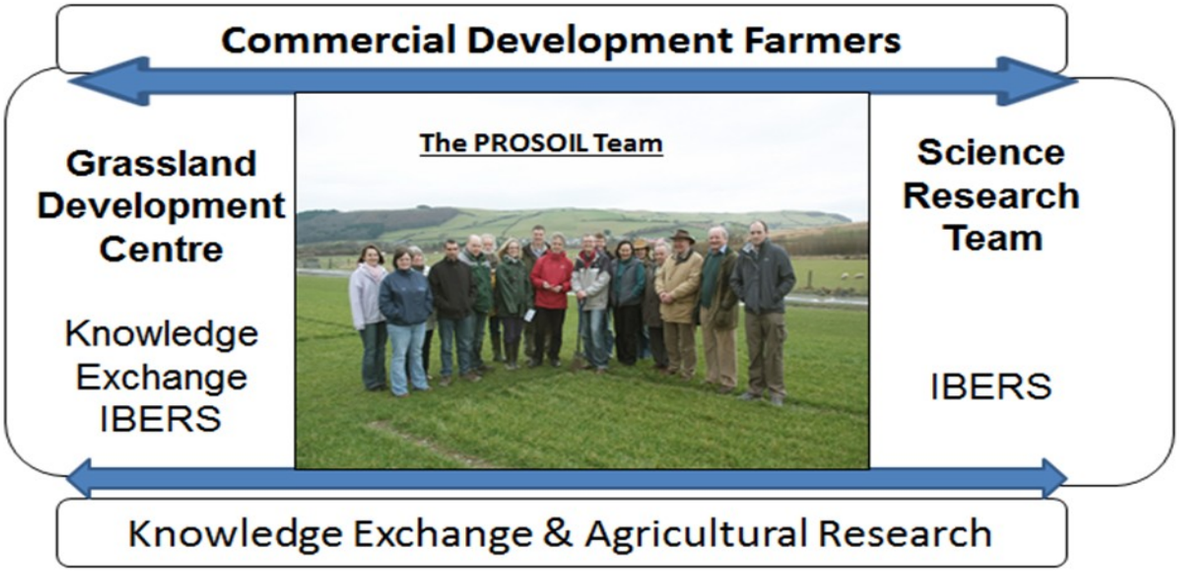
www.prosoilproject.uk



PROSOIL Project

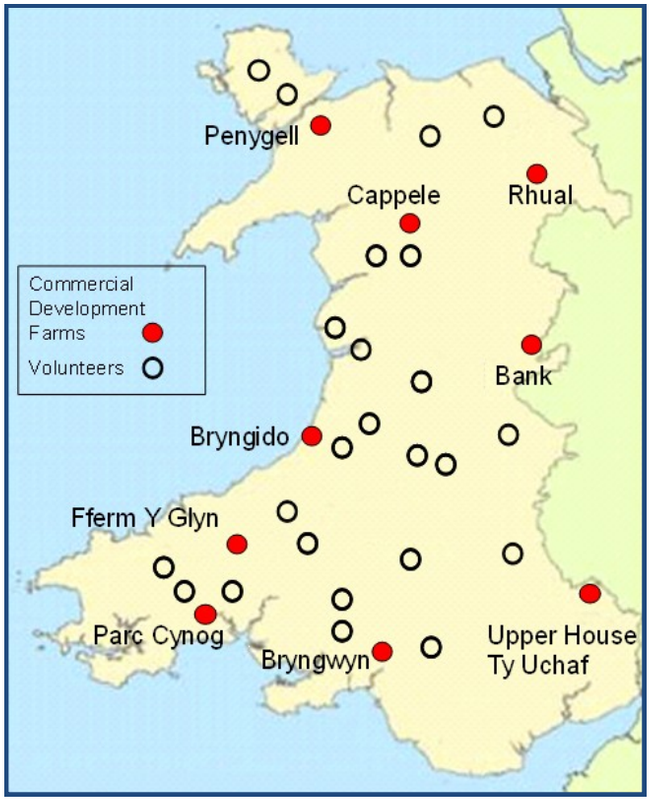
The IBERS PROSOIL project evolved as Welsh livestock farmers and IBERS scientists sought to tackle the many challenges of soil management. Taking an innovative approach it linked scientific research in soil management techniques to farm practice bringing together commercial livestock farmers, IBERS scientists and knowledge exchange staff.

The project launch at the 2010 Royal Welsh Show received an enthusiastic response with over 30 livestock farmers volunteering to take part in the project as PROSOIL Commercial Development Farmers. These were narrowed down to nine to give a good spread of farm, soil type, geographic region and soil management approaches.



Commercial Development Farmers taking part in the PROSOIL project

Soil management techniques suggested by the Commercial Development Farmers developed into experiments completed at IBERS, with each Commercial Development Farmer trying one at field scale and actively measuring the effect on soil health. The IBERS plot work allowed robust scientific measurements to be made comparing the various approaches. The results were shared with the original volunteer farmers and the wider farming industry through newsletters, website, factsheets, agricultural shows and five Regional Development Groups.



Regional Development Groups

Building on the measurements taken on the Commercial Development Farms and the enthusiasm of the original volunteer farmers, five Regional Development Groups were set up across Wales in 2014, covering North East, North West, South East, South West and Mid Wales. Group participants took part in activities on their own farms, including monitoring soil temperature, counting earthworms, and analysing soil, manure and compost. These were related to a range of soil management issues and formed the basis for discussions at the Regional Development Group meetings held in each region.

NW Group

NE Group

Regional Development Group Topics

- Soil slices
- Earthworm counts
- Soil temperature
- Solving compaction
- Deep rooting crops
- Min till and ploughing
- Soil and manure analysis
- Multispecies leys

Mid Group

SW Group

SE Group

Bank Farm Case Study: Digestate

Bank Farm, Mid Wales

Clive and Nina Pugh were keen to take part in the PROSOIL project to look at the effect of applying the liquor separated from digestate on soil health.

Soil: Silty clay loam and silt loam.

Farm: 132 ha (325 acres) with additional rented land; dairy, arable and sheep enterprises.

Clive built an anaerobic digester which uses clean waste feed stocks to produce biogas. The digested feed stocks form "digestate" which is separated into liquor and fibre before being spread on the land.

Clive Pugh

At **Bank Farm** liquor was squeezed out of the digestate and applied to some of the land in the PROSOIL project. Analysis showed that the nutrient content of the liquor varied between years. Soil pH was also analysed to examine the effect of liquor and lime applications on soil acidity.

Using digestate liquor

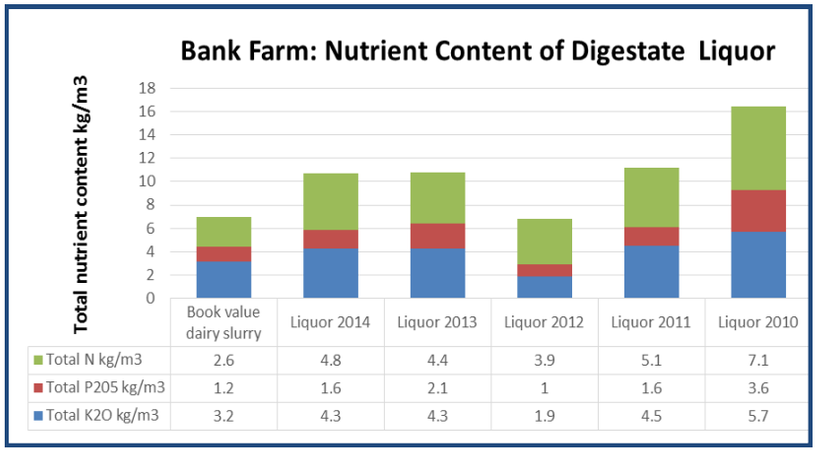
At **Bank Farm**, liquor always had more nutrients than the "book value" for dairy slurry and was worth between £10 and £20 more.

- Analyse liquor for pH, nitrogen (N), phosphate (P), and potash (K) regularly; the nutrient content depends on the nutrient concentration of the feed stock.
- Adjust nutrient applications based on liquor and soil analysis to meet grassland needs as detailed in Defra Fertiliser Manual RB209.
- The nutrients in liquor are more readily available than those in farmyard manure and slurry.

£ Value per 4.5 m^3 (1000 gal)	
2014	32
2013	32
2012	22
2011	34
2010	50

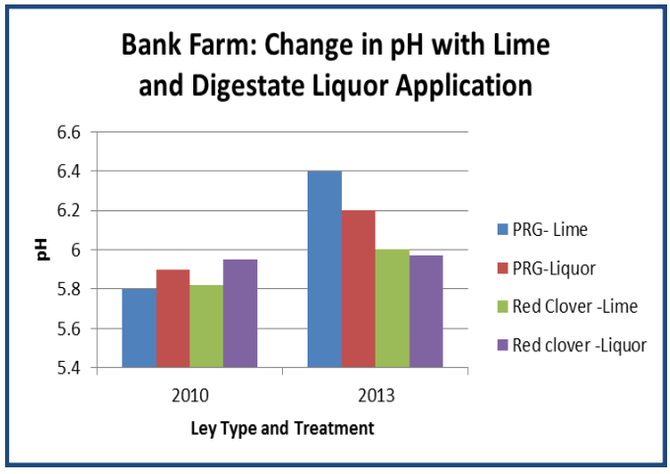
Clive Pugh: "Through being part of the PROSOIL project I have found out how much the analysis of the liquor varies depending on the nutrient value of the feedstock, and that using the liquor is not adversely affecting earthworm numbers."

Anaerobic digester at Bank Farm



Digestate liquor and soil pH

Soil pH is a measure of the acidity or alkalinity of the soil and it affects the availability of nutrients to plants. The ideal pH for optimum nutrient availability in grassland is 6.0-6.2. The liquor at **Bank Farm** was alkaline with pH ranging from 7.6-8.1. As part of the PROSOIL project a red clover ley and perennial ryegrass ley were split and either up to 44 m^3/ha (9700 gal) digestate or 1 tonne / ha/yr (0.4 t /ac/yr) ground limestone were applied each year. The pH was monitored over 3 years and the soil became less acid with both lime and digestate applications at **Bank Farm**.



Earthworm numbers

Earthworm numbers are an indicator of soil health. Clive dug holes and counted earthworms regularly. Applying liquor did not negatively affect the earthworm count at **Bank Farm**. On the PROSOIL farms the highest earthworm numbers were usually found in October.

Economics

Earthworm activity creates soil and we can put a financial value to this from the numbers of earthworms in the soil. At **Bank Farm** the value of soil formation by earthworms was estimated under different managements below.

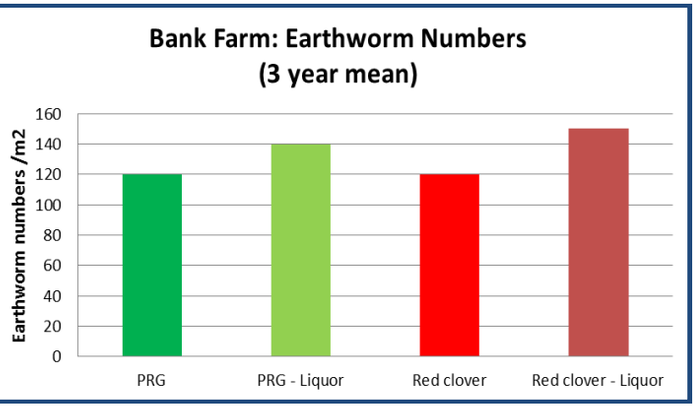
	£/ha/yr	£/ac/yr
Ryegrass with no digestate	3.67	1.50
Red Clover and digestate	4.51	1.83

The value of nutrients

- The value of nitrogen fixed by red clover at 150 kg/ha (60 kg/ac) = £123 /ha (£50 /ac)
- Benefit of applying digestate at 13.5 m^3/ha (1200 gal/ac) valued at £33 /4.5m^3 (1000 gal) = £247 /ha (£100 /ac)

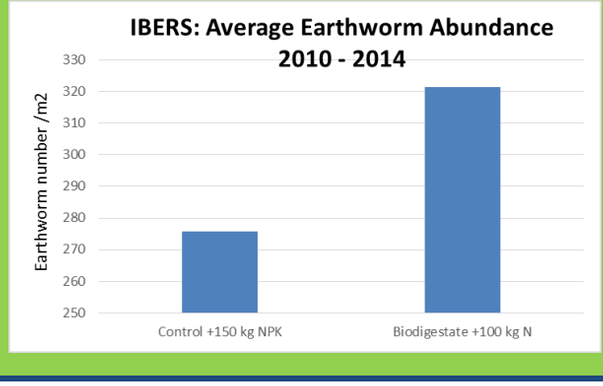
*Slurry analysis: 3.37% DM; 1.66 kg N/m^3, 1.45 kg P/m^3, 5.18 kg K/m^3 at N (80p /kg), P (66p /kg) and K (47p /kg) (Dec. 2014)

Clive Pugh: "We can't change the weather but if we take care of our soil, it will take care of us when the rain comes."



IBERS PROSOIL Project Research Link

At IBERS earthworm numbers were significantly higher in soils under plots which had received digestate compared to the control +150 kg/ha NPK.



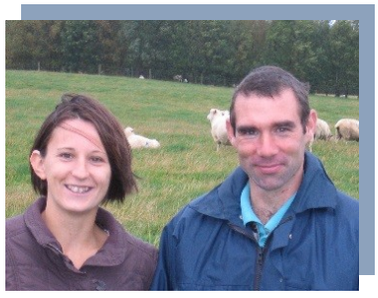
Bryngido Case Study: Multispecies Ley

Bryngido, West Wales

Anwen and Rhodri Hughes volunteered to take part in the PROSOIL project. They wanted to try growing a multispecies ley as an alternative to a perennial ryegrass ley and look at its effect on the soil whilst seeing if it helped to meet their objective of "producing twin lambs with minimum concentrates that weigh the same as the ewe by weaning."

Soil: Silt loam.

Farm: 57 ha (140 acres) grassland
480 Highlander ewes and pedigree Lleyns
Welsh Black Cattle

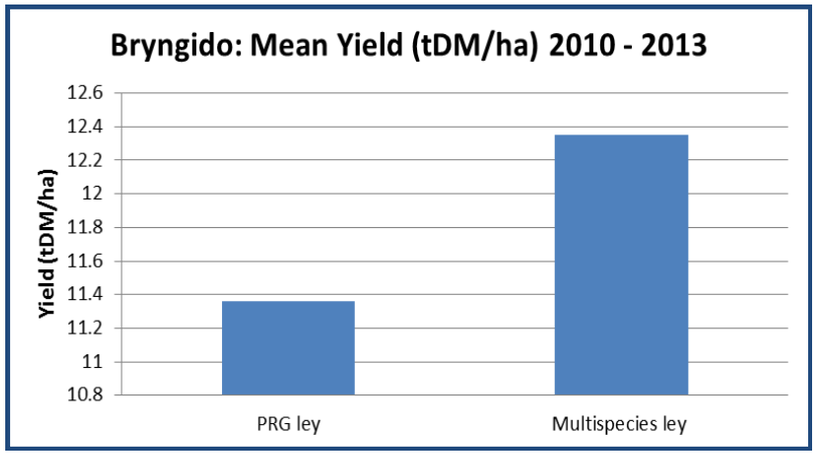


Anwen and Rhodri Hughes

At **Bryngido** a multispecies ley mix (ryegrass, four different clovers and a range of pasture species, including sainfoin, chicory, yarrow, and ribwort plantain) gave higher yields and developed deeper roots than the perennial ryegrass (PRG) ley. Trace element levels tended to be higher in the multispecies ley and Anwen and Rhodri observed that sheep preferred to graze it.

Multispecies ley

Ribwort plantain



Rhodri and Anwen Hughes: "Through being a PROSOIL Commercial Development Farm we've learned that different leys can have a role to play in our future management. On our farm the sheep preferred to graze the multispecies ley rather than the ryegrass ley".

Why consider a multispecies ley?

- Provide diversity and boost ley yields
- Increase forage intake and improve livestock performance
- Enhance the protein content and fix nitrogen with legumes
- Potential to improve mineral content

Select forage species suitable for your soil type, e.g. timothy on heavy soils, chicory on drought-prone soils
Ensure soil pH, phosphate (P), potash (K), and soil structure are optimum for successful establishment

Economics

Earthworm activity creates soil and we can put a financial value on this from the numbers of earthworms in the soil. At **Bryngido** the value ranged from £4.40-£5.60 /ha/yr (£1.78-£2.27 /ac/yr).

From the yield and relative feed value the multispecies ley was worth over £30 /ha (£12 /ac) more than the ryegrass only ley and gave 900 extra ewe grazing days per year.

