Should we grow nitrogen on trees? Perennial Green Manures for greater nitrogen use efficiency and ecological resilience

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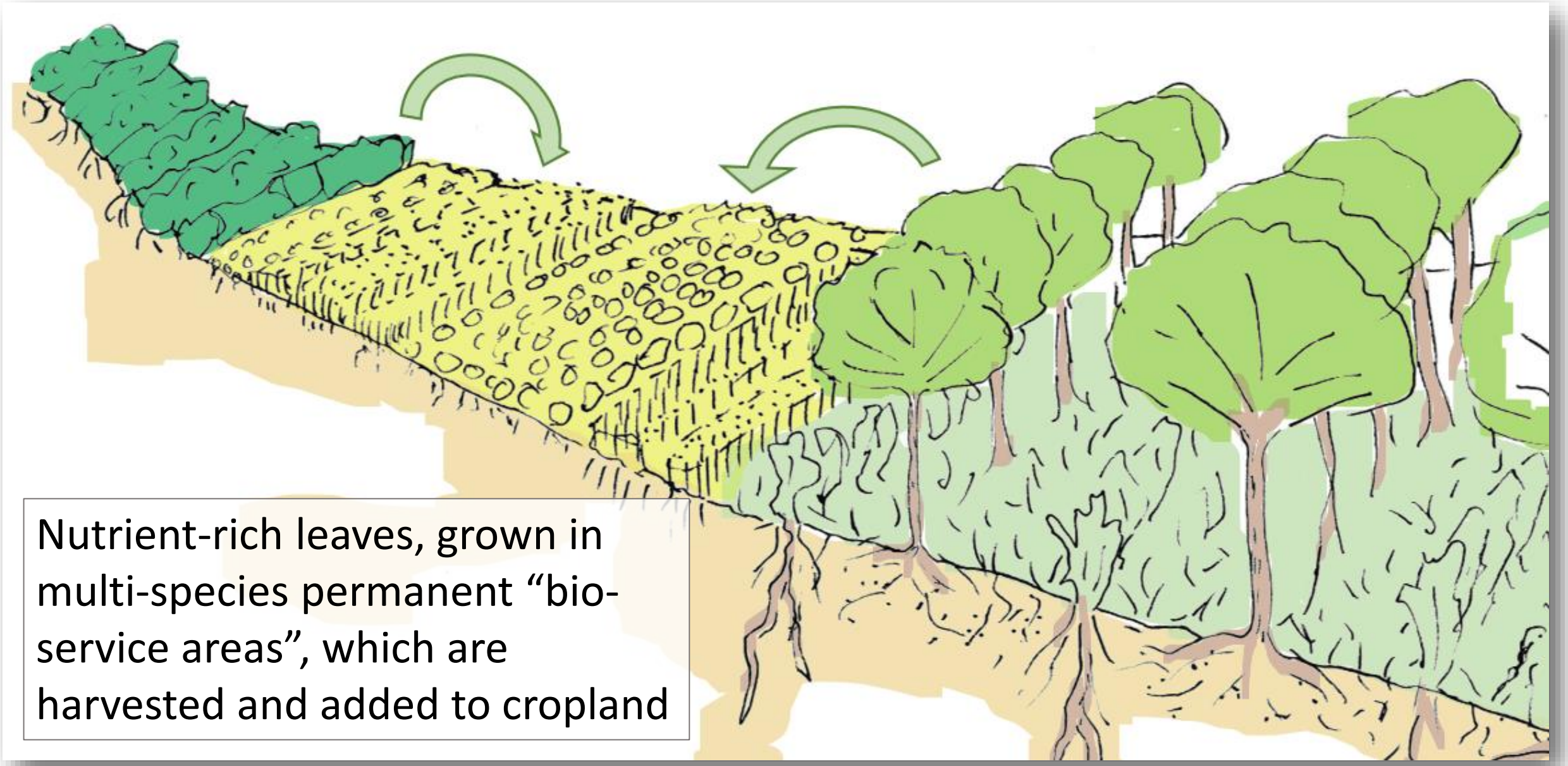
FoU-dagarna 2024

8th November

Alder leaves and nitrogen fixing nodules (*Alnus glutinosa*)

Perennial Green Manures (PGMs)



Nutrient-rich leaves, grown in multi-species permanent “bio-service areas”, which are harvested and added to cropland

Research at Bangor University, see
https://doi.org/10.1007/s10705-022-10253-x

Follow on horticultural trials:
https://www.dyfibiosphere.wales/perennial-green-manures

