Insights from the Perennial Green Manures project:

An innovative approach to fertilising cropland

Summary report

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Tilly Gomersall

Tilly Gomersall was the project manager for the Perennial Green Manures (PGM) project. Tilly’s interest in farming came from a fascination with botany, a concern for the natural world and a desire to find ways of producing food without exploiting nature and people. She has been working in commercial vegetable production since 2020 and has been running her own business, ‘Hadau a Phridd’, producing fresh vegetables for the Mach Veg Box scheme and other local outlets. She also produces seed for Wales Seed Hub. Tilly has been studying for an MSc in Sustainable Food and Natural Resources at the Centre for Alternative Technology where her focuses are soil health in food production, and adaptive crops for changing climates.

Clo (Chloe) Ward

Clo (Chloe) Ward was the researcher for the PGM project. Clo has worked in horticulture for over 30 years, specialising in perennial systems and promoting environmental techniques by display gardening, writing and teaching. Seeking answers to climate questions in agriculture Clo returned to scientific study in 2013, undertaking an MSc in Food Security at Aberystwyth University. This led to a PhD at Bangor University on ‘An evaluation of perennial mobile green manures for climate change mitigation in agriculture’ which forms the basis for this project.

 **= Research need**

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Alder roots with nitrogen-fixing nodules

Insights from the Perennial Green Manures project: An innovative approach to fertilising cropland

Current methods of fertilising crops are not ideal. They impact on greenhouse gas emissions and the biodiversity and carbon sequestration within the farming landscape. Much of this is due to the supply and management of nitrogen. Nitrogen is an essential nutrient for crop growth, but agriculture's impact on the nitrogen cycle has far-reaching consequences for the environment.

Perennial Green Manures (PGMs) are plant-based fertilisers made from the harvested foliage of perennial plants, including trees and shrubs grown in what we have termed 'bioservice areas' integrated into farmland. This report will explore whether PGMs could offer a more sustainable way to fertilise crops. Could combining the benefits of organic nitrogen for soil and crop health with the precision of modern agricultural methods increase nitrogen use efficiency and reduce pollution?

Our PGM project ran from May 2022 to July 2024 in the Dyfi Valley, Mid Wales. We supplied PGMs to five horticultural producers who trialled them alongside their usual methods of fertilising crops. We gathered opinions from growers, farmers, foresters and environmentalists on how PGMs could be used for socially, economically and environmentally sustainable agriculture. The project culminated with the planting of five bioservice areas, to provide future PGMs to horticultural enterprises.

The full PGM report is available on the website. In this summary we outline the environmental issues with supplying nitrogen to crops and the ways in which Perennial Green Manures could address these pitfalls. We summarise the research to date on PGM use, including our own trials. We cover the possible implications, obstacles and benefits of growing PGMs at scale, and lay out the further research needed to progress with PGM use for possible benefits to farmers, land managers and the rural environment.

Maintaining high crop yields whilst also improving environmental outcomes is challenging. Farmers face an unpredictable economic climate affecting the prices of inputs, notably fertilisers. Could perennial green manures offer a way to increase farm resilience whilst also contributing to biodiversity restoration and climate change mitigation?

Challenges in sustainable crop production

The recent 'Report of the Nutrient Management Expert Group' (Defra 2024)[1] states the following: "Mitigating and adapting to climate change and protecting environmental quality whilst meeting society's needs for food and other resources is one of the most pressing challenges facing humanity. Nutrient management plays a key role in ameliorating this crisis."

The most common limitation on crop yields is lack of the nutrient nitrogen. Plant roots mostly take nitrogen up in the forms of ammonium or nitrate. These can be increased in soil by adding manufactured fertilisers or by adding nitrogen-rich organic materials such as manures, composts or green manures.

All plant-available forms of nitrogen – manufactured or organic – have been converted from nitrogen gas which makes up 78 % of the air. This process is known as 'nitrogen fixing', a chemical reaction which requires a great deal of energy. Biological nitrogen fixing is performed by some species of bacteria which live in the roots of nitrogen-fixing plants. The plants donate sugars made by photosynthesis to the bacteria which use them to fuel the nitrogen fixing that converts nitrogen gas to forms of nitrogen that plants can use. Nitrogen is also fixed industrially, using fossil fuels to provide the energy to make nitrogen fertilisers.

This process (known as 'Haber Bosch' after the inventors of the technique), results in carbon dioxide emissions, though in future it may be possible to power the process via electrolysis using renewable energy.[3] Supplying nitrogen to crops by use of either industrial or biological methods can have associated environmental problems, as shown in Figure 1.

Biologically fixed nitrogen is traditionally supplied to crops by use of nitrogen-fixing green manures such as clovers and vetches grown in rotations. These are grown on cropland which is periodically taken out of production to increase the soil fertility. The nitrogen fixed in the roots becomes concentrated in the leaves where it performs many vital functions. The green manures are then usually incorporated into the soil by cultivation such as ploughing or harrowing. They can also be killed off by other methods which enable them to be left as a mulch on the soil surface. As they then decompose the soil gains ammonium and nitrate which are used by the next crop.

Nitrous oxide emissions from agricultural soils are a neglected issue in climate change mitigation. It is responsible for 32 % of agricultural emissions in the UK.[2] Nitrous oxide is produced in soil in warm, wet conditions when there is more available nitrogen than the crops can use.