	Yield tDM/ha	Yield tDM/ac	Relative feed value £/tDM*	Forage Value (£/ha)	Forage Value (£/ac)
Multispecies ley	12.4	5	226	2,802	1,134
Ryegrass ley	11.5	4.7	241	2,771	1,121

At **Bryngido** there was an economic benefit to sowing multispecies ley compared with a ryegrass ley

10 ha of the multispecies ley could provide 45 additional grazing days for 200 ewes compared to a ryegrass ley

*Relative feed value compared to barley and soya at £125 /t and £350 /t respectively

Root structure in multispecies leys

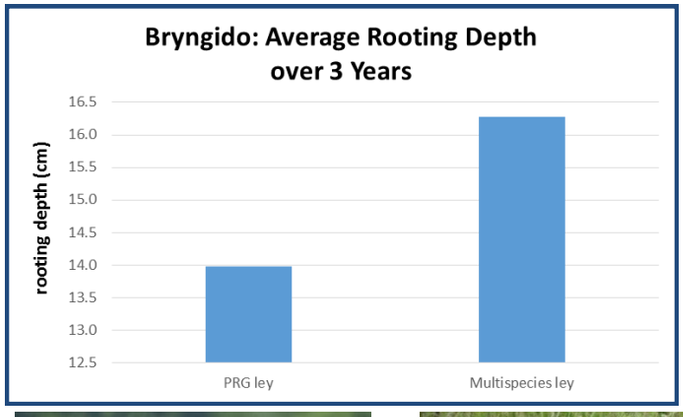
The diverse root structure in a multispecies ley can improve uptake of plant nutrients and water, soil structure and nutrient cycling within the soil. Deep tap roots may have a role to play in breaking up compacted layers in the soil.

The roots in the multispecies sward at **Bryngido** were longer than those in the perennial ryegrass ley**.**

Examples of Diverse Root Structure:

Tap Root (left)
e.g. ribwort plantain

Fibrous Root (right)
e.g. grass



Rhodri and Anwen Hughes: "Learning from other farmers on the PROSOIL project farm network has made us think about the soil, including compaction and its effect on grass yields. We want to build on what we have learned and improve our soil structure as we have discovered that some of our fields are compacted. We hope to use more clover and grow multispecies leys again to improve the soil structure and reduce the amount of applied nitrogen."

Red clover in a multispecies ley

White clover and ribwort plantain in a multispecies ley

IBERS PROSOIL Project Research Link

Analysis of red and white clover and chicory as part of the PROSOIL project showed higher levels of some minerals and trace elements than in perennial ryegrass over two harvest years (see pp. 34-35).

Bryngwyn Case Study: Deep Soil Aeration on Reclaimed Soils

Bryngwyn, South Wales

Jeremy and Mike Tancock were keen to take part in the PROSOIL project to look at the effect of deep soil aeration on heavy soils.

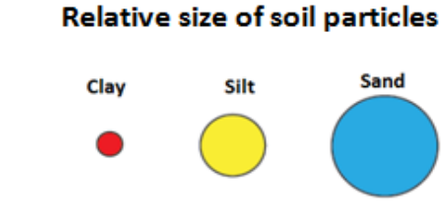
Soil: Clay loam.

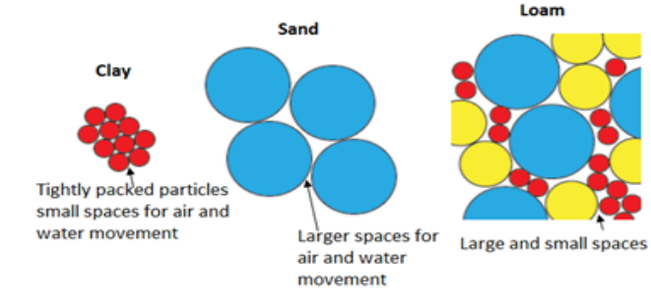
Farm: 121 ha (300 acres), beef and sheep around 218 m (720 ft). The soil, restored after opencast coal mining, is very wet despite the installation of field drains. The project looked at the effect of deep aeration on soil health.

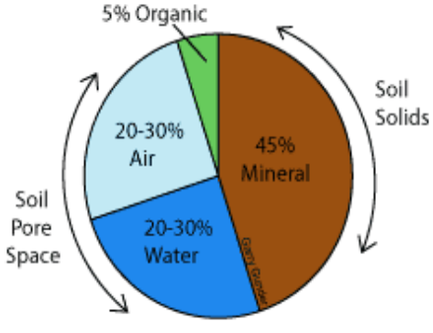
Jeremy Tancock

Subsoiler at Bryngwyn

Clay particles are very small and closely packed, with small air spaces between them which slow down air and water movement. As a result clay soils hold water, drain slowly after rain, and compact easily, so are prone to poaching and are difficult to cultivate. They are also slow to warm up in spring, delaying plant growth and leading to a short growing season. The high water content and small air spaces affect root health and growth and soil life. On the plus side, clay soils hold nutrients well.







Jeremy Tancock: "Over 3 years the average soil moisture during autumn sampling at Bryngwyn was 50%. The soils on the majority of PROSOIL farms contain around 30%. At Bryngwyn deep aeration did not reduce soil wetness."

Grassland subsoiler

Economics

Earthworm activity creates soil and we can put a financial value to this from the numbers of earthworms in the soil. At **Bryngwyn** the value of soil formation by earthworms was estimated at between £6.09 and £8.04 /ha/yr (£2.50 and £3.25 /ac/yr).

Deep aeration is expensive and the benefit on a restored opencast coal mining area is short term and financially difficult to justify. However when the soil was aerated, there was a tendency for earthworm numbers to rise.

Deep aeration using a vibrating sub-soiler costs approximately £40-55 /ha (£28 /ac).

Day to day management of heavy clay soils

- Minimise the use of machinery on the land
- Create tracks for livestock and machinery
- Only drive on the land when absolutely necessary and in dry weather
- Improve soil organic matter content using compost or farmyard manure
- Apply lime to maintain a pH of 6-6.2
- Minimise ploughing
- Consider long term leys to protect soil structure and earthworm numbers
- Use on-off grazing
- House livestock whenever heavy rain is forecast or land becomes damp and soft
- Regularly maintain in-field ditches and drains

Wheeling damage

"The Squelch Test" guide to risk of soil compaction by livestock and machinery

Walk across the field and note how the ground feels underfoot; use the chart below to identify the risk of soil damage by livestock of machinery.

1. Baked hard	2. Dry on top	3. Damp and firm	4. Damp and soft	5. Squelchy in patches	6. Squelchy all over	7. Very soft	8. Water-logged

Good condition ⟷ Poor condition

Condition 1 - 3: the soil is suitable for stocking and trafficking with low risk of damage Adapted from Scottish Farm Soils Plan		Condition 6 – 8: stock or traffic on the land could result in significant soil damage
	Condition 4 – 8: the soil is increasingly likely to suffer from compaction and rutting	

Field drainage

- Works well on a slope of more than 4%
- Improved if combined with regular subsoiling
- Consider reverting land with a slope of less than 3% to a wetland habitat
- Use a cost-benefit analysis to determine if drainage or reversion is the best option

Compaction

Compaction is expensive! See p. 31.

Remember:

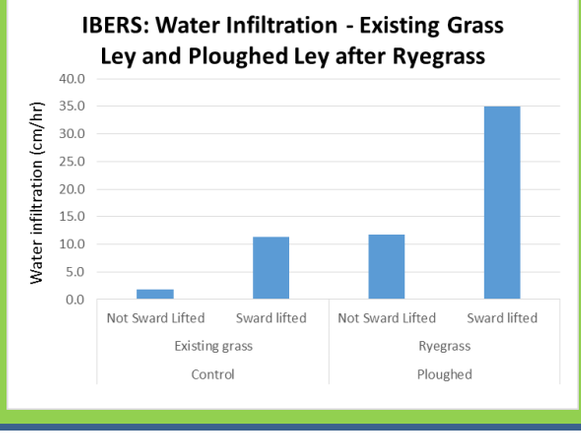
- The wetter the soil, the deeper the compaction
- The heavier the soil, the deeper the compaction

Deep compaction is more expensive to correct.

IBERS PROSOIL Project Research Link

IBERS PROSOIL research studied the effect of sward lifting on an existing ley and a ploughed ley.

Water infiltration was greater on the sward lifted plot.



Cappele Case Study: Trailing Shoe Slurry Application

Cappele, North Wales

Sion Williams was keen to take part in the PROSOIL project to look at the effect of trailing shoe slurry application on soil health.

Soil: Silt loam; prone to seasonal water-logging.

Farm: 239 ha (590 acres) upland organic beef and sheep farm at 300-487 m (1000-1600 ft), 840 Welsh mountain ewes and 85 suckler cows plus agricultural contracting business.
Farm rotation includes swedes, arable silage, wholecrop and clover leys.

Heather McCalman (IBERS) with Sion Williams (Cappele)

Slurry is a key source of nutrients for grass and forage crops at **Cappele**. In the PROSOIL project a trailing shoe was used to spread slurry as it enables more of the nitrogen in the slurry to be used by the plants than if spread by a splashplate. Sion aerated the soil to reduce compaction and increase the spaces between the soil particles to support soil organisms, water and air movement.

Benefits of trailing shoe slurry application

- Reduced ammonia losses and improved slurry nitrogen (N) use efficiency
- More available spreading days and less odour
- Can be applied closer to silage making if the nitrogen can be used by the growing crop
- Stock can re-graze more quickly with less sward rejection and better utilisation
- Less risk of transferring diseases from slurry to livestock
- Eligible for Glastir Entry Points

Make the most of slurry

- Apply to fields that need the full nutrient content of slurry
- On livestock farms these are silage or cropping fields where nutrients are removed with each harvest. In grazing systems, nutrients are recycled by the stock via dung and urine returns to the soil
- Balance crop needs with crop offtake to prevent nutrient surpluses building up
- Check soil indices by regular analysis and sample slurry to see how much nitrogen (N), phosphate (P) and potash (K) it contains, so that nutrient planning can be done effectively
- To make the best use of N apply when the crop is actively growing and N demand is greatest, e.g. early spring

Sampling slurry for analysis

To get a representative sample take at least five sub-samples of 2 litres, pour into a large container, stir thoroughly and pour a 1-litre sample immediately into a clean sample container.

Above-ground stores: Stir slurry and sub-sample from the reception pit or where there is safe access from an operator's platform, e.g. sample using a weighted 2-litre container attached to a rope.

Below-ground pits: Sub-sample at points using a weighted container.

Earth-banked lagoons: Either agitate the slurry and take sub-samples from a valve on a stationary tanker or irrigator during field spreading, or sample direct from the lagoon where there is a safe, secure operator's platform.

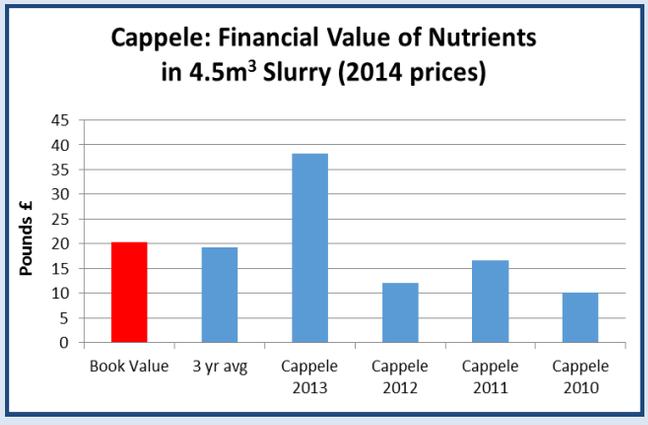
Sion Williams: "What I'd like to see at Cappele are healthy soils giving us quality grass and conserved forage from minimal inputs. We also want to make the most of our slurry and apply it using a trailing shoe."

Economics

Earthworm activity creates soil and we can put a financial value to this from the numbers of earthworms in the soil. At **Cappele** the value of soil formation by earthworms was estimated at between £6.70 and £10.30 /ha/yr (£2.70 and £4.17 /ac/yr).

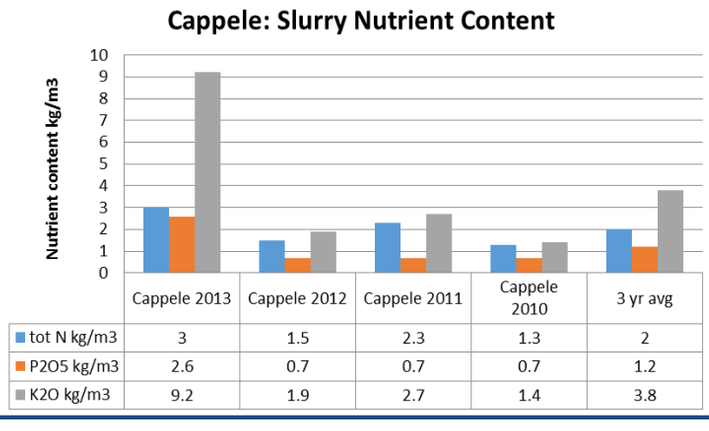
The value of nutrients

Understanding the nutrient content is key to providing the right nutrients to optimise crop growth and/or adjust yield expectations on an organic farm where nutrients may be limiting. Slurry applied by trailing shoe or injection gets more plant-available nitrogen into the soil and is one of the farm's chosen prescriptions in the Glastir agri-environment scheme.



- Value of 4.5 m^3 (1000 gal) slurry = £21.45*
- The value of the nutrients in 9 m^3 (2000 gal) of this slurry covered the analysis costs of £40
- As the main source of nutrients on an organic farm, it is vital that slurry is analysed in order to make the most of the N, P and K and maintain yield and profitability
- Dry matter ranges from 3 to 16% and affects nutrient content, storage and spreading costs
- Analysis showed that the nutrient and financial value of the slurry varied considerably between years. In 2013 the slurry contained more than 6 times more P and K per 4.5 m^3 (1000 gal) than in 2010

*Slurry analysis: 3.37% DM; 1.66 kg N/m^3, 1.45 kg P/m^3, 5.18 kg K/m^3 at N (80p /kg), P (66p /kg) and K (47p /kg) (Dec. 2014)



	Cappele 2013	Cappele 2012	Cappele 2011	Cappele 2010	3 yr avg
tot N kg/m3	3	1.5	2.3	1.3	2
P2O5 kg/m3	2.6	0.7	0.7	0.7	1.2
K2O kg/m3	9.2	1.9	2.7	1.4	3.8

NIRS (Near Infra-red Reflectance Spectrometry) offers a rapid, reliable, cost effective slurry analysis

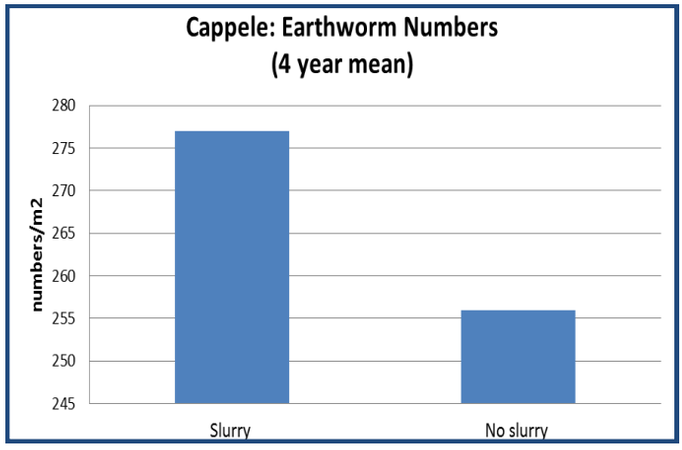
Slurry Gases can kill: Lethal gas is released from slurry as it is mixed.

Do not enter a slurry pit, reception pit, stand above a slurry tank or lean into a slurry pit.

Looking after soil biology at Cappele

One area of a field received regular applications of slurry and one area received none; the earthworm population was higher on the area receiving the slurry.

Sion and Ceinwen Williams: "We've learnt a lot through being part of the PROSOIL project, especially the importance of soil biology and the need to protect and respect the soil if we are to get the best returns from it."



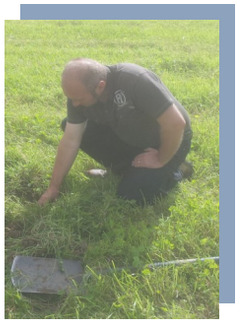
Fferm Y Glyn Case Study: Lime and Soil Aeration

Fferm y Glyn, West Wales

Aled Rees volunteered to take part in the PROSOIL project in 2014 to examine farm soils and explore different management options including small regular applications of readily available prilled lime and shallow aeration.

Soil: Loamy sand.

Farm: 105 ha (260 acres) mixed cattle, sheep and arable at 60 m (150 ft) plus an organic dairy unit.
Crop rotation includes ryegrass, winter barley, winter oats and spring wheat.