Nutr Cycl Agroecosyst
https://doi.org/10.1007/s10705-022-10253-x

ORIGINAL ARTICLE

Potential to improve nitrogen use efficiency (NUE) by use of perennial mobile green manures

C. R. Ward · D. R. Chadwick · P. W. Hill

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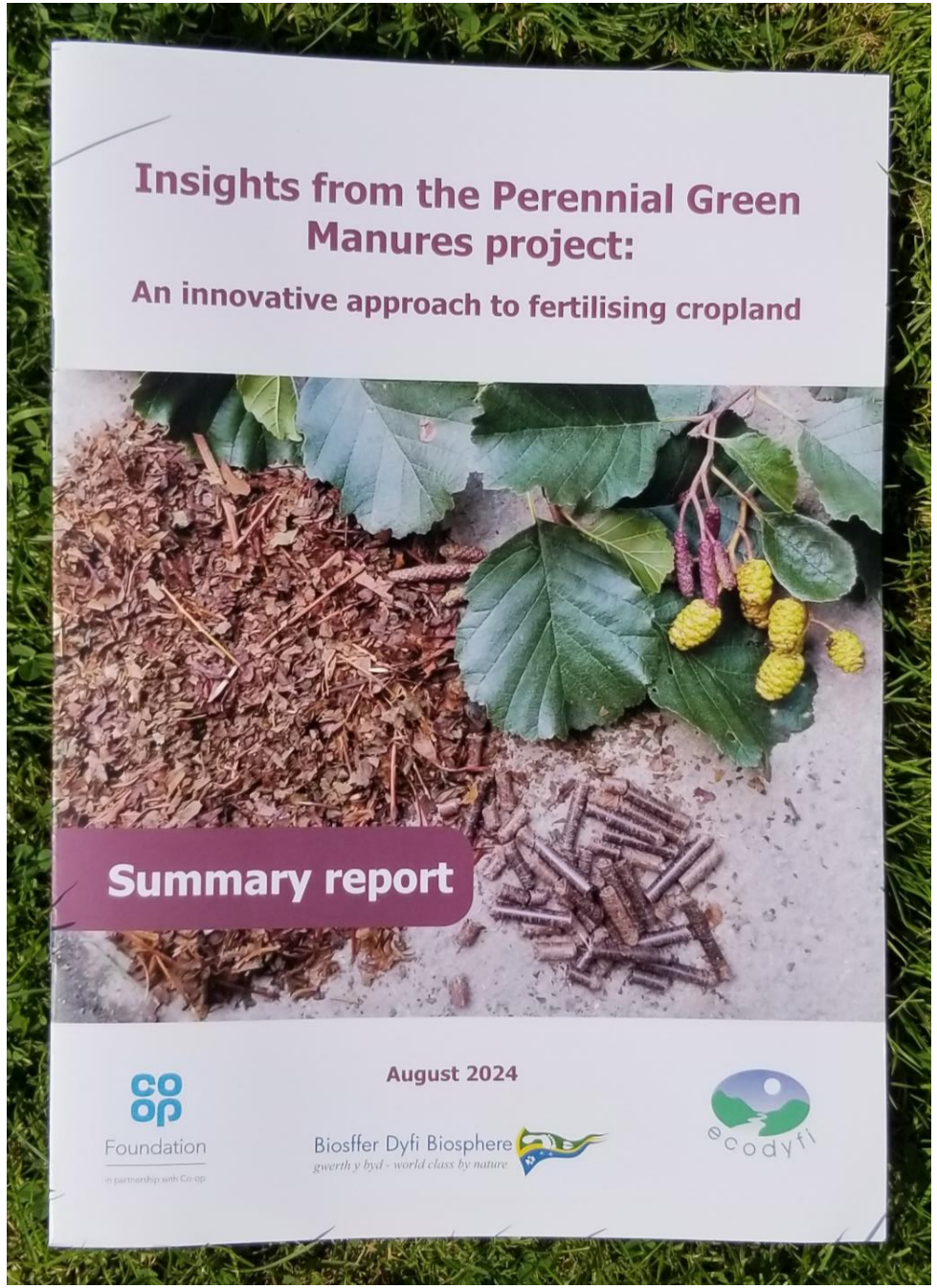
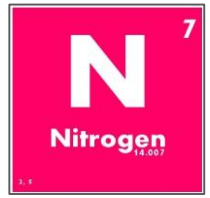
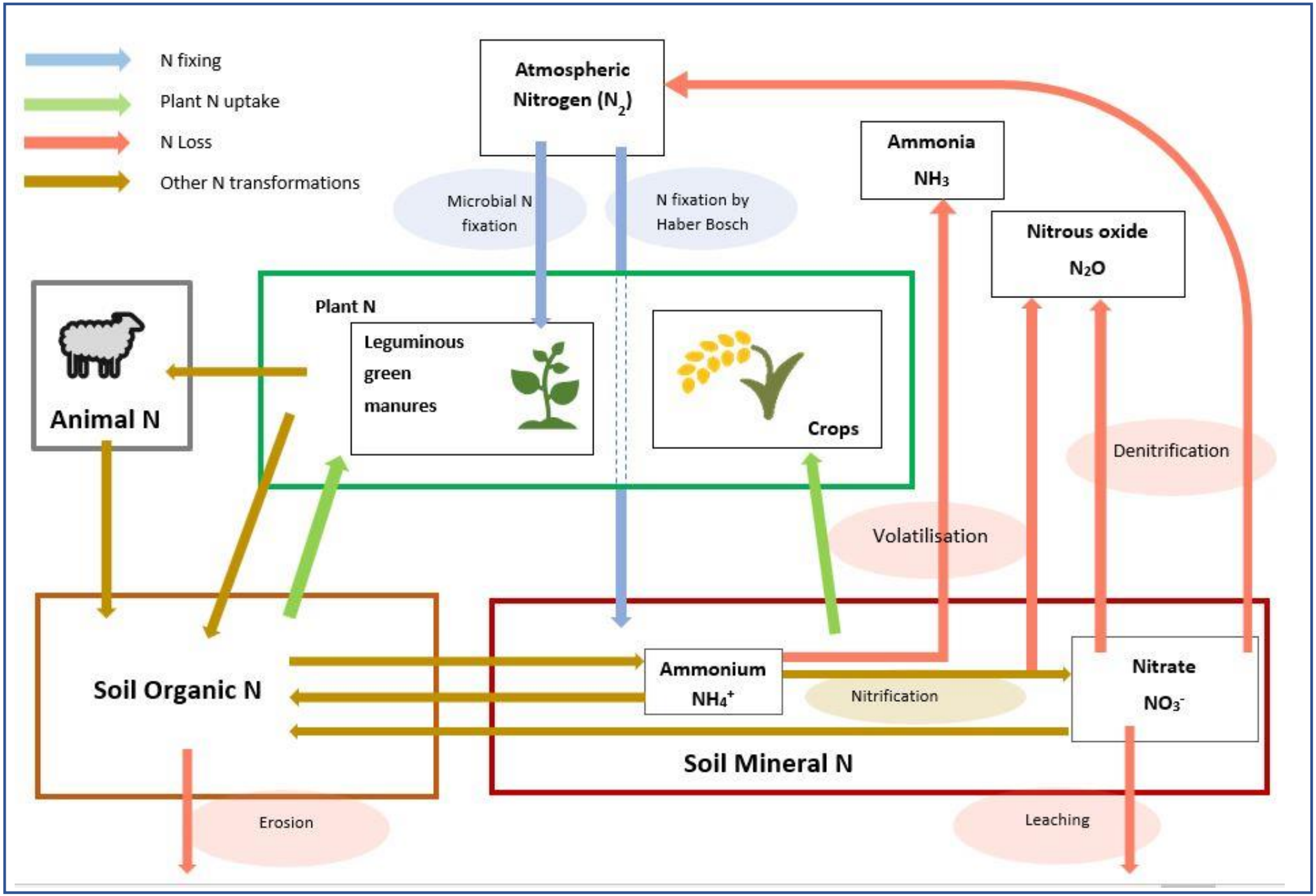
Abstract Supplying nitrogen (N) to crops by incorporating N_2-fixing green manures into soil can improve soil functioning and increase soil carbon storage. However, as with N-fertiliser use, excess min- from only 14 kg NH_4NO_3-N ha^{-1}, but after two yearly harvests with annual gunnera additions it increased to 70 kg NH_4NO_3-N ha^{-1} $year^{-1}$ equivalent. In a 1-year pot experiment, PMGMs resulted in equal or higher