The Nitrogen Problem

Method of nitrogen fixing	Traditional green manures	Manufactured nitrogen fertiliser
	Grown in rotation on cropland. Biological nitrogen fixing using sunlight energy. 	Added to soil as a chemical compound. Fixed industrially using fossil fuel energy. 
CO_2 emissions in production	Carbon neutral	Industrial nitrogen-fixing for fertilisers produces 1 to 2 % of the world's CO_2 emissions
Adding organic matter to soil	Provides organic matter improving soil health and adding carbon to soil	No organic matter provided
Matching of nitrogen supply to the crop's needs	It can be hard to add exactly the right amount of nitrogen at the right time. Too much nitrogen in soil is prone to losses.	Easy to apply exact amounts of nitrogen when and where it is needed by crops
Efficient use of agricultural land	Green manure systems use prime cropland for nitrogen fixing in rotations, so reducing overall yields per unit area.	No extra cropland needed

Figure 1. The nitrogen problem. A comparison of supplying biologically fixed nitrogen by traditional rotational green manures and industrially fixed nitrogen fertiliser, and their associated environmental issues.

The organic matter in green manures is great for soil functioning, feeding soil fauna, and giving soil a spongy structure which helps with water retention and drainage. However, providing nitrogen in this way has some down-sides. One is that they take up space, reducing the land area available for crops. Nitrogen-fixing green manures can be grown in and among crops, and are commonly included in cover cropping mixes over winter which does not interfere with the productive output of the farm. However, to fix a lot of nitrogen, a large amount of space is needed during warm, sunny conditions. Therefore growers who rely on green manures as their main nitrogen source typically set aside one quarter to one half of the cropping area for green manures, including during summer. Taking land out of cropping for nitrogen fixing increases the overall area used for crop production, leaving less for forests and other habitats.

These systems also don't allow much flexibility to add the right amount of nitrogen at the right time. Nitrogen should be added with care. In whatever form the nitrogen is added, the nitrogen compounds in soil are easily converted into forms which can be lost as pollutants, such as nitrates which are leached into watercourses or gas nitrous oxide, a powerful greenhouse gas emitted from soil. Therefore, it's important to add the right amount at the right time to avoid it building up in the soil. This is increasingly possible with manufactured fertilisers using precision techniques, but is more tricky with green manures which are cultivated into soil.

Many growers use bulky soil treatments such as composts and manures which are great for soil health, but there wouldn't be a sufficient quantity to fertilise all our crops this way. It's also important to remember that the nitrogen within them has originally been fixed by either industrial methods or by nitrogen-fixing plants, with their associated environmental impacts.

For example, the nitrogen within animal manure has come from the animals' food. The nitrogen in this food may have been fixed by leguminous plants, in grazed grasslands or within organic systems producing fodder. Alternatively, it could have been produced by industrial processes supplying fertiliser nitrogen to grasslands or fodder crops.

What are Perennial Green Manures and how could they help?

Perennial green manure in dried and pellet form

Perennial Green Manures (PGMs) are long-lived plants including nitrogen-fixing species, and can be trees, shrubs or leafy ground covers, grown in separate areas which we call ‘bioservice areas‘. Though nitrogen is fixed in the roots or taken up from soil, it accumulates in the leaves which are then harvested and added to cropland to fertilise the soil. Unlike in the production of manufactured fertiliser, supplying nitrogen via PGMs does not cause carbon dioxide emissions, and unlike traditional green manures grown in rotation, PGMs can be grown on marginal land e.g. steep slopes or flood-prone areas, making efficient use of farm resources. PGMs provide organic matter so are good for soil health. They can be added at any time (fresh, dried or pelleted) to match with the crop nutrient needs, so increasing efficiency and reducing nitrogen pollution. Figure 2 shows how PGMs could be grown in bioservice areas to provide nutrient-rich leaves to fertilise cropland.