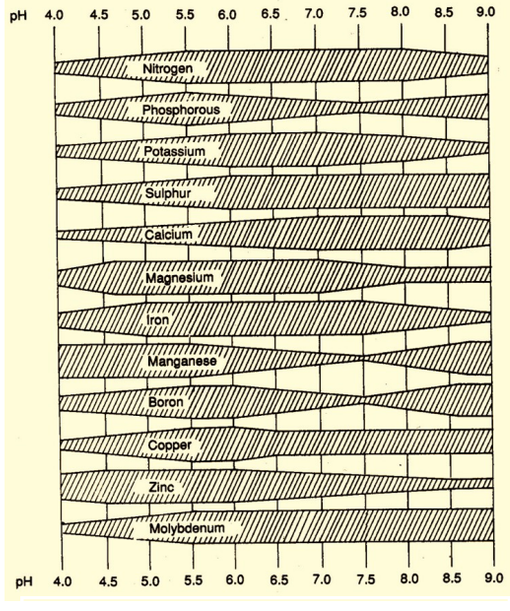


Aled Rees

Applying lime

As an organic farmer, Aled Rees works to optimise soil conditions to make the most of the available nutrients for crop growth. Soil acidity or alkalinity (pH) affects plant nutrient availability and the optimum availability for each nutrient occurs over a specific and narrow pH range. As this is different for each nutrient scientists have worked out the pH which provides the best conditions for nutrient availability for each crop and soil type. Aled tests his soil and applies lime as needed to optimise nutrient availability and crop performance.

Optimum Soil pH		
Soil type	**Mineral soil**	**Peaty soil**
Continuous grass /grass clover	6.0	5.3
Grass with occasional wheat or oat crop	6.0	5.3
Grass with occasional forage crop	6.0-6.5	5.3-5.8
Grass with occasional barley crop	6.2	5.5
Continuous arable	6.5	5.8



Adapted from Troug, E. (1946)

Soil pH and Nutrient Availability
Wider band=greater nutrient availability

Lime

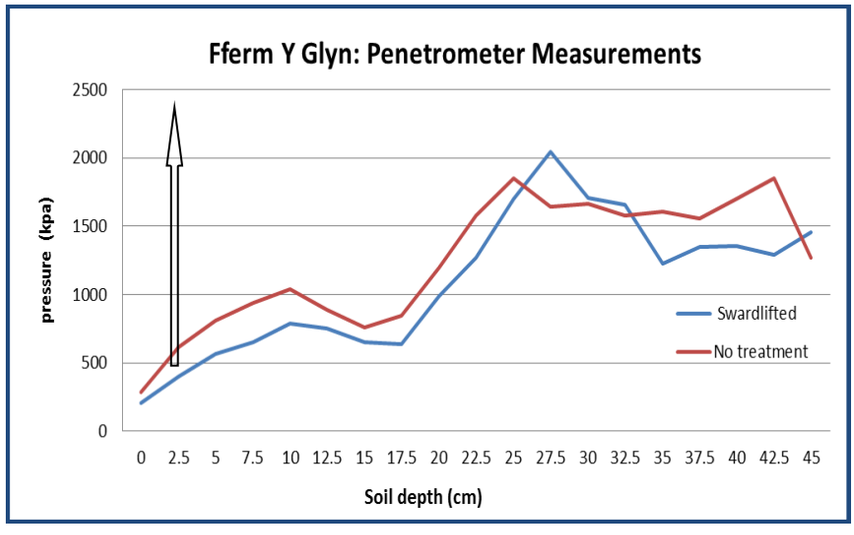
- Test soil acidity regularly, every 3-5 years, and apply lime to optimise nutrient use efficiency, crop yield and quality
- Avoid over application (pH above optimum); it costs money and affects trace element availability in stock and crops
- Effectiveness of liming material depends on neutralising value (NV), reactivity (fineness) and hardness of parent rock
- Calcium and magnesium limestone; NV 50-55 are the most common natural liming agents in Wales
- Granular prilled lime has a similar NV to calcium and magnesium lime
- Calcium lime should be used where soil magnesium (Mg) indices are 3 or above
- Maximum surface application to grassland is 7 tonnes /ha (3 tonnes /ac)
- Spread only when the ground conditions are dry enough to avoid compaction and soil damage

Soil structure

An open soil structure with good levels of organic matter, and soil particles creating small rounded aggregates and plenty of space for air and water movement is ideal for crop growth. Squashed or compacted soil reduces nutrient use efficiency, crop yield and quality (see Bryngwyn case study, pp. 10-11).

Aled was keen to understand whether the deep soils on his farm were compacted and also wanted look at the effect of using a sward lifter. A digital soil penetrometer which measures the pressure needed to push a probe into the ground was used to test for compaction. Root growth of many plants begins to be affected when more than 1,500 kPa pressure needs to be applied with growth stopping at or around 2,500 kPa (USA data).

Penetrometer measurements showed that the soil in the main rooting zone at **Fferm y Glyn** was not compacted, although there was an area of slightly tighter soil below 20-23 cm. Aled also used the penetrometer to measure the effect of a sward lifter on his healthy soils. He found that the penetrometer readings were slightly lower where it has been used, but as root growth is not being inhibited in this area, it is unlikely that there will be a benefit from sward lifting.



Aled Rees: "We joined the PROSOIL project with an interest in knowing more about how to manage our soils and to make the most of them. We're interested in improving soil structure and the health of the soil and are monitoring the effects of aerating and sward lifting some of our pastures".

- Air allows the plant roots, soil animals, insects and fungi to "breathe" and influences the availability of many plant nutrients.
- A healthy soil has at least 25% air, which is found in spaces between soil aggregates.
- A compacted and/or waterlogged soil will have less air space and biological activity.
- Aerating and sward lifting compacted soil can help improve yield and quality where compaction is identified.

Sward lifting and aeration

Taking penetrometer readings at Fferm y Glyn

Parc Cynog Case Study: Aerated Slurry

Parc Cynog, South West Wales

Iori Evans volunteered to take part in the PROSOIL project. He wanted to look at the effect of aerating slurry.

Soil: Silty clay loam.

Farm: 445 ha (1100 acres) with 750 spring calving, grass fed British Friesian cows rearing 220 replacement heifers per year.

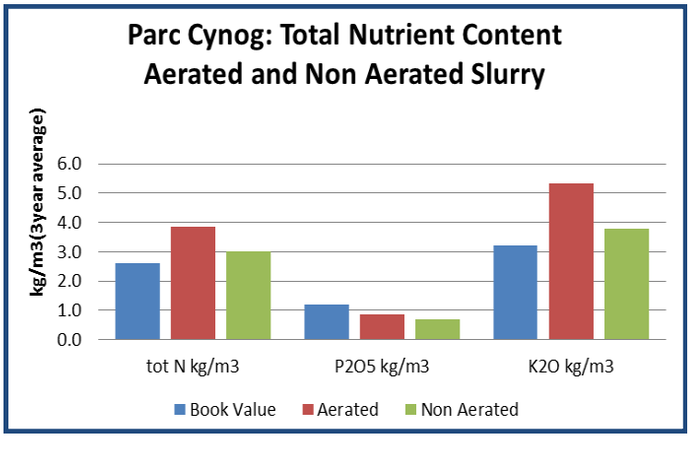
Optimising nutrient management at Parc Cynog

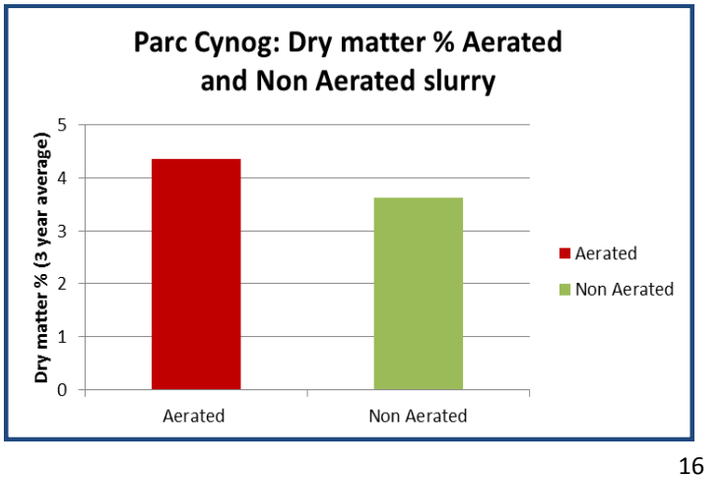
Correct plant nutrient supply, good soil structure and biology are the three key areas which produce healthy soils and good agricultural production.

On grassland, soils with good structure, organic matter levels, a soil pH 6.0-6.2 and phosphate and potash indices at 2 and 2- allow swards to grow well, provided the correct level of nitrogen (N), phosphate (P) and potash (K) is supplied from manures, legumes and fertilisers to meet crop needs for a specific level of production. Slurry is an important source of plant nutrients at **Parc Cynog**, so understanding slurry nutrient content is vital in order to apply the correct level of nutrients and minimise the purchase of bought-in fertiliser. Iori was interested in understanding the effect of aeration on slurry nutrient content. Aerated slurry and non-aerated slurry were analysed for total N, P, K and dry matter.

Dry matter and total nutrient content % of aerated and non aerated slurry

At **Parc Cynog** analysis showed that aerating slurry increased dry matter %, total nitrogen, phosphate and potash.



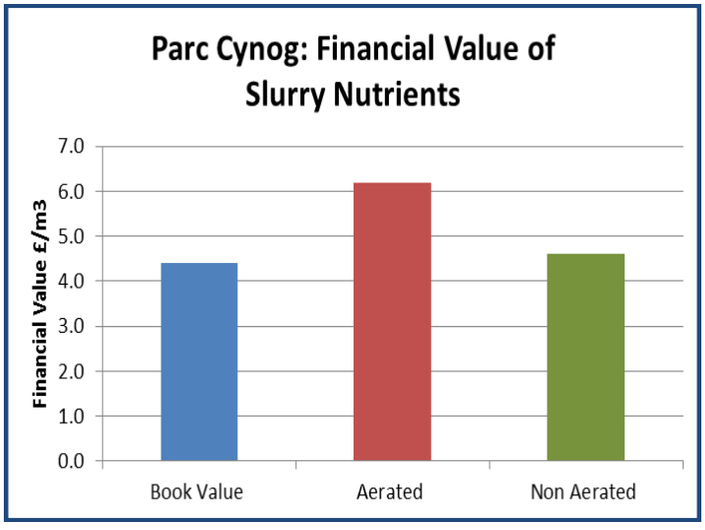


Iori Evans: "Being a PROSOIL Commercial Development Farm has really showed me the importance of the major nutrients for grass production, particularly nitrogen. It would be fantastic for our farm and the industry to see the development of grass that could fix its own nitrogen, like clover and other legumes."

Commercial Development Farms

Why consider aerating slurry?

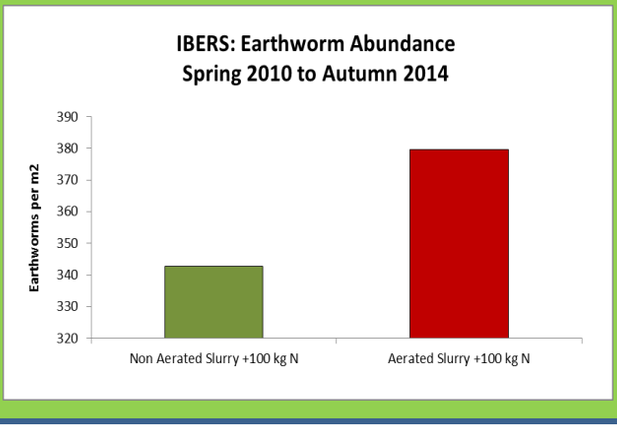
- Higher levels of total N, P and K compared to non-aerated
- Enhanced nutrient content gives greater financial value
- Reduces requirement for bought-in nitrogen
- Consistency - every load is homogenised and has an even distribution of nutrients
- Slurry maintained in an easy-to-manage state
- Low capital cost, maintenance cost and running costs



IBERS PROSOIL Project Research Link

IBERS Research studied the effects of aerated slurry and non-aerated slurry on soil health and herbage yields. Applications of slurry significantly improved yield compared to other treatments.

There was no significant difference in yield or earthworm numbers between aerated and non-aerated slurry applied at the same rate.



Iori Evans: "It has been interesting to see the project develop and its findings. We were surprised at the number and variety of bugs/ worms in the soil. We have also enjoyed the farm visits and the opportunity to speak to fellow farmers."

Economics

Earthworm activity creates soil and we can put a financial value on this from the numbers of earthworms in the soil. At **Parc Cynog** the value of soil formation by earthworms was estimated at £5.84 /ha/yr (£2.36 /ac/yr).

The value of nutrients

- At **Parc Cynog** the aerated slurry was worth £8.90 more per 4.5 m^3 (1000 gallons) than non-aerated slurry
- The average value of 4.5 m^3 (1000 gal) over 4 years was £20, but ranged from £15 to £23, so it is important to analyse it in order to use it effectively
- Analysis costs are quickly recovered
- It costs £112 /ha (£45 /ac) to apply the recommended (RB209) amount of fertiliser for 1st cut silage*
- Applying 23 m^3/ha (2000 gal/ac) of **non-aerated slurry** saves £60 /ha (£24 /ac) on fertiliser for 1st cut silage
- Applying 23 m^3/ha (2000 gal/ac) of **aerated slurry** saves £68 /ha (£28 /ac) on fertiliser for 1st cut silage

Analyse your slurry, which is variable; save on fertiliser and maintain yield
Over or underestimating nutrient content affects yield and profitability

At **Parc Cynog** the aerated slurry was worth £8.90 more per 4.5 m^3 (1000 gal) than non-aerated slurry.

* on soils of P index 2 and K index 2- and N (80p /kg), P (66p /kg), and K (47p /kg) (Dec. 2014)

Penygelli Case Study: Soil Aeration

Penygelli, North West Wales

Alwyn Phillips wanted to look at the effect of shallow aeration using a spiked soil aerator on his soils because he was concerned about shallow compaction.

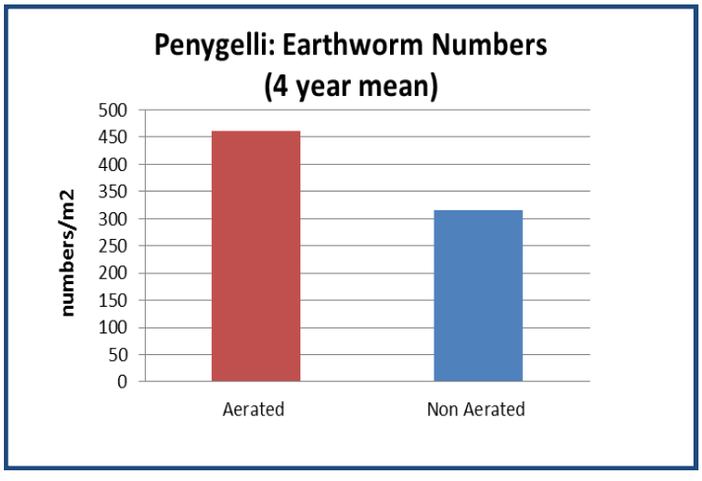
Soil: Sandy silt loam.

Farm: 53 ha (130 acres) with additional rented land
400 ewes, 2 closed flocks:
Poll Dorset: December lambing
Texel: March lambing
Signet recorded, grass fed flock
20 beef cows
Cropping: Barley, oats and fodder beet

Alwyn Phillips

Spiked soil aerator

At **Penygelli** one half of a grazed permanent pasture was aerated. Alwyn dug holes and counted earthworms regularly. He found that the aerated areas had the highest earthworm numbers over a four year period.