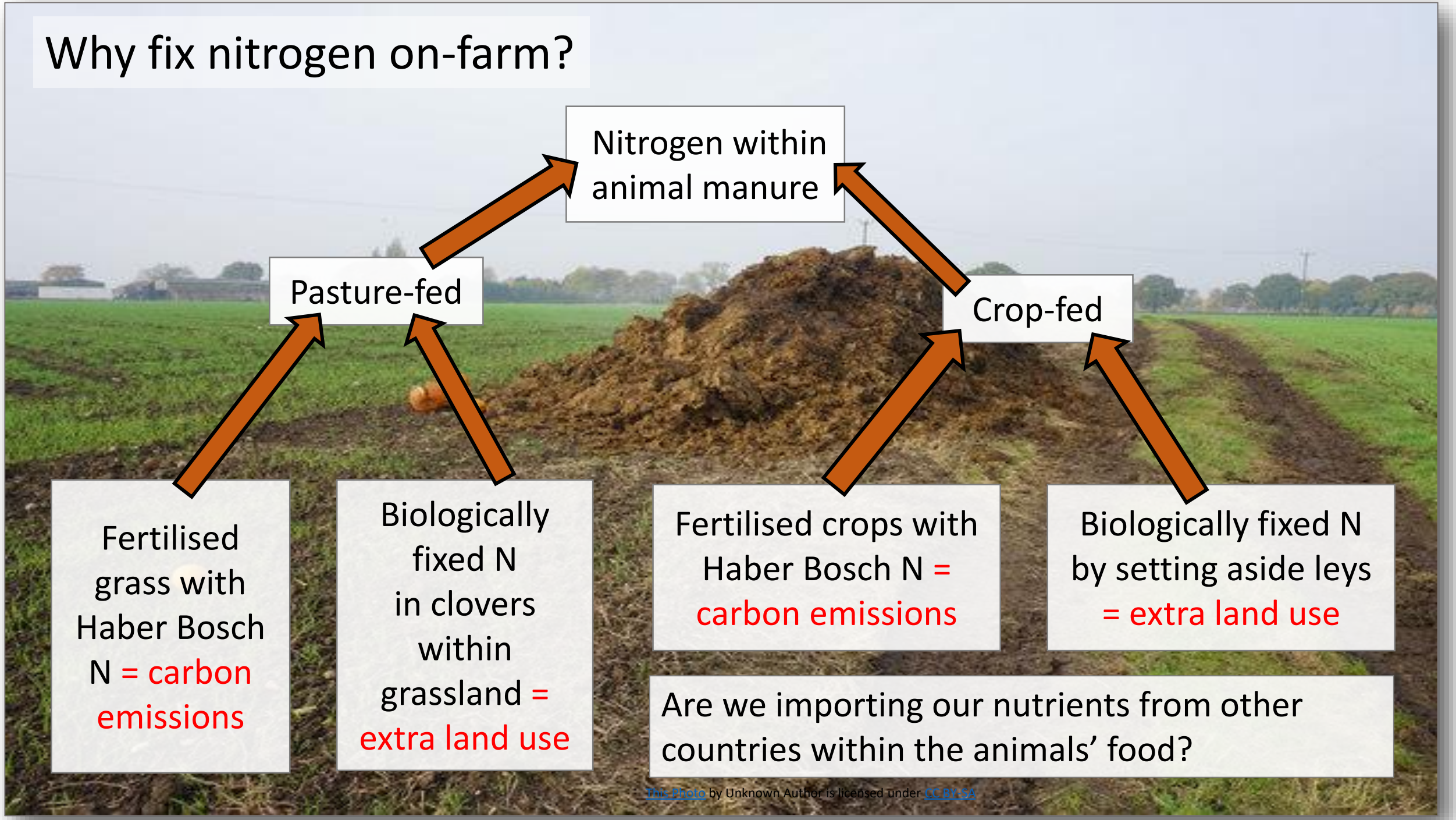
The Nitrogen Problem…

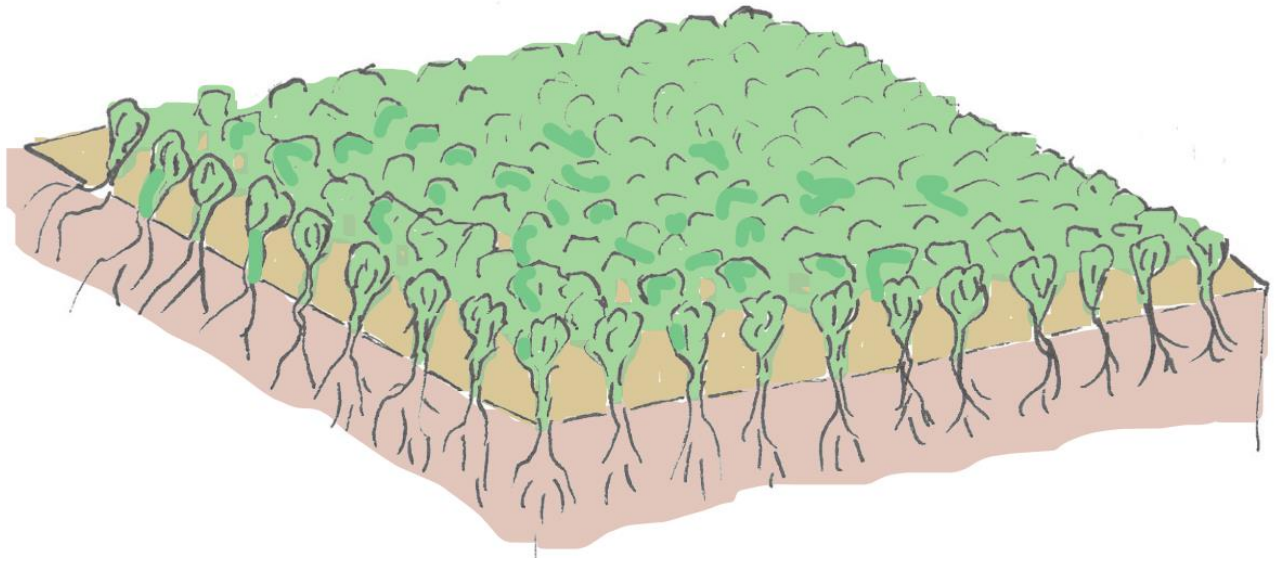


Method of N fixation	**Biologically fixed N supplied via green manures** 	**Manufactured N fertiliser via the Haber Bosch process** 
Negate CO_2 emissions in production?	Carbon neutral 	Produces 1 to 2 % of the world's CO_2 emissions (But this might change….) 
Add organic matter to soil?	Yes 	No 
Enable synchrony of supply and demand?	Difficult to achieve 	Allows targeting of N 