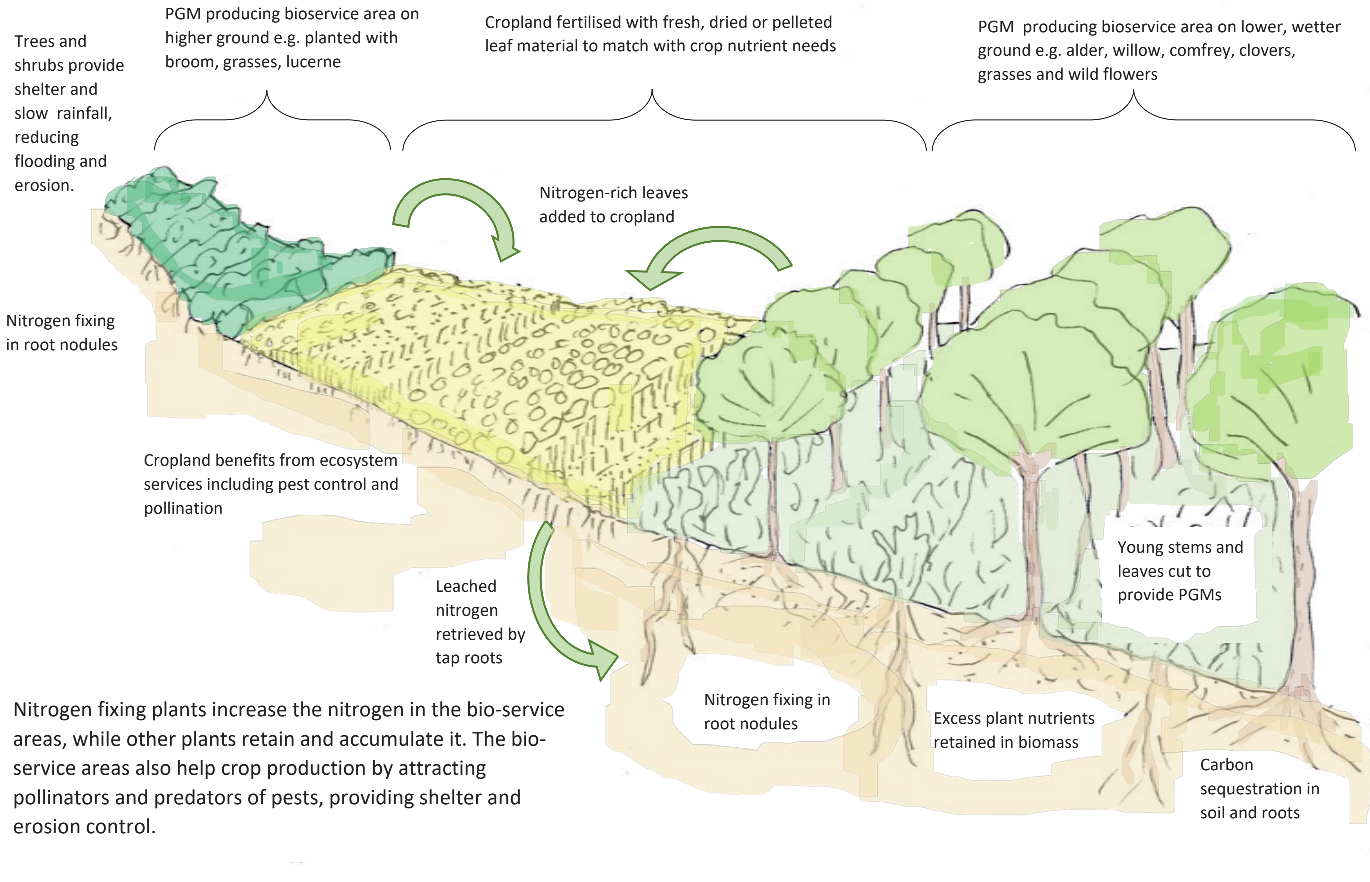


Figure 2. Bioservice area producing PGMs integrated into cropland for maximum ecological and agricultural value.

Could the growing and application of the PGM material offer an elegant way to address the nitrogen problem?

The land where PGMs are grown can be largely left undisturbed, so providing permanent habitat, unlike green manures in rotation. Carbon stores can also build up in the uncultivated soil and roots to mitigate climate change. The bioservice areas can be situated to provide other benefits to crops, for example to reduce wind and water erosion, and to increase beneficial insects that pollinate crops and keep pests in check. Skilled landscape design would be needed to maximise ecological services, and not all land would be suitable for bioservice areas. Land which is already ecologically rich and well managed needs to be preserved as it is.

What plants make good PGMs?

PGMs can be made from the leaves of many different plants – those that fix nitrogen, but also those that are very good at taking up nutrients. Some of these are the same species long used as rotational green manures, such as clovers, vetches, trefoils, and various grasses. Others such as comfrey and nettles have been traditionally used by vegetable growers to make liquid feed.

Trees and shrubs such as alder, willow, broom and gorse can also be used. In fact, any perennial plant that either fixes nitrogen and/or grows fast is a possible PGM – we've only tried out a few of them so far. They can be cut and applied fresh, or dried or pelleted and stored for use at a later time.

Different types of plants have different qualities when used as PGMs. As an example some rot down quickly giving a fast nutrient boost to crops, and some are slow to decompose, releasing nutrients over a longer time. The ratio of carbon to nitrogen in plant tissue is a key factor – a high ratio and the nitrogen takes a long time to get to the crop, a low ratio and nitrogen is usually released quickly. Different PGMs also have varying amounts of other essential nutrients such as phosphorus, potassium or magnesium, so can be added appropriately for the crop's needs.

Development of the PGM method

As far as we know using PGMs grown in bioservice areas this way is not yet practiced in temperate horticulture or agriculture. However similar techniques are becoming increasingly popular. For example the practice of 'crop and drop' is popular among gardeners, in which prunings are dropped from where they are cut onto the soil surface. Some farmers mow fields of green manures and add them to other areas of cropland as 'transfer mulch', 'mobile', or 'cut and carry' green manures. Transfer mulches used in temperate agriculture are usually non-woody, traditional green manures, but in tropical agriculture smallholders do add the green foliage of nitrogen-fixing trees and shrubs to fertilise soil. In the UK the use of fresh or composted woodchip or ramial chipped wood as a soil conditioner is becoming increasingly popular. Ramial chipped wood is made from thin branches (< 7 cm) and is added to soil to provide nutrients and improve soil functioning.[4]

Spreading ramial chipped wood at Tolhurst Organic

Background of the PGM project

Perennial green manure research plots at Bangor University

Use of PGMs was first investigated at Bangor University, researching fertilising crops with foliage from plants including alder trees and gorse bushes. Pot and field trials compared using PGMs to a traditional red clover green manure and to an ammonium nitrate fertiliser. It was found that the PGMs had the potential to fertilise crops successfully with lower risk of nitrate pollution and lower nitrous oxide emissions than ammonium nitrate or clover used in the traditional way.[5] The results of the research at Bangor were sufficiently encouraging to suggest it would be worth going on to develop methods for the use of PGMs. We designed the subsequent PGM project to explore a wide range of factors in PGM use, such as considering the practicalities and logistics for farmers.