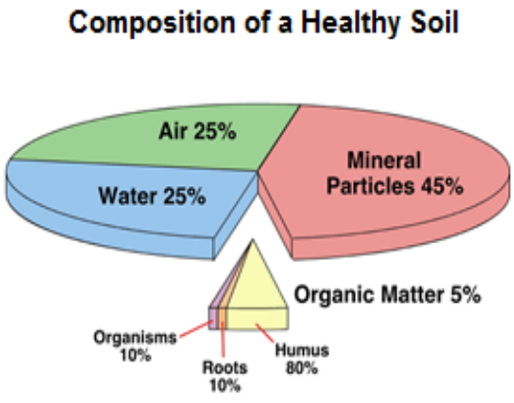
Using a shallow aerator

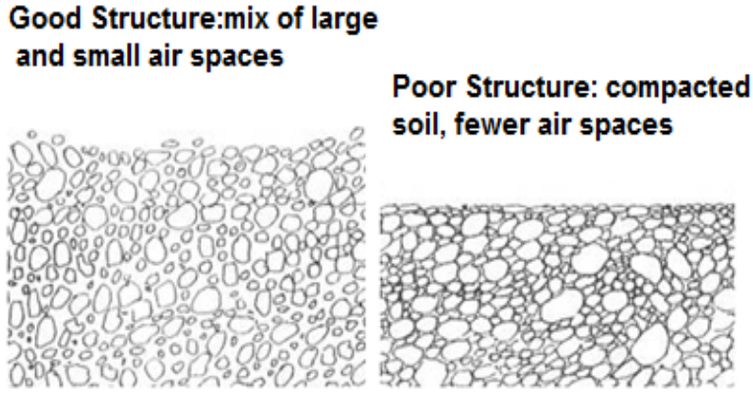
- Dig a hole to see if the soil is compacted in the top 10 cm.
- Aerate only when conditions are correct. Do not aerate when soils are wet and will smear, or when very dry when soil will lose moisture and damage plant roots.
- Where there is no compaction or the compaction is deeper, shallow aeration will not improve soil structure.

Alwyn Phillips: "By volunteering for the PROSOIL project I've learned that successful grass production all starts with healthy soils. Aeration has improved my soils and increased earthworm numbers. When I first started I thought, like most farmers, that having soil analysis based on correct N, P, K, and pH was sufficient. I now know that there are so many other important factors to consider in growing better grass and improving soil structure. My objective now is to put into practice what I have learnt across the whole farm including arable fields. We are told that we must produce more from less and it all starts with a healthy soil."

How earthworms improve soil health

A healthy soil with good structure has around 25% air, 25% water, 45% minerals (sand, silt and clay) and 5% organic matter. Good soils have a mix of large and small air spaces. The air spaces are key to water and nutrient movement, aiding root development and plant growth. Soil can become compacted by livestock and machinery, which decreases the space between the mineral particles, and the amount of air and water within the soil, which affects flow and reduces the movement of nutrients through the soil to plant roots.





Earthworms are soil engineers - they loosen and mix up the soil, creating tunnels both vertically and horizontally and increasing air space between soil aggregates. They also break down and recycle organic matter, move nutrients to the surface and make them more available for plants to use.

All the farmers in the PROSOIL project counted earthworms. Worm casts are rich in recycled nutrients and can hold as much as 5, 7 and 11 times more available nitrogen (N), phosphate (P), and potash (K) than the surrounding soil. There are 3 common groups containing 20+ species of earthworms in the UK. The IBERS team has carried out detailed studies on the earthworm species across a range of soil management treatments (see pp. 36-37).

Economics

Earthworm activity creates soil and we can put a financial value to this from the numbers of earthworms in the soil.

The value of what earthworms do is expressed in pounds per hectare per year of the soil they turn over.

	£/ha/yr	£/ac/yr
No aeration	7.71	3.12
Aeration	15.78	6.39

The cost of spiked aeration is £28 /ha (£11.33 /ac)

Alwyn Phillips: "It has been noticeable over the last four years that sheep have preferred to graze the aerated areas. These areas have shown the greatest increase in the number of earthworms. Could this be due to deeper roots producing more nutritious swards?"

Rhual Case Study: Nutrient Applications

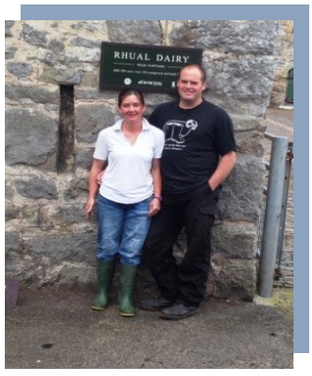
Rhual, North East Wales

John and Anna Booth were keen to take part in the PROSOIL project to understand the effect of lime and nutrient applications on their soils and grazed swards.

Soil: Sandy silt loam. Farm in NVZ.

Farm: 233 ha (575 acres) at 325 m (800 ft), running 300 dairy cows, 150 young stock and a 100 poll Dorset ewes.

Cropping: 190 ha (470 acres) perennial ryegrass leys plus maize and whole crop for silage.

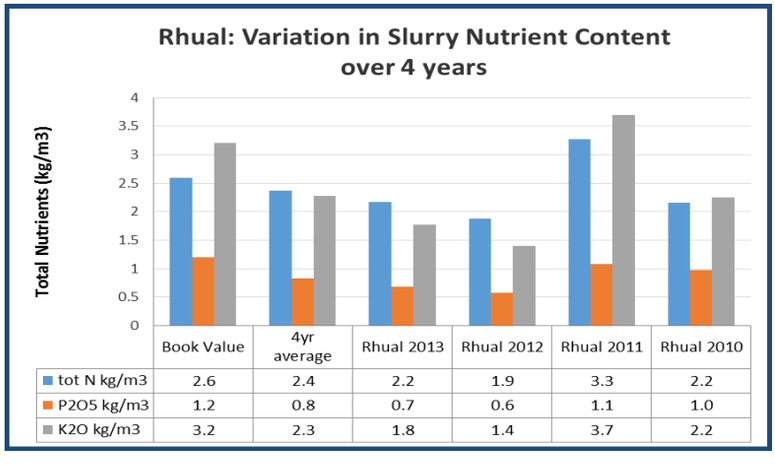


John and Anna Booth

John and Anna aim to maximise milk from grazing

John and Anna have cut fertiliser use by over 30% in the last 12 years at **Rhual** by making the most of slurry. Key to this has been to have the slurry analysed. Analysis showed the slurry was extremely variable with dry matter ranging from 2.6 % to 10.7% and total value of the nutrients ranging from £11.23-£22.34 per 4.5m^3 (1000 gal) at December 2014 fertiliser prices.

They have worked to improve soil health as this is important in optimising nutrient use efficiency. This has helped them achieve their target of increasing milk yield as efficiently as possible whilst complying with NVZ regulations.



	Book Value	4yr average	Rhual 2013	Rhual 2012	Rhual 2011	Rhual 2010
tot N kg/m3	2.6	2.4	2.2	1.9	3.3	2.2
P2O5 kg/m3	1.2	0.8	0.7	0.6	1.1	1.0
K2O kg/m3	3.2	2.3	1.8	1.4	3.7	2.2

John and Anna Booth: "We are trying to maximise milk yield from grazing without compromising on cow health and fertility. We love seeing our cows at grass; they are happy, which means we are happy! It is essential that the right grass varieties and soil structure are managed well."

Rhual: making the most of soil nutrients

Regular soil analysis highlights pH, phosphate, potash and magnesium levels and guides lime, slurry and fertiliser applications.

Digging holes and counting earthworms helps to identify soil issues/compaction and is an indicator of soil health.

Slurry analysis shows the variability in nutrient content between years, so that adjustments can be made to application rates to meet crop needs more accurately whilst complying with NVZ rules.

Applying slurry via a trailing shoe maximizes the use of available nitrogen in slurry. It has also helped gain entry into the Glastir scheme which reduced slurry damage to the leys and stopped the smell of slurry causing concern.

Preparing maize stubble for planting forage rye

Heifers grazing forage rye

Commercial Development Farms

Economics

Earthworm activity creates soil and we can put a financial value on this from the numbers of earthworms in the soil. At **Rhual** the value of soil formation by earthworms was estimated at between £2.63 and £3.39 /ha/yr (£1.06 and £1.37 /ac/yr).

The value of nutrients

- 4.5m^3 (1000 gal) slurry with highest nutrient content (2011) was worth £24.50*
- The value of nutrients in 7.3m^3 (1600 gal) of this slurry covered the analysis costs of £40
- On soils with P index 2 & K index 2- applying the recommended amount of fertiliser (RB209) for 1st cut silage costs £112 /ha (£45 /ac)

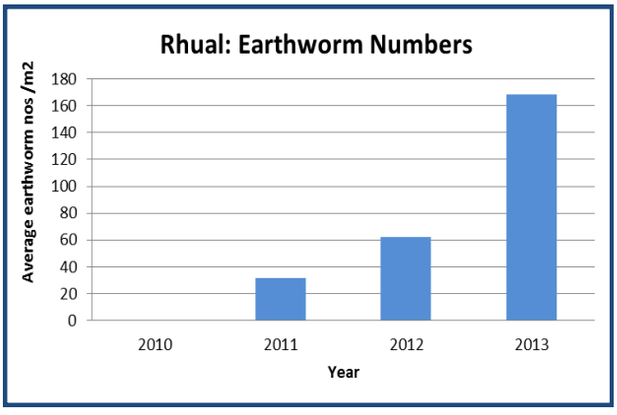
Savings of £80 /ha were made on fertiliser costs by applying 11.4m^3 (2500 gal) slurry (2011 analysis) to replace fertiliser nutrients.

Analyse your slurry which is variable, save on fertiliser and maintain yield
Over or underestimating nutrient content affects yield and profitability

* on soils of P index 2 and K index 2- and N (80p /kg), P (66p /kg), and K (47p /kg) (Dec. 2014)

Benefits of earthworms

- Aerate the soil
- Increase number of large soil pores, water and air spaces
- Improve water infiltration
- Breakdown dead plant material
- Concentrate plant nutrients
- Create channels for root growth
- Mix and create a more stable soil
- Spread nutrients throughout the profile
- Control soil borne pests



John and Anna found that white clover content increased when they applied less nitrogen fertiliser on grazed land. White clover can supply up to 150 kg/ha (61 kg/ac) of N/yr and improve soil structure. It is important to get the correct balance of grass to clover to optimise sward and livestock performance; aim for an average of 30% over the season (10% early season rising to 60% late summer).

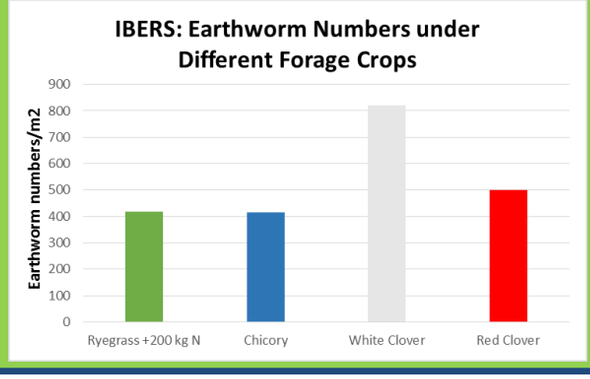
How to increase earthworm numbers

- Consider min till and reduce cultivations particularly in autumn when earthworms are breeding
- Apply manures and composts rich in organic matter
- Increase diversity of plant species e.g. grass and legume, multispecies ley and sound rotation, grass margins in arable fields
- Lime to maintain soil pH around 6.0-6.2
- Limit the use of pesticides
- Correct soil compaction and improve drainage

John and Anna Booth: "In the future we aim to continue increasing milk yield and continue to enjoy farming. We also plan to be more self-sufficient and grow more feed/ bedding materials rather than relying on buying them in. It is very important that we look after the soils if we want to do this."

IBERS PROSOIL Project Research Link

PROSOIL research showed that earthworm numbers are significantly greater in soil under white clover than perennial ryegrass.



Upper House/Ty Uchaf Case Study: White Clover

Upper House/Ty Uchaf, South Wales

John and Hilary Garn were keen to take part in the PROSOIL project to look at the effect of increasing the content of white clover in their pastures on their soils. The farm has now been taken over by Tom and Kate Pitts-Tucker.

Soil: Fine red silty clay loam.

Farm: 4.5 ha (11 acres) small holding at 182 m (450 ft) provided grazing for the Garn's pedigree flock of Black Welsh Mountain sheep.

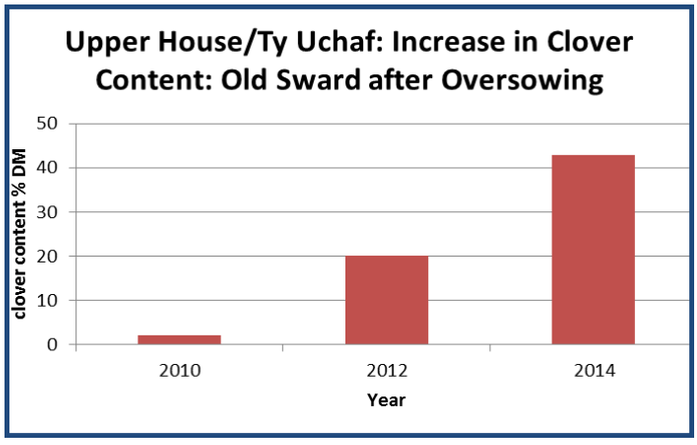
John and Hilary Garn with Huw Powell of the PROSOIL project

Slot seeding clover into an old sward at Upper House/ Ty Uchaf

At **Upper House/Ty Uchaf** white clover was oversown into an old sward after a hay cut following harrowing to expose the soil. Clover content was monitored regularly and increased each year of the project. Ideally the white clover content should be maintained at an average of 30% sward dry matter over the season to achieve the optimum protein : energy balance for ruminant livestock.

Benefits of white clover in grazing swards

- Improved soil porosity and water infiltration
- Better fertiliser/nutrient recovery
- Nitrogen fixation; equivalent to up to 150 kg N/ha (61 kg N/ac)
- Increased forage intake and digestibility
- Improved sward crude protein content
- Higher content of key minerals
- Greater species diversity, nectar for bees
- Higher sward yield



Improving sward clover content by oversowing

John and Hilary Garn: "The addition of clover has resulted in more even grazing by the flock across our fields."

- Check and correct soil pH, P and K indices
- Solve soil compaction and poor drainage
- Aim to oversow after a hay or silage cut when sward is open
- Harrow to create at least 25% bare soil
- Use a specialist grass seed drill or broadcast
- Broadcasting: mix the seed with sand or fertiliser in the hopper immediately before sowing
- Oversow in the early autumn while soils are moist and warm
- Roll and roll again
- Graze until the seedlings emerge (normally 7-10 days)
- Remove the stock and rest the area for 4-5 weeks
- Graze hard to a sward height of 4 cm and rest again
- Repeat grazing /rest cycle until grass growth stops

Cost of grassland renovation around £45 /ha or £15 /acre

Earthworm numbers at Upper House/Ty Uchaf

Earthworm numbers are an indicator of soil health. Three years after oversowing clover at **Upper House/Ty Uchaf**, the number of earthworms, counted in October, had doubled from 50 /m^2 to 100 /m^2. Improved earthworm numbers were also seen in IBERS plots under white clover.

Counting earthworms

Earthworm numbers vary during the year and are generally lowest during the summer months and highest in the autumn. Dig a hole, a spade width by a spade depth. Take the block of soil from the hole, break it up, count and record the number of earthworms. Carry out the earthworm count at the same time each year in order to get a year on year comparison of earthworm numbers.

Economics

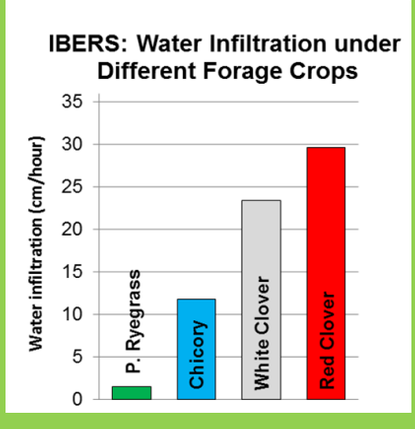
Earthworm activity creates soil and we can put a financial value to this from the numbers in the soil.

At **Upper House/Ty Uchaf** the value of soil formation by earthworms was estimated at between £2.12 and £3.34 /ha/yr (£0.86 and £1.35 ac/yr)

- The value of fixed nitrogen from white clover at **Upper House/Ty Uchaf** ranges between £50 and £100 / ha/yr (£20 and £40 /ac/yr)
- The relative feed value of forage from the PROSOIL areas ranged between £1500 to £2400 /ha/yr (£607 to £900 /ac/yr), reflecting a difference in yield of 4.5 tDM/ha from poorest (little clover) to best performing fields (clover rich)

IBERS PROSOIL Project Research Link

When white clover or red clover was present in experimental plots at IBERS the rate of water infiltration was much higher compared to the ryegrass plots.



John and Hilary Garn: *"*When volunteering for the PROSOIL project we simply wanted to understand the selective grazing our flock were doing. We have since learned that it is all due to the sward. This obviously comes from soil. We are what we eat, and the importance of soil cannot be underestimated. It has been an amazingly fascinating journey, and one we can only thank the PROSOIL team for."

Water infiltration

Water infiltration rate is an indicator of how well water can move into and through the soil profile. Good infiltration rates help soil water storage, making it available for root uptake and plant growth and also providing a habitat for soil organisms. It can also reduce the risk of flooding.