Efficient use of agricultural land?	Requires use of agricultural land 	No land requirement 


N fixing
Plant N uptake
N Loss
Other N transformations
Atmospheric Nitrogen (N_2)
Ammonia NH_3
Nitrous oxide N_2O
Microbial N fixation
N fixation by Haber Bosch
Plant N
Leguminous green manures
Crops
Animal N
Denitrification
Volatilisation
Soil Organic N
Ammonium NH_4^+
Nitrate NO_3^-
Nitrification
Soil Mineral N
Erosion
Leaching

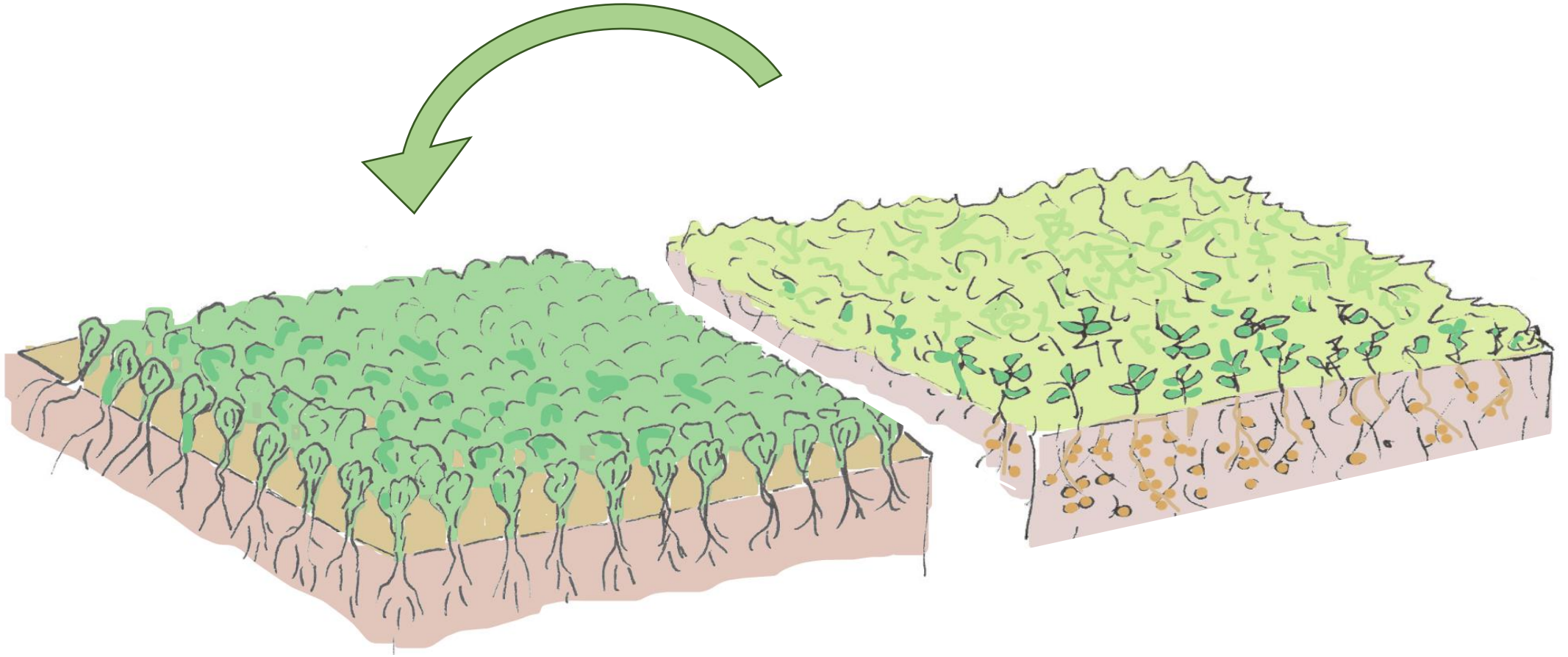
Why fix nitrogen on-farm?