The Perennial Green Manure trials

Tilly recording potato growth at Ash and Elm Horticulture

The Perennial Green Manure trials took place in the Dyfi Valley in Mid Wales, between February 2023 and February 2024. The aim of the trials was to assess the effects of using PGMs in a range of real-life situations. We sought to recruit both organic and conventional growers, however there are few large-scale arable or horticultural growers in Mid Wales and uptake to join the trials was exclusively from small-scale organic producers. Though we collected data on crop yields and soil characteristics, the trials were just as much about gaining insights from the growers' experiences.

The plants we used as PGMs are shown in Figure 3. We chose species which are abundant or easily grown in Wales and provide good habitat for wildlife. Some are nitrogen-fixing plants, and others are good at scavenging nutrients and retaining them in the system. They were applied dried, pelleted or fresh. Foliage of alder, willow, and clover was collected in late summer and dried and the leaves separated from the branches. The leaves only were retained for use in spring because leaves contain the most nitrogen with an appropriate carbon:nitrogen ratio. Some of the dried alder and clover was also milled and pelleted by the Beacon Project at Aberystwyth University. Grass and gorse were harvested and applied fresh, and comfrey was bought in as ready-made pellets. Samples of all PGMs were analysed for nitrogen, carbon, phosphorus, potassium and magnesium, and sulphur.

Red Clover (*Trifolium pratense*): A nitrogen-fixing leafy ground cover

Gorse (*Ulex europaeus*): A nitrogen-fixing spiky shrub, native to the UK, which is tolerant of windy and dry conditions

Alder (*Alnus glutinosa*): A nitrogen-fixing tree, native to the UK, which thrives in wet ground

Grass (various species): Grasses make good ground cover which protects soil, and takes up and retain nutrients

Comfrey (*Symphytum officinale/S x uplandicum*): A herbaceous perennial with deep roots to take up nutrients from deep in the soil

Willow (*Salix* species): Fast-growing trees which are tolerant of wet ground and poor soil

Figure 3: PGMs used in the trials

Our trial methods

We chose the PGMs which we thought would best fertilise each crop (Table 1). They were applied at rates to supply enough nitrogen to the crop as advised in the widely used Nutrient Management Guide (RB209)[6], taking into consideration the original soil nitrogen content and the likely speed of PGM nitrogen release. We aimed to match the supply with crop requirements by using combinations of slow-release PGMs (called PGM1 in the table) such as alder, and fast-release PGMs (PGM2) such as comfrey which were added for a nutrient boost when needed.

Five horticultural growers trialled PGMs on one or more of their usual crops, including potatoes, courgettes, kale, beetroot and lettuce

We compared this with a control where nothing was added to the soil and also with the growers' usual method of fertilising the crop e.g. composts or manures in the quantity they normally apply. The composts and manures added were weighed and samples were taken and analysed to calculate the quantity of nitrogen added. If space allowed, we included two or three duplicate plots of each treatment (replicates) to make the trials more scientifically robust.

Alder leaves

We tested the soil for nutrient content before and after the trials, measured the yields, and the growers kept a lookout for any other effects on the crops.

Table 1. PGMs used in the trials. See the full report for details of trial designs.

Trial	PGM 1	PGM 2	Crop(s)	Usual soil addition	Number of replicate plots
1. Einion's Garden	Alder	Clover	Early potatoes	Horse manure	2
2. Ash and Elm	Alder	Clover	Main crop potatoes	Horse manure	3
		Grass			
3. Dan yr Onnen	Alder	Comfrey	Beetroot/kale/ chard	Bagged compost	2
	Willow	Comfrey			
	Alder				
	Willow				
4. Centre for Alternative Technology	Alder	Clover	Lettuce/kale/ daikon/kohlrabi	Own compost	1
5. Enfys Veg	Gorse	Comfrey	Courgettes	Green waste compost	1

Outcomes

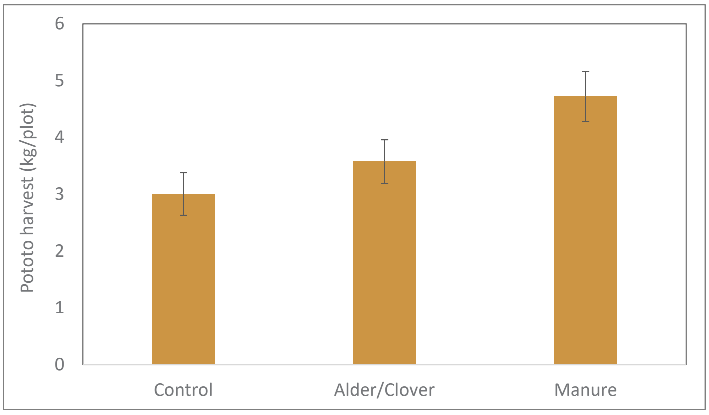
Ruth recording courgette yields at Enfys Veg

Harvesting, processing and applying PGMs

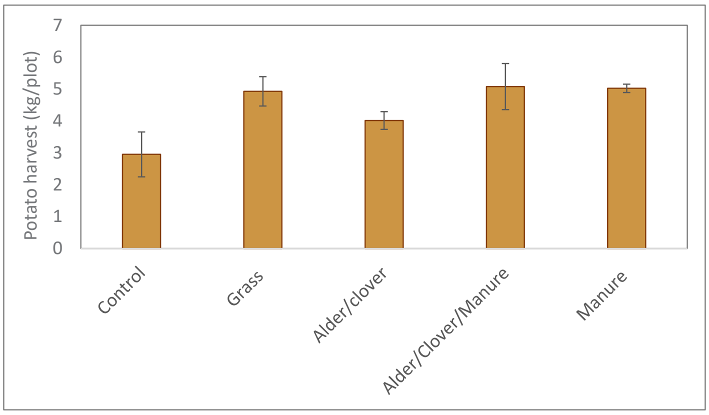
The pre-harvesting, drying and pelleting of PGMs successfully produced a fertiliser which was compact to store and could be applied to soil in precise quantities. Application of fresh PGMs however, which were harvested from nearby the cropping areas, was less time and energy consuming, but with the exception of evergreen PGMs this has the disadvantage that timing is restricted by the seasonal growth of the PGM plants. Harvesting the tree foliage by hand was time consuming, as was the separation of leaves from branches, though drying the foliage makes removal of the woody material much quicker. The energy consumption of the pellet production was high and further research is needed to assess whether this can be reduced as discussed on page 20.