Sampling and Analysing Soils and Manures

Good soil management depends on assessing the soil's physical and biological condition as well as managing nutrient inputs based on regular soil and manure analyses. Soil analyses show the effects of farming practices on soil fertility and are the best way to guide nutrient applications for grassland growth and to help protect the environment.

Sampling and analysing soils and manures gives a "snapshot" of pH and nutrient levels. PROSOIL Regional Development Group (RDG) members sampled and analysed their soils and manures, discussing the results, sharing past field history, and working out the best way to improve soil nutrient status.

pH, phosphate (P), potash (K) and magnesium (Mg)

- pH affects nutrient availability and nutrient balances (see Fferm y Glyn case study, pp. 14-15).
- Maximum yields of grass crops are reached at index 2 for P and 2- for K where no other nutrients are limiting. These levels can be maintained by replacing the nutrients taken off in harvested crops.
- If the index is below target, the crop yield is reduced.
- Where the index is above target, planned reductions in nutrients allow the soil index to fall without a drop in yield.
- P and K move slowly from the soil to plant roots. In deficient soils an application of P and K may not become available for uptake by plant roots to benefit the growing crop that harvest year.
- A magnesium (Mg) index of 2-3 is suitable for grass crops.
- At soil Mg index 2 or below, magnesium limestone applications to correct low pH can be cost effective.
- Mg levels above index 3 increase the risk of crop K deficiency, grass staggers (hypomagnesaemia) and tight compacted soil.
- Manures and slurries are important nutrient sources on livestock farms and should be targeted to silage ground where offtake is highest to enable fertiliser savings.

Under supply of nutrients	Over application of nutrients
• Reduced crop yield • Shortfall in home grown forage • Shorter ley life • Higher sward weed content • Increased purchased feed costs	• Spending on nutrients greater than necessary • Losses of P to the environment • Animal health problems • Lower forage quality

Make the most of analysis

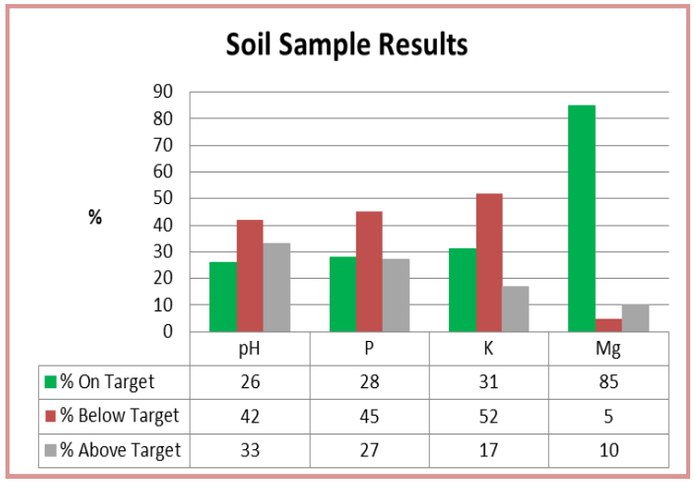
PROSOIL Regional Development Group (RDG) members sampled and analysed soils that were generally underperforming.

The results highlighted the value of regular soil analysis to pick up indices which are **below** or **above** target so that corrective action can be taken.

59%, 55% and 48% of pH, P and K were outside the target level.

85% of samples had Mg indices within a suitable range.

Several farms had Mg indices of 4-6 due to long-term use of Mg lime.



	pH	P	K	Mg
% On Target	26	28	31	85
% Below Target	42	45	52	5
% Above Target	33	27	17	10

Regional Development Groups

Manure analysis

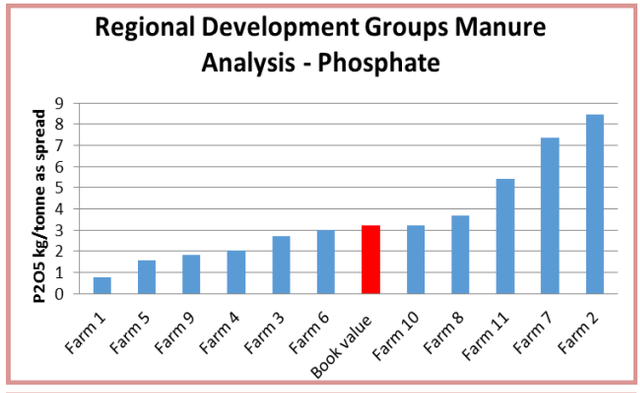
Standard book values (Defra Fertiliser Manual RB209) are generally used for nutrient planning. Where crop offtake of nutrients is replaced with nutrients from manures, slurries, and inorganic fertiliser, and soil indices are rising or falling, there is a case for analysing manures and slurries.

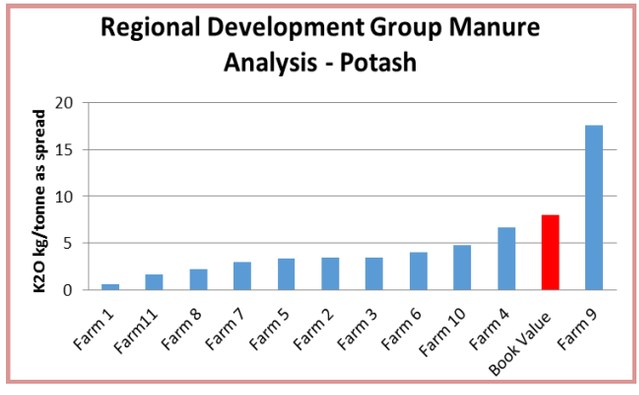
Analysis of slurry at Rhual and Cappele Commercial Development Farms (CDFs) over a number of years showed a wide variation in P and K values. The results showed that total P and K content was more than 50% below book value in one year out of the four (see Cappele and Rhual case studies, pp. 12-13 and 20-21).

RDG members analysed fresh and composted farmyard manures which showed variation from the standard book value with total phosphate levels below book value in 55% of samples and potash below book value in 90% of samples.

Regional Development Group members analysed fresh and composted farmyard manures.

Results showed variation from standard book value, with total phosphate levels consistently below book value and potash showing almost the same number above and below.

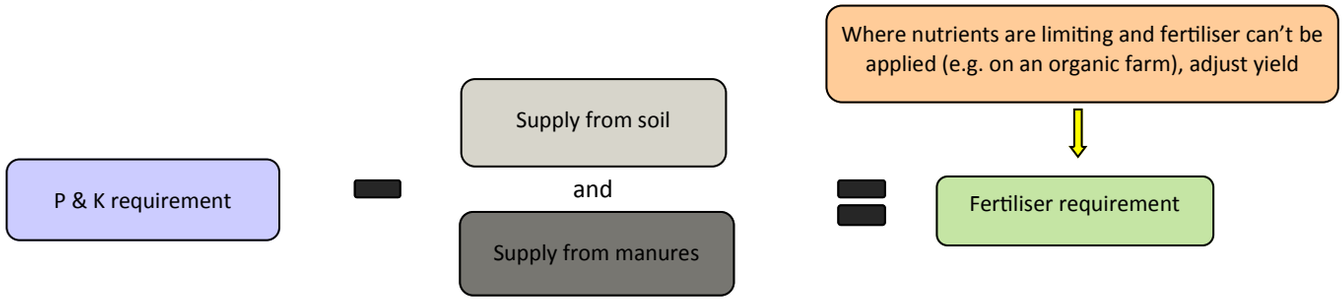




Regional Development Group Manure Analysis Variation in Phosphate and Potash Levels		
	P_2O_5 kg/t	K_2O kg/t
% above book value	10	45
% below book value	90	55

Make the most of manures

- Target manure applications where needed based on soil sample results and manure analysis
- Apply to fields that can use the full P and K nutrient content of manures
- Silage or cropping fields where nutrients are removed with each harvest are the priority on livestock farms
- Remember grazing fields receive recycled nutrients from dung and urine
- Always balance crop needs with crop offtake to prevent nutrient surpluses building up
- Check soil indices by regular analysis and sample manures for P and K, so that nutrient planning can be done effectively

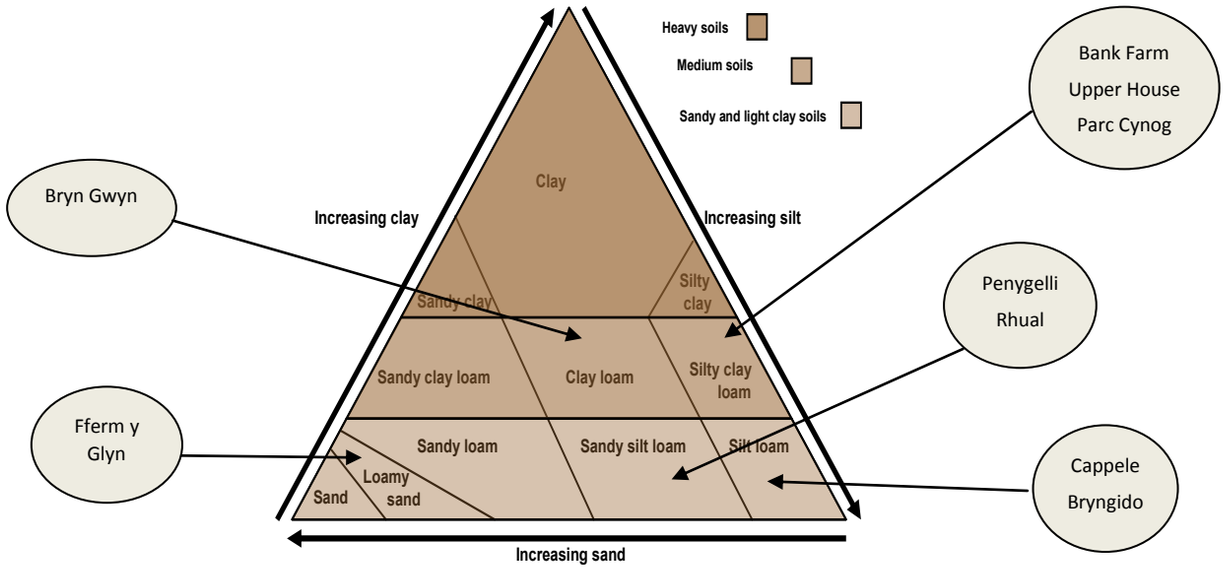


Soil Texture

Soil health and fertility are key to successful farming. Good soil management depends on assessing soils and managing them to improve the biology, chemistry and structure. Soil texture is the relative proportion of sand, silt and clay which can be accurately measured mechanically or assessed on farm by hand. Texture influences how much water and nutrients a soil can hold. Although it cannot be altered by farming practice, knowing the texture will help determine how to manage soils to optimise structure and nutrient supply in grassland. There are 11 texture classes or soil types identified in the UK.

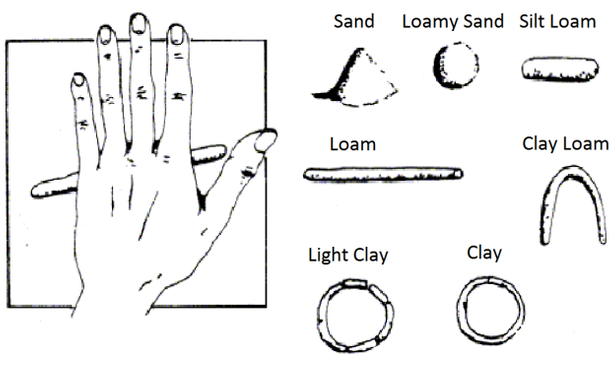
Management needs to take into account that sandy soils are free draining and warm up quickly, but do not hold nutrients well, though they enable early turn-out as they are less likely to poach. Clay soils hold nutrients and retain water better in drought, but are heavier and colder in the spring and are more likely to suffer from compaction and poaching. Whatever the texture, a soil with good soil structure will be more resilient to water stress, hold nutrients better and remain healthy.

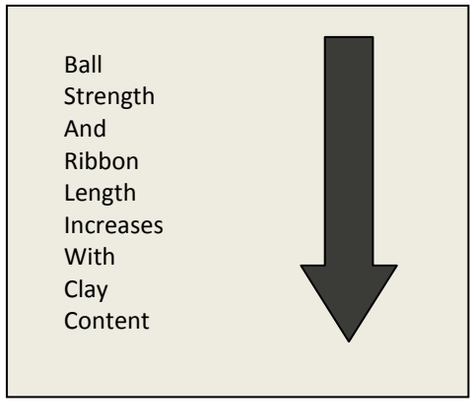
Soil textures on Prosoil Commercial Development Farms



Hand texturing soils

Place some moist soil in the palm of your hand and try kneading into a smooth and plastic consistency like moist putty and see which of the shapes below can be made (see p. 29).





Qualities	**Sandy and light silt soils** • free draining, can be worked without damage for long periods • warm up quickly in the spring; long growing season • weak structure with low clay and organic matter, which may cap or slump • prone to compaction by deep cultivation or harvesting in wet conditions • sensitive to drought
Feel	• don't stick together very easily, feel gritty • don't stain the fingers when wet • sand can't be moulded and won't make a ball • loamy sand forms a very weak ball that is fragile and easily deformed • sandy loams form a weak ball
Qualities	**Loams: medium soils, mixtures of sand, silt and clay** • contain enough clay to stick particles together • cap and slump less frequently unless soil has a high proportion of silt or fine sand • machinery and livestock can cause compaction if the water table is high or subsoil holds water • surface and deep compaction can lead to erosion in wet conditions particularly on slopes
Feel	• mould into ball more easily and form a sausage-shaped ribbon • sandy silt loams are equally gritty and "soapy" • silt loams have a more smooth, silky or "floury" feel • clay loams are sticky • sandy clay loams smear when rubbed; sand particles are visible • silty clay loams have a "soapy" feel, are sticky when wet, and take a polish when rubbed
Qualities	**Clay soils: heavy soils** • hold soil particles together; low risk of erosion • wet and cold in winter, dry in summer, with a short growing season • prone to poor drainage, water logging, and ponding • require careful management as high risk of compaction from machinery and livestock • surface run-off during periods of heavy rain can carry nutrients, pesticides and sediments causing pollution
Feel	• mould into robust balls which are not easily deformed; soil is very sticky, smears to give a polished surface, and can be rolled into long sausage-shaped ribbons over 5 cm long • sandy clays – sand is obvious on the surface • silty clays – feel smoother and more buttery • light clay – a rolled ribbon will form a ring that cracks • heavy clay – a rolled ribbon will form a ring without cracking

Soil texture and Cation Exchange Capacity (CEC)

Cation Exchange Capacity (CEC) is a measure of the ability of a soil to hold on to nutrients and is affected by the soil texture and organic matter content. It is part of soil analyses for Base Cation Saturation Ratio (BCSR).

The total CEC of a soil is a measure of the maximum number of negatively-charged sites able to bind positively-charged cations including calcium, magnesium, sodium, potassium, hydrogen and others in an exchangeable form. CEC is expressed as milli-equivalents/100g of soil.

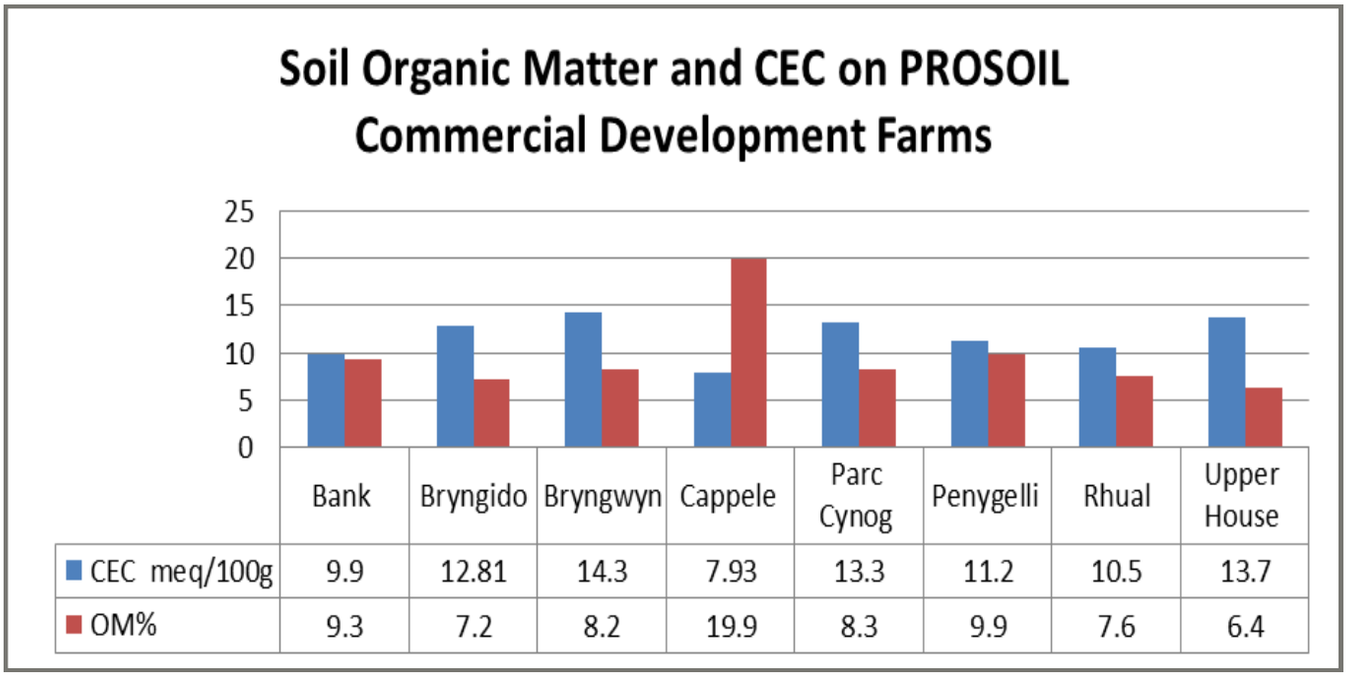
In general, the more clay and organic matter in the soil, the higher the CEC. Although the amount of clay in a soil cannot be changed, the organic matter content can be managed. The CEC of a light soil may be improved through the addition of organic matter such as well-composted manure.