Green manures grown in rotation

Mobile green manures



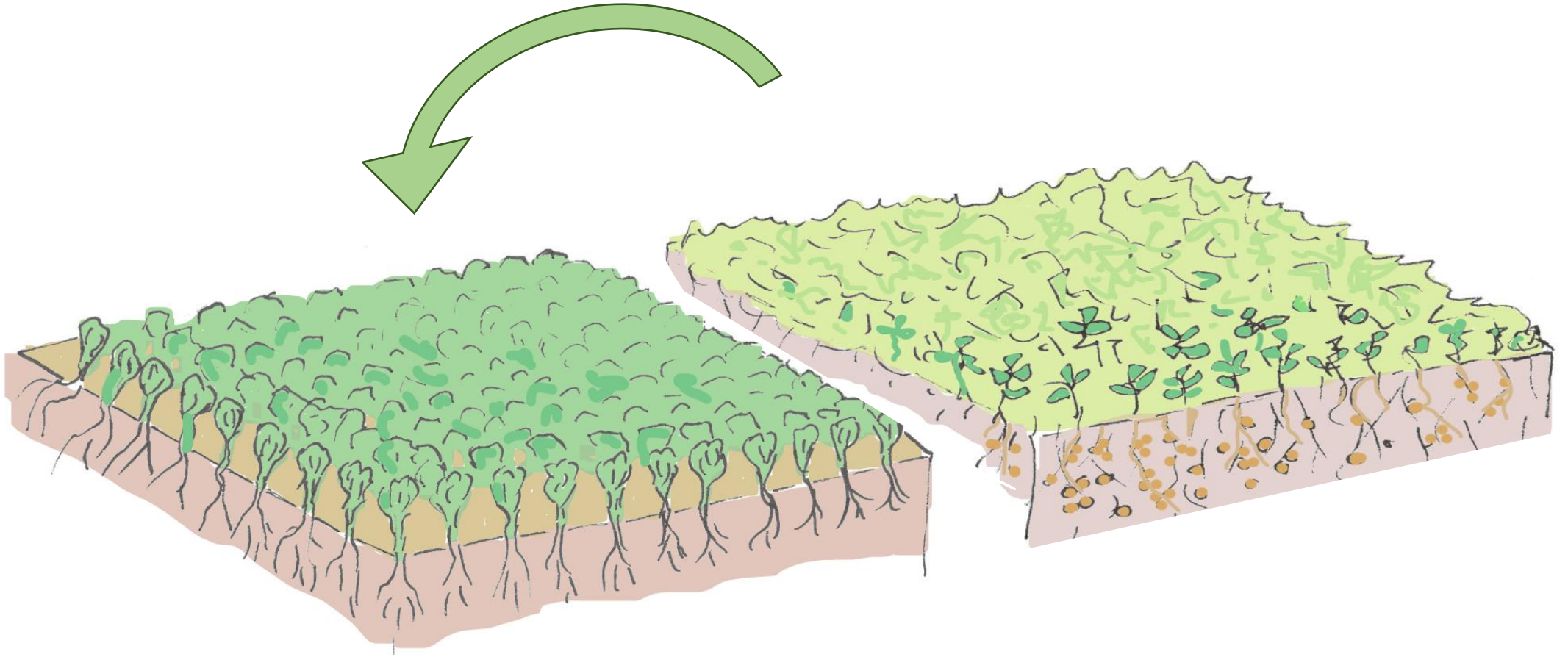
‘Mobile’ green manures or ‘transfer mulch’