The PGMs had nitrogen contents ranging from 2.3 to 3.6 % of dry matter, which was similar to that of the manures and composts. Different PGM species had differing qualities, including carbon:nitrogen ratio, and varying quantities of other macronutrients which can be used tactically for appropriate crops.

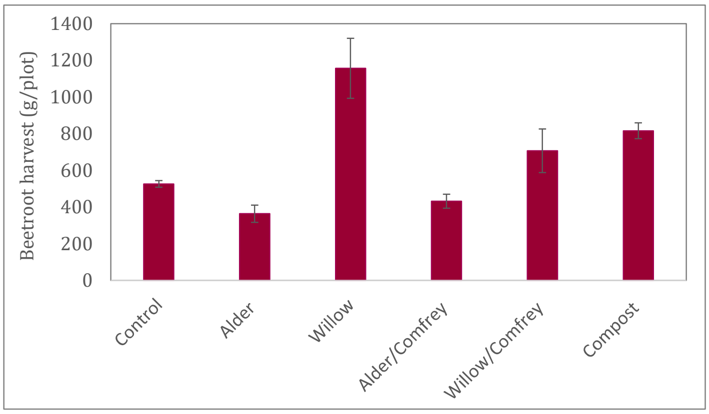
Effectivity of PGMs on crop yields



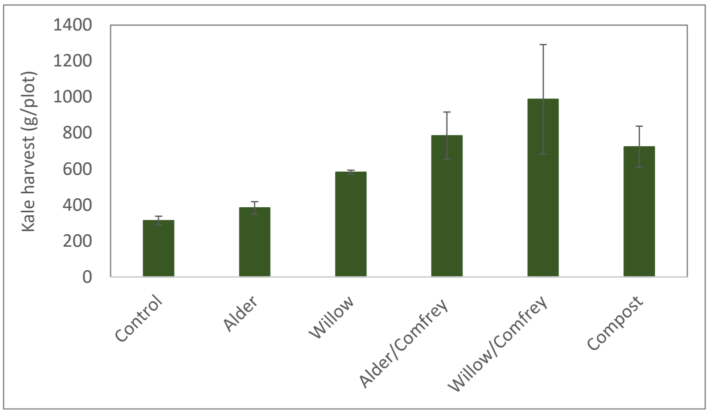
Trial 1 Crop yields in early potatoes



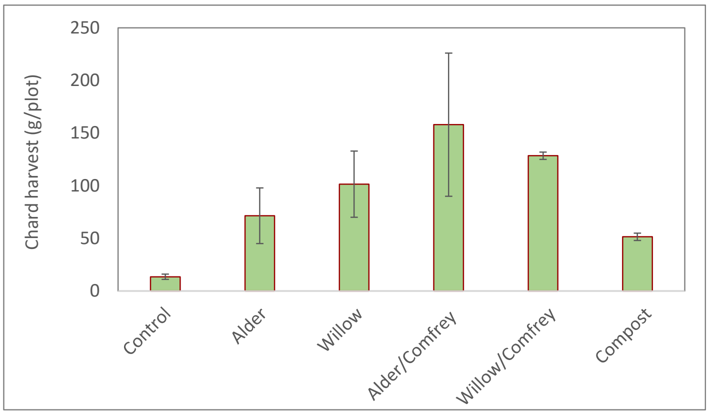
Trial 2 Crop yields in maincrop potatoes



Trial 3 Crop yields in beetroot



Trial 3 Crop yields in kale



Trial 3 Crop yields in chard

Graphs of crop yields in trial 1: early potatoes, trial 2: main-crop potatoes, trial 3: beetroot, kale, and chard.

In trials 1 and 3 error bars represent the range between the two replicate harvests. In trial 2 error bars are standard errors of the three replicates. Yields from trials 4 and 5 which did not have replicates are included in the main report.

Across the trials there was a general trend of PGM-fertilised crops having higher yields than the unfertilised control crops, and the results confirmed that PGMs have very different effects depending on the species used. Willow leaves were only used in one trial, but were surprisingly effective in increasing yields of beetroot which were harvested just three months after being planted as plugs into soil with willow added. Alder did not appear to be effective in the short term, but results indicate that it may have increased the yield of chard harvested 10 months after the alder addition. This suggests that alder is best used to provide fertility over a very long timeframe.

Growers were keen to try out an organic fertiliser that they could produce themselves. "*Once we have established alder, willow and comfrey patches on our site, we will have access to this fertility whenever we need it, free of charge for many years.*"
Lucy, grower at Dan yr Onnen

Gorse was used in just one trial, and like previous field trials it did not boost yields and possibly had a stunting effect. This may be due to a chemical constituent of the gorse leaves which prevents growth of other plants, an effect known as allelopathy. Clover, comfrey, and grass, as expected, were all effective in boosting yields. All of these results need to be treated with caution however, as the trials were limited in the number of replicates and though there were clear trends, results were not always statistically significant.