	Optimum	Sandy	Intermediate texture classes	Clay	Peat
CEC (meq/100 g)	>12	from 2	mostly 10 -30	up to 50	>50

Soil organic matter percentage measured on PROSOIL Commercial Development Farms (CDFs) ranged from 6.4% to 19.9% with CEC ranging from 7.9 to 14.3 meq/100g. These figures are typical of grassland soils and reflect the differing soil types across the PROSOIL project.

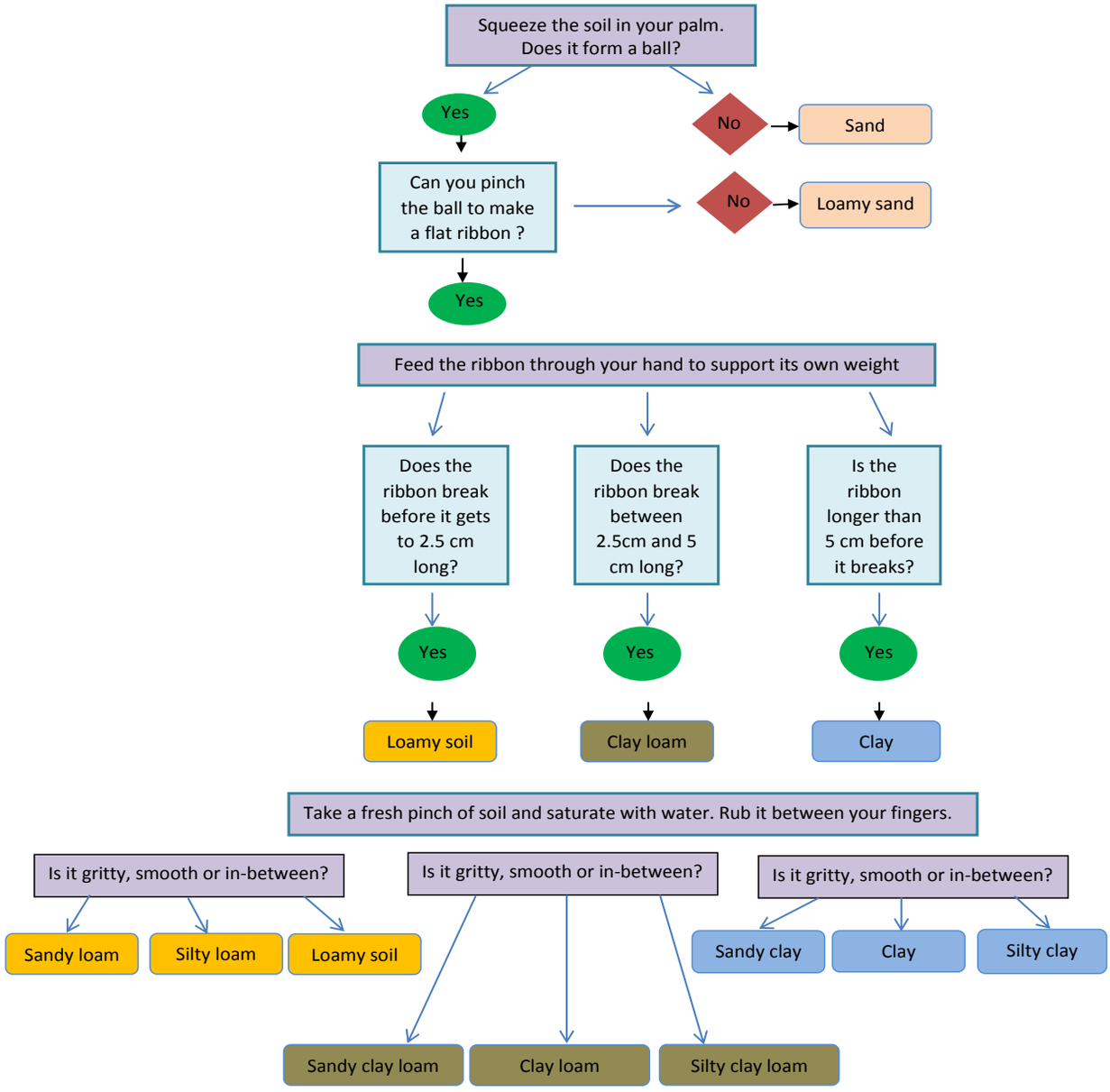
Organic matter, like composted manure, improves the CEC of all soils. Stable organic matter can hold on to basic nutrients at least twice as well as clays, enables heavy soil to drain more effectively, and helps sandy soil to hold on to plant-available water.

Although clay and organic soils need more lime than sandy soils to increase the pH by one unit, due to their higher CEC sandy soils have a reduced capacity for holding liming materials and are more vulnerable to leaching, so tend to have a quicker return to a low pH.



Identifying soil type

Place a handful of soil in the palm of a hand. Slowly add water drop by drop kneading the soil to make a smooth consistency like moist putty.



Soil Analyses for Farmers

Soil health and fertility are key to successful farming. Good soil management depends on assessing the soil's physical condition and interpreting soil analyses effectively. Regular soil analysis can show the effects of farming practices on soil fertility and is used to keep nutrients at an optimum level for crop growth. Two approaches to soil analysis are outlined below.

The Defra RB209 "Sufficiency" method is widely adopted in the UK. Soil pH, indices of available P, K and Mg and crop offtake are used to determine the inputs of animal manures and fertilisers required to maintain soil nutrient contents at a sufficient level to support the optimum economic yield while minimising losses. The RB209 publication is the basis of decision tools like PLANET and MANNER and is based on results from many years of UK research.

'Mineral balancing' - Base Cation Saturation Ratio (BCSR)

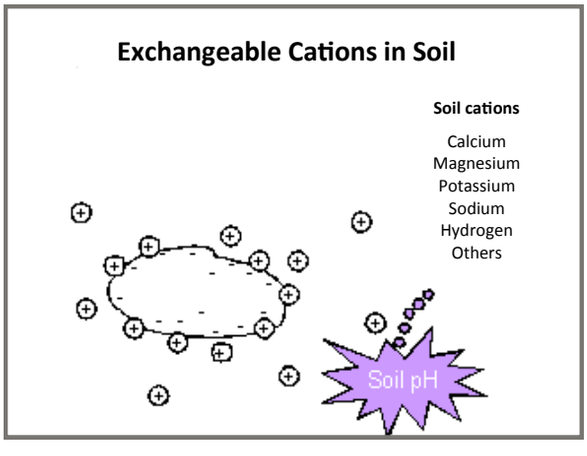
Developed by Prof. Albrecht in the USA, the BCSR theory looks at nutrient cations and their balance in the soil and is based on an understanding of cation exchange capacity (CEC).

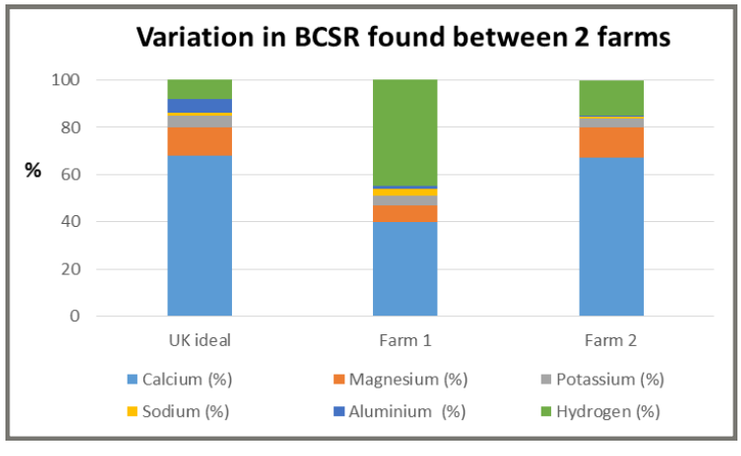
- The total CEC of a soil is a measure of the maximum number of negatively-charged sites able to bind positively-charged cations in an exchangeable form. CEC (expressed as milli-equivalents/100g of soil) is a characteristic of the soil type (e.g. clay soils have a higher CEC than sandy soils) and is not significantly altered by normal management practices.
- These exchangeable ions are an important reserve of plant nutrients. Roots excrete hydrogen ions (H^+) which can displace the nutrient cations from soil exchange sites into the soil solution where they are available for uptake.
- The BCSR theory states that there is an ideal ratio of the different exchangeable cations in the soil that is optimal for plant growth. Fertiliser recommendations based on this theory are designed to adjust the proportions of exchangeable cations to this optimum ratio.
- The four key elements are the base cations - calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na), together with hydrogen (H) and other (mainly assumed to be aluminium) which determine soil pH.
- Fertiliser recommendations for other nutrients, such as P and S, are determined separately and are based on threshold levels rather than ratios.

Albrecht determined the optimal BCSR for crops in US soils. In UK soils, the ideal balance for optimum production (expressed as percentages of total CEC) is thought to be:

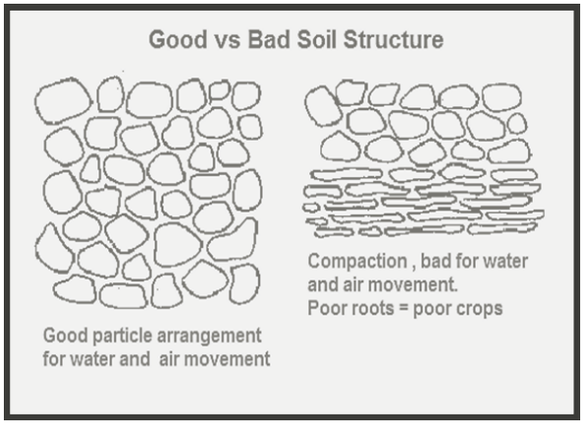
Calcium 68%; Magnesium 12%; Potassium 5%; Sodium 1%; Hydrogen 8%; Other 6% (from J. Johnson, 2011)

Soils from the Commercial Development Farms in the PROSOIL project varied in how closely they matched the 'ideal' balance, as seen in the chart below.





Cost of Compaction



Yield

Mild soil compaction causes:

- Poor root growth
- Reduced fertiliser recovery
- Increased nitrogen loss
- Yield loss of up to 15%

Cost of buying in silage to replace lost yield on 10 ha = £1050 (10 ac = £425)*

*loss 1.5 tonne DM /ha on a sward with yield potential of 10 tonnes DM /ha silage at 35 % DM £25/tonne

Plough pan

1. Reduced response to nitrogen

- Soil compaction can halve the response to applied nitrogen from manure and fertiliser, doubling the cost of nitrogen/kg!

2. Poor sward quality

- Soil compaction can increase the proportion of secondary grass species and weeds, which have lower energy than ryegrass.
- Buying compound feed to replace 1 MJ energy will increase annual bought-in feed costs by £66, £26 and £4.40 respectively per head for dairy cows, growing beef and lambs per year.

3. More frequent reseeding

- Soil compaction reduces sward quality leading to more frequent reseeding to maintain yield and quality.
- Reseeding after 5 rather than 8 years will increase costs.
- Reseeding every 5 years to maintain sward quality on compacted soils increases reseeding costs by around £38 /ha/year.

4. Reduced earthworm activity

Soil compaction reduces the number of earthworms. In a healthy well-structured soil earthworms can:

- Supply 25 kg N /ha/yr worth £20 /ha (£8 /ac)
- Increase organic matter turn over by 200-300 %
- Increase water infiltration rates 10 fold
- Reduce run off by 50%
- Form new soil (worth between £3 and £15 /ha/yr (£1.21 and £6.07 /ac/yr) on PROSOIL Commercial Development Farms)

Reducing the effects of compaction

- Aim to prevent compaction wherever possible (see Bryngwyn case study, pp. 10-11)
- Assess soil: '"Dig, Handle, Measure" (p. 42), especially where there are lots of weeds, bare ground or if grassland is not performing
- Check soil for signs of compaction:
  a) horizontal cracking
  b) roots growing sideways
  c) stale unpleasant smell
  d) orange or grey mottles
  e) blocky aggregates of soil which do not break under pressure of forefinger and thumb
- Consider using machinery when the soil is dry enough
- Management methods chosen by PROSOIL Commercial Development Farmers to improve soil structure included liming (£60-£75 /ha or £24-£30 /ac), spiked aeration/sward lifting (£60-75 /ha or £24-£30 /ac), subsoiler/vibrating aerator (£130-150 /ha or £52-60 /ha), and multispecies ley (£500 /ha or £202 /ac)

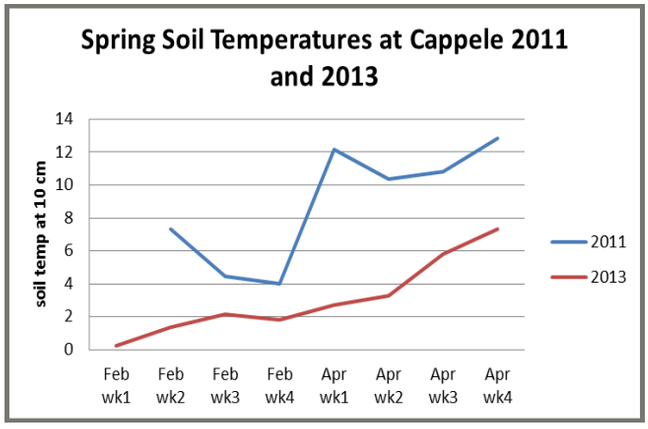
Soil Temperature

Warm soils are key for effective nutrient applications, sowing, crop root and shoot growth.

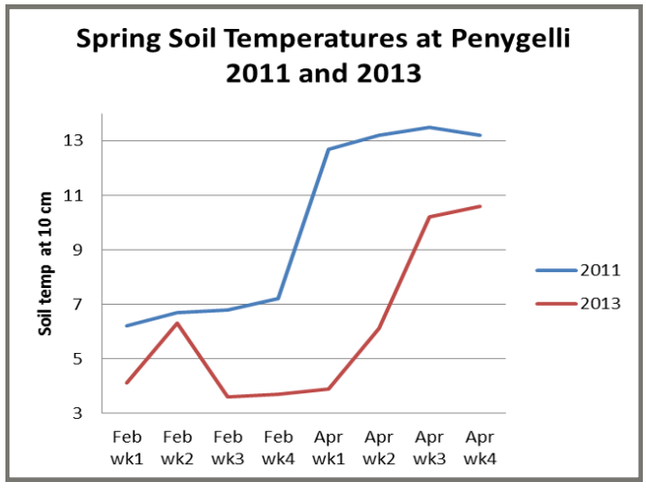
Perennial ryegrass starts to grow when the soil temperature at 10 cm depth reaches 5.5^{0}C for 5 consecutive days. Nitrogen fertiliser applied before the soil reaches the minimum temperature is not used efficiently, and risks losses to the environment. Making the most of spring grass growth is a key factor in reducing feed costs on farm, with 1 kg grass dry matter costing 75% less than the equivalent energy provided in bought-in supplementary concentrates. Applying fertiliser at the correct time is key to minimising costs and optimising grass growth for many farming systems in Wales.

Minimum Soil Temperature ^{0}C for Crop Growth* *at soil depth of 10 cm	
Crop	**Temperature when Growth begins (^{0}C)**
Ryegrass	5.5
Clover	8.0
Lucerne	10
Brassica	10
Forage Maize	8-10
Multispecies ley	5.5-10

Soil temperature also affects soil biological activity; for example, earthworm activity is reduced when soil temperatures are above 21^{0}C or below 5^{o}C. This influences mineralisation of nutrients and their availability for plant growth. Poor drainage and soil compaction will also affect soil temperature, reduce biological activity and the length of the growing season.