Potential advantages over rotational green manures:

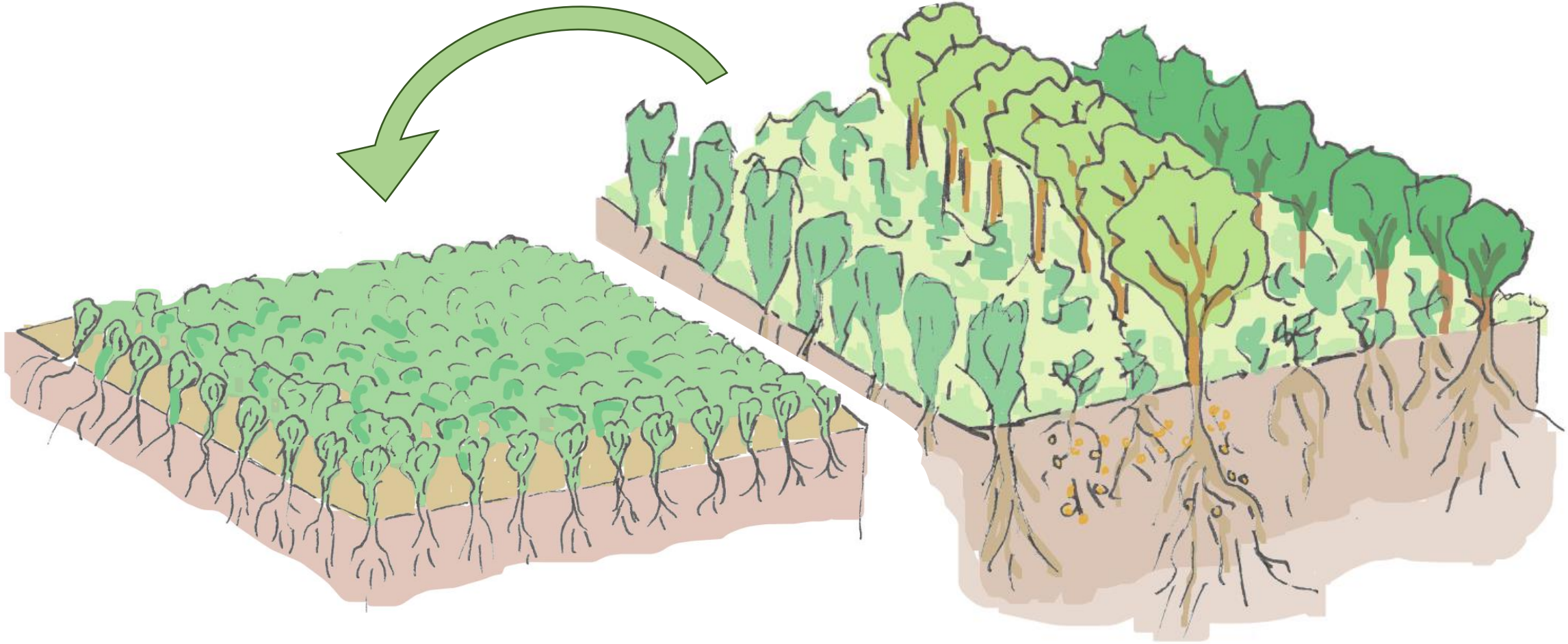
- Improve N synchrony by storing and adding when needed
- Could improve carbon sequestration as the green manure areas don’t require ploughing

N offtake has been measured as **300 to 640 kg N/ha/yr** in Denmark in harvests from permanent stands of alfalfa, white clover, red clover, red clover/ryegrass mix (Lynge et al 2022 https://doi.org/10.1002/jpln.202200031).