Though the PGMs increased yields over the control, PGM-fertilised crops mostly had lower yields than crops fertilised with manures or composts. It's difficult to interpret these results as the amount of nitrogen added in the grower's own additions was always higher than that added in the PGMs. The nitrogen application rate varied from 328 to 812 kg N/ha in growers' usual additions, whereas PGM N was applied at 200 to 300 kg N/ha. These differing amounts of nitrogen addition occurred because we supplied the amount of nitrogen within PGMs that we estimated the crops should need, but left the growers to add their usual soil treatments without influence from us, only calculating the amount of nitrogen added afterwards. Although this has made it harder to make direct comparisons it has provided useful knowledge on common practice of small-scale producers, and gives rise to questions as to whether the quantities of their usual soil treatments could be reduced.

The influence of environmental conditions on the speed of PGM decomposition is an important factor for future consideration. There was very dry weather in the early summer of 2023 which may have reduced the efficacy of PGMs in some trials, and this could be overcome by irrigation or by using fresh PGMs instead of dried when appropriate.

Spreading alder for the trials at CAT

Effect of PGMs on soil

The differences between macronutrient content of the various PGMs and the other organic additions could be seen in the soil at the end of the trials. For example, in one trial the plots which received additions with a high potassium content showed higher potassium concentrations in the soil at the time of harvest. In another trial, the yields of a potato crop appeared to be limited by a low potassium content in the soil of some of the plots. This suggests that PGMs could be used more strategically with regard to macronutrient content to increase crop yields. Various soil characteristics also affect soil fauna, and knowledge on soil health and plant-microbe interactions may in the future enable most appropriate PGM use for improved nutrient cycling.

Growers are keen to experiment further on the benefits for soil health. ***"I'd like to try them over a longer period of time, fresh, just put through a small shredder as a thin surface mulch. In summer, I see a lot of worm activity, I find a lot of leaves pulled into the ground by worms and I'd like to see whether they'd do that with alder or willow."***
Ann Owen, Einion's Garden

The trialists found the dried and pelleted PGMs very easy to apply, and commented that they would be easier to store and transport than composts and manures. Three of the five trialists said they would potentially buy PGMs if commercially available in the future, but others wanted to keep a closed loop system of nutrient supply. Growers commented that the dried or pelleted PGMs did not appear to benefit soil structure in the way that compost or manure did, and that PGMs which were dried but not pelleted risked being blown away after application and so needed to be dug into soil rather than mulched.

Dan yr Onnen trial after treatments added

Dan yr Onnen trial

Other trials

In a smaller trial, two participants experimented with adding dried PGMs to potting compost. One found that adding dried clover to potting compost when growing kale seedlings in modules considerably increased the growth of the seedlings over potting compost alone. This could be a useful strategy for improvements in potting compost for home and commercial growers.

Trial pack

Alongside the PGM project trials, master's student Maria Cooper researched PGMs for her dissertation on Sustainable Food and Natural Resources, at the Centre for Alternative Technology. Maria experimented with fertilising kale plants with leaves of alder, gorse and broom, and found that alder and broom successfully fertilised the kale with yields as good as those from manufactured fertiliser. The kale developed deep tap roots when fertilised with the PGMs which they didn't when fed with fertiliser. This could be a very beneficial trait if we were able to use appropriate PGMs to influence root growth for greater drought resistance or nutrient-scavenging ability when needed. Read more about Maria's project in our full report available online.


Maria Cooper's pot experiment for her master's dissertation on PGMs

Feedback from stakeholders

We took PGMs on the road, including experimenting with methods of chopping foliage, and gathering views from farmers at Talybont agricultural show

Throughout the project we discussed possible opportunities and implications with farmers, foresters, ecologists, and others with an interest in the rural landscape. Farmers and growers were keen to reduce expenditure on fertilisers, but expressed reservations about the cost-effectiveness of growing, harvesting and applying their own PGMs. Many saw opportunities in mixing in plant wastes from other sources such as from roadside hedge trimmings, forestry waste and clearing of bracken or invasive species. One organic grower who currently uses rotational leys to build fertility commented that it is a necessary part of the system to rest the soil periodically, but many small-scale growers said they do not have enough land to periodically have land out of cropping.

> ***"I think the pellets are a great idea, for ease of use, convenience. A great replacement for chicken pellets... On-farm production would be tricky, but these could be produced on scale at a dedicated coppice woodland and sold as a fertiliser boost."*** **Emma Maxwell, Ash and Elm Horticulture**