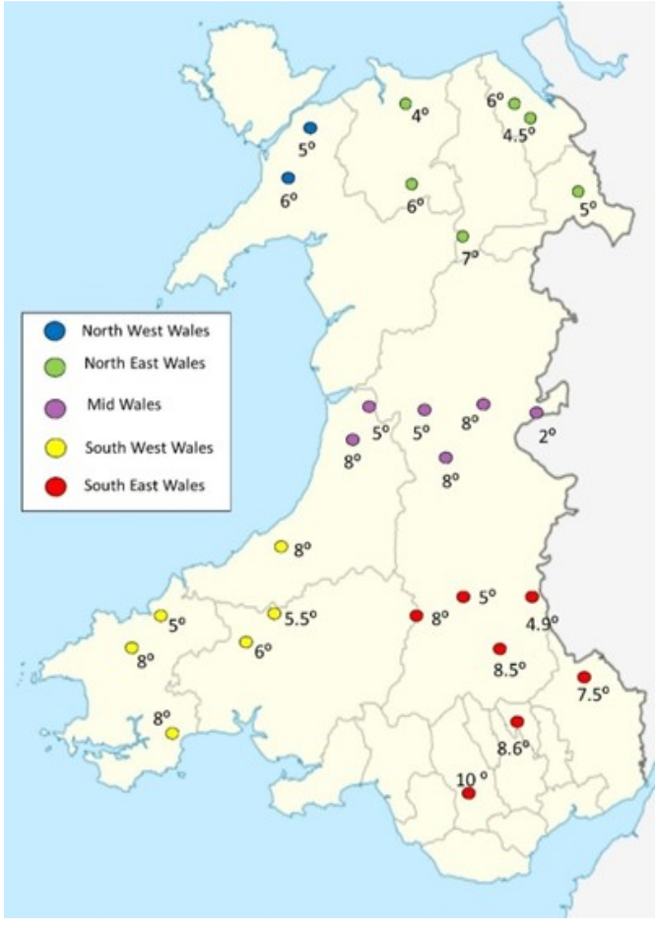


PROSOIL Commercial Development Farmers regularly took soil temperatures and showed how soil temperature measured at the same time of year varied between years and between fields. This highlights that it is vital for farmers to take the temperature of their own fields to optimise nutrient use, seed germination and grassland performance.



PROSOIL farmers taking part

Some farmers in Wales told the PROSOIL project team that they used daffodil flowering to identify when to apply nutrients. To test the theory PROSOIL Regional Development Group farmers took part in a farmer-led experiment, planting daffodil bulbs (early-flowering variety "Tamara") and sent valuable information about flowering date and soil temperature by text, postcard or via twitter. The soil temperatures when the "Tamara" daffodils flowered showed that this is not a reliable indicator for nutrient applications.



Soil temperatures at daffodil flowering, Spring 2015

Measuring grassland soil temperature

- Insert soil thermometer probe 10 cm into the ground
- Wait for the reading to settle and record
- Measure in the middle of the day or morning and evening and calculate the average of the readings

Forage Mineral and Trace Elements

Farms in the PROSOIL project have been monitoring the mineral and trace element levels in forage as part of the study into the effect of different soil management practices on soil health.

Mineral and trace element analyses of forage provide a farm-specific "snapshot" of levels which can inform investigations into mineral and trace element deficiency in livestock. Deficiency in stock is most accurately diagnosed by blood and tissue analysis.

Fifteen mineral and trace elements are essential to animal production, with minerals like calcium and phosphorous needed in relatively large amounts; trace elements like manganese (Mn), zinc (Zn), selenium (Se), copper (Cu), cobalt (Co) and iodine (I) are equally important, but needed in much smaller quantities.

Individual forage species have a different mineral and trace element profile. At IBERS red and white clover and chicory contain more minerals and trace elements in general than perennial ryegrass. Chicory contained higher concentrations of most major minerals, except sodium (Na), compared with perennial ryegrass by the second harvest year.

Mineral content of forages

Species	Chicory	PRG	Red Clover	White Clover	Species	Chicory	PRG	Red Clover	White Clover
% content					**mg/kgDM**				
Calcium	1.3	0.8	1.8	1.6	Manganese	100	109	75	63
Phosphorus	0.3	0.26	0.27	0.35	Zinc	114	35	56	32
Magnesium	0.4	0.23	0.4	0.27	Selenium	0.36	0.02	0.03	0.02
Potassium	1.7	0.99	1.14	1.29	Copper	13.5	6	12	9.2
Sodium	0.34	0.42	0.23	0.33	Cobalt	0.09	0.04	0.07	0.05
Sulphur	0.19	0.16	0.16	0.19	Iodine	0.34	0.23	0.26	0.31

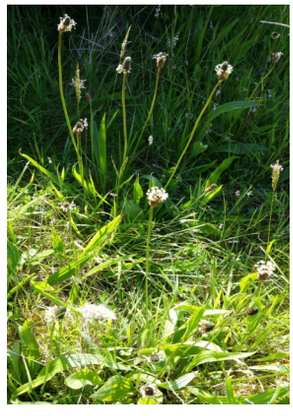
Source: Mineral content of chicory compared to perennial ryegrass, red clover or white clover over two harvest years, Marley C.L *et al.* (2013)

Case study: minerals and trace elements in a multispecies sward

Bryngido Commercial Development Farm, a beef and sheep farm in Llanarth, Ceredigion, established ryegrass and a multispecies ley as part of the PROSOIL project. The multispecies ley contained ryegrass, cocksfoot, timothy, fescue, four different clovers and a range of pasture species including sainfoin, chicory, yarrow, sheep's parsley, burnet, birdsfoot trefoil and plantain.

Sward yield and root depth were measured and trace element levels were analysed in the spring and autumn.

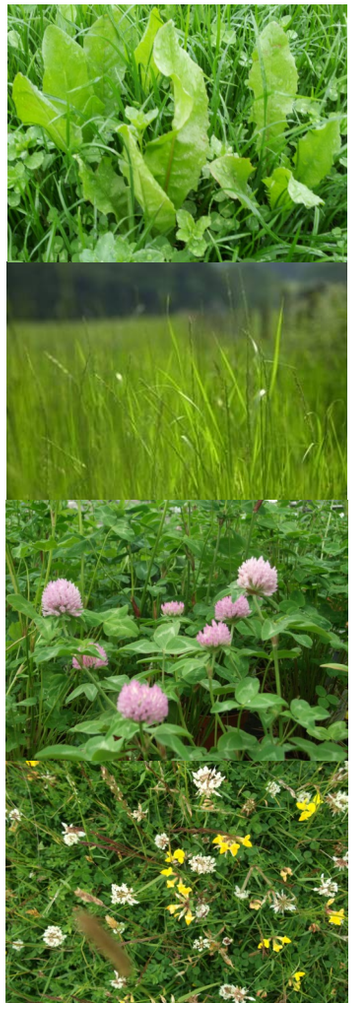
Levels of the majority of minerals and trace elements tested in both swards were within the typical range for UK pastures two years after establishment. However the ryegrass sward contained higher levels of potassium and sulphur and lower levels of zinc than typical pastures.



- The multispecies ley contained higher levels of sulphur and manganese than typical pastures
- There was seasonal variation in mineral and trace element content:
  a. Levels were higher in the autumn than in the spring
  b. The multispecies ley tended to have higher levels than the ryegrass ley in the autumn
- The multispecies ley was higher yielding and deeper rooting than the ryegrass ley over three harvest years

Multispecies ley

	Typical range in UK swards	Bryngido: ryegrass	Bryngido: multispecies
Calcium %	0.5-0.7	0.7	0.7
Phosphorus %	0.3-0.4	0.4	0.4
Magnesium %	0.15-0.25	0.22	0.22
Potassium %	1 to 3	3.4	3.0
Sulphur %	0.15-0.25	0.27	0.26
Manganese mg/kg	75-125	101.8	162.3
Zinc mg/kg	40-80	34.6	44.0
Selenium mg/kg	0.1-0.2	0.1	0.1
Copper mg/kg	8 to 12	8.8	9.4
Cobalt mg/kg	0.2-0.3	0.2	0.3
Iodine mg/kg	0.5–1.5	1.2	1.4



Summary

Diverse multispecies leys can be used to help modify the mineral and trace element content of sward. They offer a natural way to manipulate levels and have a role to play when livestock depend upon forage as the main source of minerals and trace elements in their diet. In the PROSOIL project leys were able to support healthy productive livestock and stock appeared to prefer to graze the diverse ley compared to ley containing ryegrass only. Over three years the multispecies ley at **Bryngido** was higher yielding and deeper rooting (see pp. 8-9).

Earthworms

Under ideal conditions, it is estimated that a healthy earthworm population can process around 12 tonnes of soil and organic matter in a year, and a healthy pasture will have a greater weight of stock beneath the surface than above. Research from Rothamsted Experimental Station has produced figures suggesting that even poor soil may support 62 /m² (250,000 /ac), whilst rich fertile grassland may have up to 432 /m² (1,750,000 /ac).

Earthworms and soil health

Earthworms improve soil structure by dragging down organic matter, mixing soil and creating tunnels that improve drainage.

Worm casts are rich in recycled plant nutrients, and can contain up to 40% more beneficial humus than the top 23 cm of soil.

A fresh worm cast can hold as much as 5 times more accessible nitrogen, 7 times more accessible phosphorous and 11 times more accessible potash than the surrounding top soils.

It is estimated that there are around 3000 different species of earthworms found globally, with 20 species in the UK. There are three more common groups or ecotypes:

Lumbricus.rubellus by James Lindsey at Ecology of Commanster.

Organic matter dwelling (epigeic)

- Live at or near the soil surface.
- Tend not to burrow into the soil.
- Eat material that is high in organic matter, e.g. decaying plant roots and shoots, dung and leaves.
- Reproduce rapidly.
- Short lived.
- Often bright red, with no stripes.

A sub-group of these are compost worms

They prefer warm and moist environments with a ready supply of fresh compost material. They very rapidly consume this material and reproduce very quickly.

Compost earthworms tend to be bright red and stripy, and larger than most other mature earthworms.

Topsoil dwelling species (endogeic)

- Live in the top 20-30 cm of soil.
- Eat significant volumes of soil and decaying organic matter.
- Burrow through the soil, ingesting as they go, creating branching horizontal burrows and mixing the top soil layer - will reuse burrows to a certain extent.
- Not important in the incorporation of surface litter.
- Produce stable casts.
- Reproduce rapidly - approximately 1.4 young per adult per week in some species.
- Have no skin pigmentation. Usually pale grey or yellow.

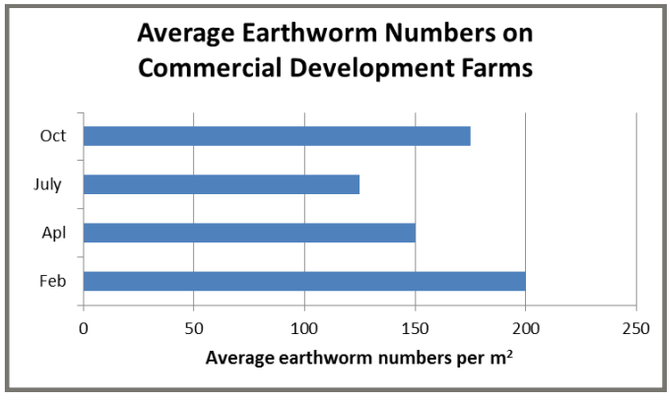
Subsoil dwelling species (anecic)

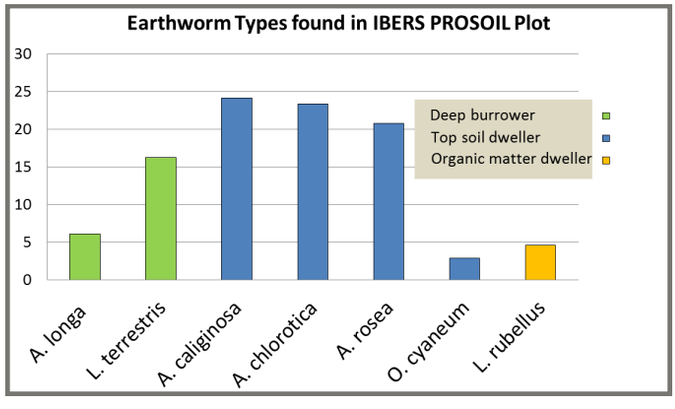
- Create large vertical, permanent burrows up to 2 m deep in the soil profile.
- Come up to the surface to feed, pulling surface plant residues and living plant material down into the mouth of the burrow to soften and be eaten.
- Responsible for most of the worm casts usually found on the surface in grassland - usually deposited around the entrance to their burrows.
- Populations are heavily influenced by tillage and rotations that reduce surface residue levels. To avoid being scooped up by predators, the species *L. Terrestris* has developed retractable bristles called “setae”, which grip the burrow wall.
- Darkly coloured at the head end, and paler towards the tail.

Looking after your earthworms

Earthworm numbers are affected by several factors:

- Soil temperature: Most earthworm species are happy at a range of temperatures but require a minmum of around 7^{o}C. Below this, the adult population drops, although eggs remain viable.
- Organic matter content: without organic matter, the earthworm population is unable to sustain itself. Soils with low organic matter have depleted earthworm numbers.
- Soil pH: an acidic soil severely impacts on earthworm numbers. Although some species in the UK have been found at pH 4.3, the optimum is above pH 6.
- Soil compaction: to a point, compaction in soils can stimulate casting activity in earthworm populations, but heavily compacted soils limit the earthworm’s ability to burrow, compounding compaction issues. In a well aerated soil, the earthworm’s movement acts as a piston, forcing air deeper into the soil, increasing drainage, and nutrient uptake. Their burrows are also very important for letting water into and through soil. This influx of water can flush air out of the soil to be replaced by ‘fresh’ air.





The economic benefit of earthworms

Economic benefit was assessed on PROSOIL Commercial Development Farms using the following assumptions:

- average biomass per worm - 0.37 g (IBERS plot data)
- 1000 kg earthworms turn over 1000 kg soil/ha annually*
- soil worth £78 /tonne - the economic benefit (£/ha/yr) is the value of the soil they turn over per hectare per year

The average number of earthworms counted by the farmers ranged from 91 to 357 and the financial value of soil creation ranged from £3 to £10.50 /ha/yr.

*Sandhu *et al.* (2008)

Mesofauna

Maintaining a healthy soil requires more than just the addition of N (nitrogen), P (phosphate), and K (potash) to maintain soil fertility. Soil is not only capable of storing nutrients but transfers these to the root surface for uptake by the plant. An unhealthy plant is likely to be the result of an unhealthy soil. A healthy soil contains nutrients, microbes, fungi, trace elements and mesofauna, which all work together and form an essential system for sustainable plant growth. There are two main groups of mesofauna living within the soil: springtails and mites.

Springtails

Springtails are small, soil and litter dwelling arthropods (related to insects). They are soft-bodied, wingless and mostly blind. Body length ranges from about 0.2 – 6 mm. Springtail colours vary but most are grey, white or purplish. Springtails have six legs (like insects), but have a unique means of locomotion – the "springtail". This is a fork-like tail structure (furcula) that is folded up under their body during normal locomotion. However, when disturbed (e.g. to escape predation), the furcula is released and pushes the springtail off the ground, allowing it to jump a distance equivalent to 10 times its own body length.

Springtails are abundant in decaying plant material and are one of the principal decomposers in soil. Most springtails consume fungi, algae, lichens, decaying plant material and bacteria; fertilising the soil in the process. Some act as predators to even smaller soil animals, or consume carrion within the soil. However, none of them bite and they are harmless to humans and animals. In moist soils with high amounts of organic matter, large numbers may be present – thousands per metre square.

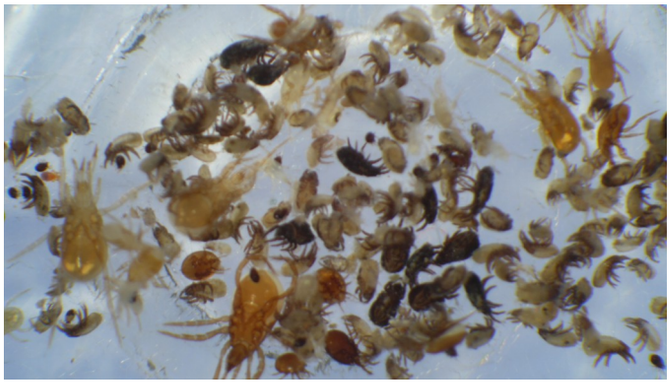
Role

Springtails appear to be extremely important in the biological cycles of plant systems because they assist in the decomposition of litter. They are generally present in large numbers and often form an important food source for generalist soil predators.