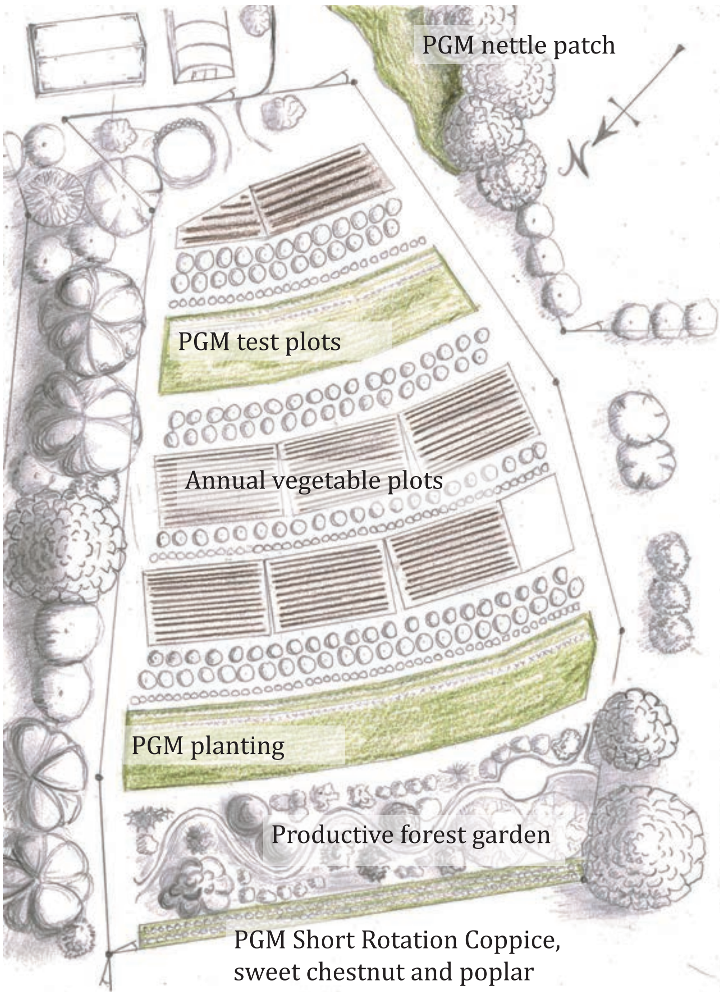
In wildlife-rich bioservice areas, the harvesting of PGMs needs to be undertaken in such a way to minimise disturbance to wildlife and keep to regulations, for example when hedge-cutting with regard to nesting birds. Research is needed into models of PGM production to enable this. Some expressed concerns over the possible visual impact on the landscape if PGM production were to become more common, for example if trees were grown in lines to enable harvesting. A fear was also raised that PGM production could be taken on by large businesses who may not grow them in an ecologically sensitive way, but instead create monocultures for industrial production. Farmers also raised the issue that tenancy agreements often forbid the planting of trees.

Tilly cutting alder with a brash cutter at Talybont Agricultural Show

Bioservice area planting

Rashid Benoy and students planting bioservice area at Black Mountains College

The final stage of the project was the planting of five bioservice areas for the future experimentation and provision of PGMs. These range from a simple comfrey patch to a complex design of over 12 different species to provide PGMs to a 2.5-acre vegetable plot at Black Mountains College in the Bannau Brycheiniog in South Wales. Species include willows, poplars, Italian alder, clover, Jerusalem artichoke, lupins and miscanthus. Horticulture tutor Rashid Benoy plans to experiment with different ways of harvesting and adding the PGMs and will measure the effects on crops and soil characteristics, including genetic analyses of the soil fauna.



The plan (right) for Black Mountain College shows bioservice areas in yellow/green shading and annual vegetable beds in brown shading with rows of trees & shrubs between. A 3-metre-wide track on the northwest side of the bioservice plots will provide room for composting and/or drying of cut PGM material.

Possible models of PGM systems

The design of PGM-fertilised cropping systems would differ depending on the landscape itself and whether the PGMs were cut and applied directly or harvested and processed for future use. In very varied landscapes there is scope to situate bioservice areas on land which is less suitable for crops, and design systems for the retention of nutrients on a landscape scale. For example, bioservice areas next to watercourses can take up leached nutrients which can be returned to cropland within the PGMs. In more uniform landscapes hedgerows could be restored or widened into bioservice areas, increasing protection against soil erosion, especially if supported by appropriate polices and subsidies. If processing PGMs into a saleable product, PGMs could be grown some distance from where they are applied. Therefore, there may be scope for PGMs to be widely grown in areas of lower grade agricultural land, particularly in areas of higher rainfall which are naturally less suited to arable and horticultural production.

For direct application of PGMs the use of alley systems with alternating strips of cropping area and bioservice area could enable PGMs to be harvested and applied by hand or by using cutting and mulching machinery. These could be leafy ground covers, herbaceous plants or trimmings from tree and shrub growth. There are various strategies which could be researched to separate nitrogen-rich tree leaves from the carbon-rich branches. For example, cutting leafy branches, laying them in rows next to cropland until dry and then using a leaf blower to move the lighter leafy material off the branches to spread over soil. Alternatively, it may be most efficient to harvest only the leafy non-woody plants for nitrogen-rich material and cut the woody tree growth in winter for chipping into ramial wood. In this way nitrogen-fixing trees would still contribute to the nitrogen production of the whole system, because each time they are coppiced they have a reduced nitrogen demand. Thus nitrogen fixed in the roots becomes available to neighbouring plants.

The amount of land which would be needed for PGM production is hard to predict and would depend on many factors including the climate, bioservice area site and soil and harvesting methods. Nitrogen fixing rates for traditional green manures are estimated at around 100 to 250 kg N/ha per year, which is a similar amount to that typically applied to crops. However, nitrogen offtake has been measured as high as 300 to 640 kg N/ha per year from regular cutting of permanent stands of alfalfa, white clover, red clover, and red clover/ryegrass mix in Denmark.[7] In theory, including trees and shrubs would result in more nitrogen fixing due to greater capture of sunlight energy in a three-dimensional system. However, some of the energy would go into wood production and harvesting of the nitrogen may be less efficient from woody plants.

This project explored PGM use in small-scale horticulture. But could PGM use be scaled up to suit arable production? Could this increase farm resilience to an unstable climate, while also mitigating climate change by carbon sequestration and carbon-neutral nitrogen fixing?