There are three main groups of springtails:

- Elongated Entomobryomorpha (top left)
- Plump Poduromorpha (below left)
- Globular Symphypleona (below right)

Springtails are known to carry spores of mycorrhizal fungi and "helper" bacteria on their cuticle, leading to the establishment of plant-fungal symbioses and thus are very beneficial to agriculture. They also reduce the occurrence of plant fungal diseases through consumption of the hyphae and spores of these fungi.



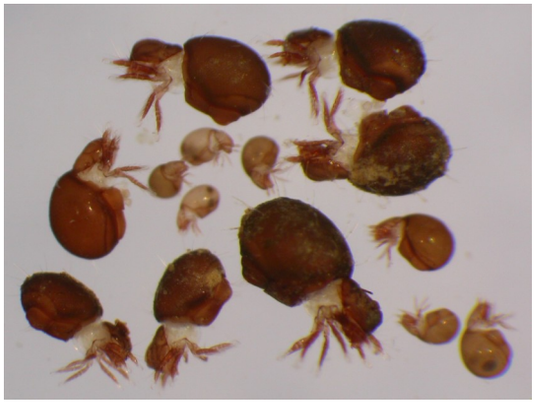
Organic matter in the soil ensures a continuous food source for soil microbes. As the microbes metabolise organic matter, they help maintain good soil structure by developing compounds that cement small soil particles together into aggregates, increasing drainage and moisture retention. The mesofauna live in the pore system and feed upon these microbes as well as decomposed plant material and mineral particles, or are predatory and reside between the soil aggregates feeding on crop pests (e.g. fly larvae or wireworms).

Mites

Mites are at first glance similar to spiders (Arachnida). However mites can be distinguished from spiders by their lack of a waist between the thorax (where the legs are attached) and the abdomen. This gives the characteristic appearance of a single oval body, with head and legs attached to it. Mites range in size from 0.1 – 5 mm with some species visible to the naked eye. Some species are hairy and vary in colour from clear/ white to a dark brown.

There are three main groups:

- Mesostigmata – predatory (bottom left)
- Oribatida – decomposers (below left)
- Prostigmata – omnivorous (right)



Mites are more variable in their function within the soil compared to springtails. Some are important predators of pest insects (Mesostigmata), whilst some species are important in the breakdown of litter, organic residues and the recycling of nutrients (Oribatida and Prostigmata).

The movement of mites through the soil can also introduce fungal spores and bacteria to fresh plant matter so that decomposition can begin. Their microbial grazing can stimulate and regulate microbial activity, just as livestock grazing can stimulate herbage growth .

Around 23,000 springtails and 41,000 mites have been found per m^2 in IBERS PROSOIL plots.

Frequently Asked Questions

Q: Aeration is always beneficial because it opens up water and air ways. Is this true?

A: NO, soil aeration is a valuable treatment when conditions are right; however in wet conditions it can cause smearing and result in poorer drainage. It is also important to look at the level at which there is compaction - if the problem is deeper down the profile, then shallow soil aeration will not be able to tackle it.

Aerator

Q: Will I damage earthworms if I apply slurry to my grassland?

A: It is important not to apply too much slurry or earthworms will come to the surface to find air. Minimise damage by keeping application levels down to 28 m^3/ha (2500 gal/acre). It depends on the dry matter of the slurry and the method of application, but the ground should not be "puddled" with slurry or earthworms will suffer.

Q: How can clover help soil structure?

A: Healthy white clover has a dense network of roots as well as stolons which can help to open up spaces between soil particles and so decrease bulk density. IBERS research demonstrated that white clover can reduce soil bulk density, which is higher in compacted soils. IBERS PROSOIL project research found that white clover improved water infiltration. IBERS research also showed that white clover improved the recovery of fertiliser from less than 50% to more than 75%. Red clover, with its deep tap root, is also able to help to open up the soil where it is mildly compacted.

Red clover

Q: Will I really save money if I take into account the N, P and K in my slurry when I apply my fertiliser?

A: YES! The nitrogen (N), phosphate (P) and potash (K) in slurry and manure contribute to crop needs. The nutrients can be deducted from crop needs and reduce the requirement for fertiliser application. With N at £286 /tonne, P at £300 /tonne, and K at £270 /tonne, the nutrients in farmyard manure are worth £6.50 /tonne, layers' manure £22 /tonne and 6% dry matter slurry £4.30 /m^3.

Q: How much advantage is there from injecting slurry compared with a splashplate?

A: This depends on the time of the year, but losses to the air are highest when the weather is hot, and up to 70% of the nitrogen can be lost to the atmosphere. Other advantages include the ability to graze soon after application and the opportunity to gain entry points for Glastir.

Q: What is the advantage of spreading digestate compared with slurry?

A: As well as the energy generated before application, digestate has a fertiliser value to the soil. It is essential to analyse pH, N, P K levels in the digestate as they vary depending on the feedstock going into the AD unit. Any additional fertilisers applied need to take account of the soil analyses (P, K and Mg) and the crop need. The digestate from **Bank Farm** PROSOIL Commercial Development Farm was more alkaline than undigested slurry and reduced the need for lime applications.

Application of digestate liquor at Bank Farm

Q: How does having a sandy soil affect my grassland?

A: Light free draining soils warm up quickly in the spring, grow early grass and tend not to waterlog unless compaction is severe. However sandy soils do not “hold” nutrients as well as a heavier loam or clay and can be vulnerable to leaching. Sandy soils with low clay or organic matter may erode and compact easily, setting like concrete. They may be unsuitable for direct drilling. They have been called ‘hungry soils’ and benefit from organic matter like farmyard manure to help retain moisture and plant nutrients and reduce the risk of compaction.

Q: What advantages are there to using a species rich ley?

A: Diverse leys include a range of species with different attributes. White and red clover are high in protein and fix nitrogen, while chicory is deep rooting, mineral rich and has good levels of crude protein. Inclusion of a range of species spreads the risk of any possible species-specific pest and diseases damaging the crop and offers complementary growth curves during the season. At **Bryngido** PROSOIL Commercial Development Farm the diverse multispecies ley out-yielded the perennial ryegrass ley and was deeper rooting.

Multispecies ley

Q: How much does the nutrient value of slurry and manures vary?

A: The PROSOIL project highlighted a wide variation in the nutrient value of slurry, digestate liquor and farmyard manures on the Commercial Development Farms and Regional Development Group members. This highlights the benefit of analysing animal manures and digestate to get N, P and K applications right for the grassland needs, maintain crop yield and quality, reduce risk of nutrient losses to the environment, and save money.

Sampling digestate liquor at Bank Farm

Q: How do I monitor earthworm numbers?

A: Dig a hole, a spade width by a spade depth. Take the block of soil from the hole and break it up. Count and record the number of earthworms. Repeat the process again at the same time next year.

“Dig, Handle, Measure”

Dig, Handle, Measure

A spade is one of the most important tools on the farm for soil management. Dig a hole to make three key checks especially where a field is to be reseeded, is underperforming, has been heavily stocked or trafficked in wet conditions. This will help to prioritise the actions needed to improve yield and performance.

- Check soil structure to assess soil compaction
- Analyse soil samples for soil chemistry to plan soil nutrient management
- Count earthworms to assess soil biological health

Assessing Soil Structure

The way the particles of sand, silt, and clay stick together (aggregate) defines the soil structure.

Compaction affects the soil structure and reduces the water and air content, ease of rooting, grass yield and ley life, the length of the growing season, and increases costs.

- Use a spade to cut three sides of a square, leaving the fourth side, then lever out the soil block.
- Look at the structure of the undisturbed side of the hole and the soil block.
- Check for horizontal cracking, shallow roots, or roots growing sideways, a stale unpleasant smell, orange or grey mottles, and blocky aggregates over 10 mm, which do not break under pressure of forefinger and thumb, and defined solid soil layers. Note the depth of these.
- Compare holes from the middle of a field with those at the base of the hedge where compaction is unlikely.
- Tap the tip of a penknife blade on the sides of the hole to identify compacted layers.
- Take photographs and make a field record.

Analyse soil samples

Soil pH, phosphate, potash and magnesium are key elements for efficient nutrient planning.

Results are only as good as the sample. To make sure that they are representative, take 15-30 cores or spade slices to 7.5 cm depth walking across the field/part-field. If texture, colour, or cropping history differs across the field take separate sub samples.

Counting Earthworms

Earthworm numbers are a useful guide to soil health.

- Dig a hole, a spade width by a spade depth
- Take the block of soil from the hole and break it up, taking care to pull apart the soil/grass layer
- Count and record the number of earthworms and take soil temperature
- Count earthworms at the same time each year for comparison (spring or autumn is best when soils are moist)

PROSOIL Top Tips

Getting the soil right is key to profitable grassland livestock farming.

Assess

- Texture — influences water and nutrient holding capacity and management decisions
- Structure — to identify compaction check colours and root depth
- Biological health — earthworms are easy to see and count
- Chemical analysis — basic pH, P, K, Mg

PROSOIL Commercial Development Farms have improved their soils through soil and slurry aeration, use of forage crops, application of manures and digestates, and acting on analyses of soils, manures, slurries, and digestate.

Dig : Handle : Measure : Act

DIG

- Soil type
- Soil structure
- Soil biology

HANDLE

- Soil structure
- Root depth
- Soil type

MEASURE

- Analyse soils, manures, slurry, digestate and forage minerals
- Biology
- Soil temperature
- Yield

ACT

- Plan nutrient management
- Choose right treatment to solve compaction
- Grow deep rooting plants like chicory and red clover
- Include white clover in the ley

Recent Scientific Conference Papers & Presentations

Bourdin, F., Fychan, R., Crotty, F.V., Rhymes, J.M., Scott, M., Davies, J.W., Cuttle, S.P., Theobald, V.J., Sanderson, R. and Marley, C.L. (2015). How can soil fertility management affect the nutritional content of a forage crop in a livestock-based farming system? "Feeding the Earth: The Soil Science underlying Food Production", SEESOIL Spring 2015 meeting, 30 April 2015, East Malling, Kent, UK.

Crotty F.V., Fychan R., Scullion J., Sanderson R. and Marley C.L. (2015). Linking legacy effects within crop rotations to the soil food web. Soil Ecology Society Conference, 8-12th June 2015, Colorado Springs, USA.

Crotty F.V., Fychan R., Scullion J., Sanderson R. and Marley C.L. (2015). Understanding the legacy effect of previous crop rotations on soil biology. "Healthy Soils – Developing Tools for land Managers", Proceedings of AAB Conference, 31 March – 1 April 2015, Marston, Lincolnshire, UK.

Crotty F.V., Fychan R., Scullion J., Sanderson R. and Marley C.L. (2014). The effects of agricultural forages on soil biology - linking the plant-soil-invertebrate ecosystem. In: *EGF at 50: The Future of European Grasslands* (ed. A. Hopkins *et al*.). Proceedings of the 25th General Meeting of the European Grassland Federation, 7-11 September 2014, Aberystwyth, Wales, pp. 267-269.

Crotty, F.V., Fychan, R., Scullion. J., Davis, J.W., Scott, M.B, Sanderson, R., and Marley, C.L. (2013). How is the soil food web affected by management practices to promote high yielding and high quality grassland. ENTO'13, National Conference of the Royal Entomological Society, 4-6 September 2013, St Andrews, UK.

Crotty, F.V., Fychan, R., Scullion. J., Davis, J.W., Scott, M.B, Sanderson, R., and Marley, C.L. (2013). Linking above ground management to below ground ecosystems: the effect of utilising alternative forages on the soil food web. "Biodiversity and Function in Soil", Soil Ecology Society Conference, 11-14th June 2013, New Jersey, USA.

Crotty, F.V., Fychan, R., Scullion. J., Davis, J.W., Scott, M.B, Sanderson, R., and Marley, C.L. (2013). How agricultural management impacts the soil food web: comparing the effects of two different soil management treatments. "Science and Practice for Grass-based Systems", British Grassland Society 11th Research Conference, 2-3 September 2013, Dumfries, UK.

Detheridge, A., Scullion, J., Griffith, G., Marley, C.L. and Fychan R. (2015). A ground truthed DNA metabarcoding technique to determine fungal community structure in soils. "Healthy Soils – Developing Tools for land Managers", Proceedings of AAB Conference, 31 March – 1 April 2015, Marston, Linconshire, UK.

Fychan R., Crotty F.V., Scullion, J., Sanderson R., and Marley C.L. (2015). Effects of forages and sub-soiling on compacted soil. 19th Symposium of the European Grassland Federation, June 2015, Netherlands.

Fychan, R., Crotty, F., Scott, M., Davies, J., Sanderson, R., Marley, C.L. (2015). Effects of different forages on the yield and composition of cereals within a rotation. "Healthy Soils – Developing Tools for land Managers", Proceedings of AAB Conference, 31 March – 1 April 2015, Marston, Lincolnshire, UK.

Fychan R., Scott M.B., Davies J.W., Crotty F.V., Sanderson R., and Marley C.L (2014). Effects of previous cropping and establishment method on mineral concentration of whole-plant spring wheat. In: *EGF at 50: The Future of European Grasslands* (ed. A. Hopkins *et al*.). Proceedings of the 25th General Meeting of the European Grassland Federation, 7-11 September 2014, Aberystwyth, Wales, pp. 404-406.

Fychan R., Scott M.B., Gordon N.M., Leyland M., Sanderson R. and Marley C.L. (2013). Effects of two different soil management treatments on forage yield, botanical and chemical composition. "Science and Practice for Grass-based Systems", Proceedings of the British Grassland Society 11th Research Conference, 2-3 September 2013, Dumfries, UK.

Recent Scientific Conference Papers & Presentations

Fychan, R., Scott, M.B., Davies, J.W., Fleming, H.R., Theobald V.J., Sanderson, R. and Marley, C.L. (2013). Effects of different soil treatments on the yield and nutritive value of perennial ryegrass. "Science and Practice for Grass-based Systems", Proceedings of the British Grassland Society 11th Research Conference, 2-3 September 2013, Dumfries, UK.

Fychan R., Scott M.B., Davies J.W., Sanderson R., Scullion J., Crotty, F.V., And Marley C.L. (2013). The effect of chicory, perennial ryegrass, red clover or white clover on the soil physical properties. "Science and Practice for Grass-based Systems", Proceedings of the British Grassland Society 11th Research Conference, 2-3 September 2013, Dumfries, UK.

Marley, C.L., Fychan, R., Scott, M.B., Davies, J.W. and Sanderson, R. (2013). Trace element content of chicory compared with perennial ryegrass, red clover or white clover over two harvest years. In À. Helgadóttir and A. Hopkins (Eds.) *Proceedings of the 17th Symposium of the European Grassland Federation: The Role of Grasslands in a Green Future, Threats and Perspectives in Less Favoured Areas,* pp. 252-253.

Marley, C.L., Fychan, R., Scott, M.B., Davies, J.W. and Sanderson, R. (2013). Yield, nitrogen and mineral content of chicory compared to perennial ryegrass, red clover or white clover over two harvest years. In À. Helgadóttir and A. Hopkins (Eds.) *Proceedings of the 17th Symposium of the European Grassland Federation: The Role of Grasslands in a Green Future, Threats and Perspectives in Less Favoured Areas*, pp. 249-251.

McCalman H.M., Powell, H.G, Buckingham, S.E and Marley C.L. (2015). Working with farmers to improve soil health: The PROSOIL Project. "Healthy Soils – Developing Tools for land Managers", Proceedings of AAB Conference, 31 March – 1 April 2015, Marston, Lincolnshire, UK.

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Soils, Crop Rotation and Plant Nutrients

Minerals and trace elements are important in both livestock and human diets, but increased crop demand and intensive cropping systems can result in crop nutrient deficiency. Due to the importance of these nutrients for crops, livestock and human health, farmers aim to maintain wheat quality whilst achieving high yields. Deficiencies in crops can be prevented by foliar sprays, and in humans by nutritional supplements. However the PROSOIL project investigated the role of the preceding forage in cereal crop rotation to achieve appropriate levels of plant nutrients.

The study looked at the ability of different forages in crop rotation to improve wheat quality. The crop rotation included red clover, chicory (200 kg N ha^{-1} yr^{-1}), white clover or perennial ryegrass (200 kg N ha^{-1} yr^{-1}), followed by wheat. Levels of a range of elements in the wheat crop varied, depending on the previous forage type, but yield was unaffected.

The graphic below demonstrates which previous forages resulted in the highest specific nutrient in the wheat grain, straw and total offtake. By using forages in the ley phase of a crop rotation, the health and nutrient status of soils can be improved, and can in turn improve wheat quality.