Movement of plant material from one area to another can be a risk in spreading plant diseases, and diseases of various tree species are on the rise in the UK. Because of this, we commissioned tree pathology consultant Alistair Yeomans of FloraSec to assess and advise on the mitigation of any risks that PGM systems may pose. The report can be accessed here. https://tinyurl.com/PGM-risks

Planting willow and alder at Dan yr Onnen

Energy costs of PGM production

Milled clover

The amount of energy needed to harvest and apply PGMs is a key factor in its environmental impact. If PGMs were to be produced as a product the process would typically include harvesting, drying, chopping/milling and pelleting. Pelleting would likely be an energy-intensive part of this. For the pelleting in our trials, the hammer mill (for grinding the material) and pellet mill had a power draw of 6.5 and 25 kW respectively, resulting in a total energy cost of 0.982 kWh to make 1 kg of alder pellets and 0.976 kWh to make 1 kg of clover pellets. Considering the nitrogen contents this translates to 34.09 kWh and 30.03 kWh to make 1 kg of N within alder and clover pellets respectively. This energy cost does not compare well with industrially produced nitrogen. Milling and pelleting vary greatly in energy consumption depending on the material, scale and energy efficiency of the machinery used, however. Literature on production of pelleted material for biomass or animal feed shows much lower energy use is possible, for both grinding (in the region of 0.005 to 0.04 kWh per kg) and pelleting (in the region of 0.044 to 0.09 kWh per kg).[8] Similarly other stages in the production of pellets, such as machinery used for harvesting, would vary in their efficiency and energy costs and research is needed into this.

How could policy and economics affect the potential for PGM use?

As with any other agricultural system, the feasibility and financial implications for farmers are influenced by land-use regulations and available subsidies. Agricultural policy in the UK is currently in flux due to new subsidy schemes being drawn up in each devolved nation after Brexit. Bioservice areas may be eligible for economic support aimed at encouraging tree planting and increasing biodiversity, but as the concept of PGM production is a new one eligibility is unclear.

Across the UK there are regulations to prevent nitrogen pollution, especially in sensitive areas called 'Nitrogen Vulnerable Zones' (NVZs) which cover large areas including the whole of Wales. Legislation on NVZs is set by each devolved nation, but generally restricts nitrogen application, whether in mineral fertiliser or from organic sources, to below 250 kg per hectare within any 12-month period. Guidance for farmers on the application of slower-release organic nitrogen in less conventional materials is limited and the applicability of NVZ rules to PGMs is unclear. It may be beneficial for guidelines to be more flexible in considering very slow nutrient release rates from less conventional materials.

> ***"Farmers need to go further than current 'best practice', for effective nutrient management that meets society's needs and challenges. Such significant change is unlikely to be achieved without considerable support from policy."***
> **Nutrient Management Expert Group[1]**

Next steps for PGMs

Increasing the sustainability of food production needs to be treated as urgent. Nitrogen use has been a neglected issue with far-reaching consequences for the environment, food security and livelihoods. Throughout the PGM project we worked with many people with an appetite for finding solutions. We think that the trials showed that PGMs could have real potential to increase the sustainability of crop production. We don’t however want to create a fad, without sound scientific evidence for its benefit. There is still much to consider, explore and research.

Using PGMs to fertilise crops takes a big shift in thinking, and requires very different systems to be put in place. Could a technique which at present seems niche and impractical become a commonplace and common-sense practice in the future? Both formal, scientific research, and practical logistical innovations are needed, some of which have been highlighted in the text above with the symbol and listed on the next page.

Following on from this project, Innovative Farmers – a UK network of farmers and growers running on-farm trials – are planning a field lab on PGMs. The participants will be trialling the application of alder leaves and grass cuttings on brassica crops and monitoring crops yields and soil health. See the Innovative Farmers website to find out more.

www.innovativefarmers.org

Willow leaves

Calling growers, farmers, researchers, environmentalists and policymakers...

Perennial green manure research plots at Bangor University

Do you think PGMs could contribute to sustainable food production? If you are involved in land management or food production could you incorporate exploring PGMs into your work? Might it be eligible for funding or studentships?

Ideas for research

- the impact of PGMs on soil health and nutrient cycling, in the short term and over many years
- lifecycle analyses of PGM systems for climate mitigation
- collating a database of nutrient content, chemical characteristics and nitrogen release rates of a wide range of potential PGM species
- the effect of long term continued harvesting on the bioservice areas, for example possible depletion of phosphorus or potassium
- design and management of bioservice areas for maximum wildlife value

Ideas for innovation

- efficient methods for harvesting PGMs in a variety of situations including steep slopes and boggy land
- processes for efficiently separating nitrogen-rich tree leaves from carbon-rich branches
- energy-efficient processes for drying or pelleting PGMs
- create pelleted PGMs which are robust enough to be used in a conventional fertiliser spreader

Ideas for discussion

- how to maximise the benefits of slow-release organic additions and how this relates to current legislation on nitrogen vulnerable zones
- would PGM systems be eligible for subsidies for environmental services on farms such as tree-planting or hedgerow-restoration grants?
- could farming subsidy schemes offer more support for practices such as bioservice areas which combine habitat creation and benefits to agriculture?
- how could legislation prevent mismanagement or poor design of PGM or other woodland-creation projects which would not be environmentally beneficial?

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The full report contains details of all the individual experiments, the background to the technique and future possibilities. We hope that it will serve as a toolkit for those wanting to explore PGMs further.

Ann Owen – Einion's garden – with dried alder