Mobile green manures



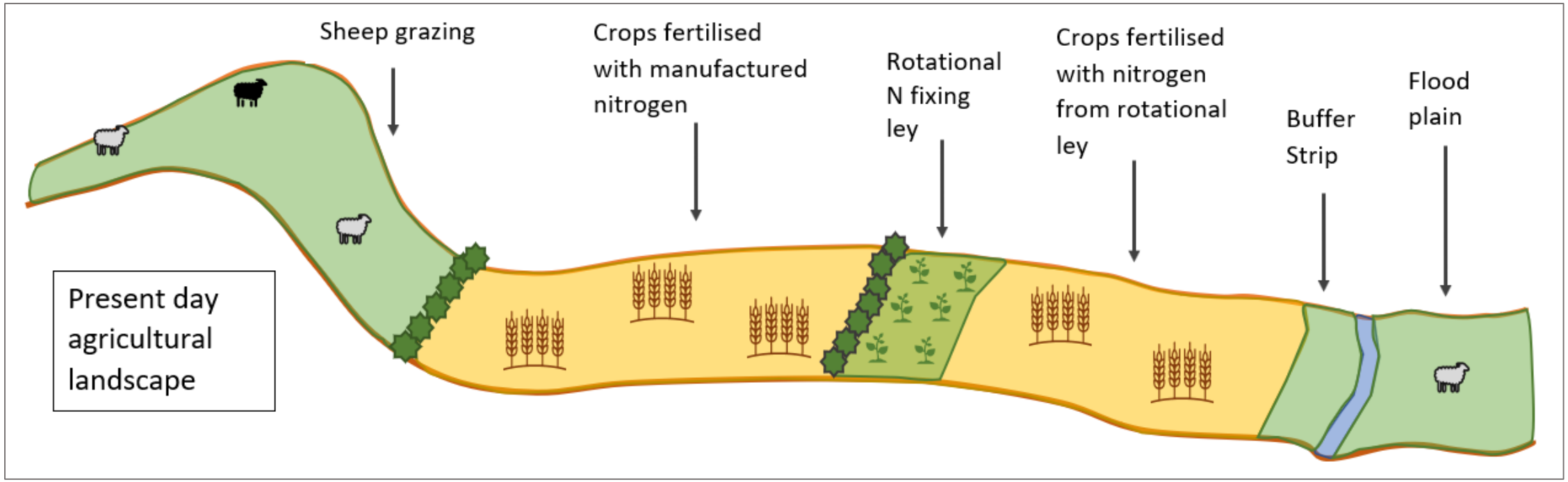
Perennial mobile green manures (PMGMs/PGMs)

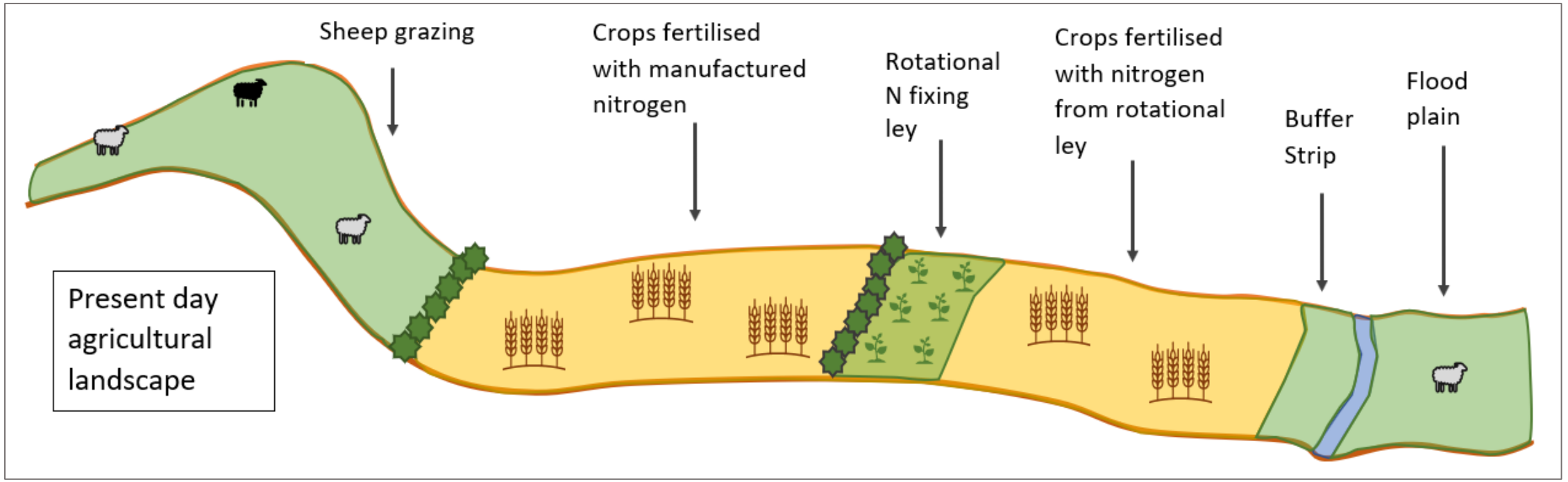


Perennial Mobile Green Manures (PMGMs/PGMs)

Further advantages:

- Environmental advantages of increasing tree cover – a fertiliser producing forest?
- Agro-ecological advantages of shelter, water regulation reducing floods and droughts, increasing biodiversity for pollination and pest control
- Could improve land use efficiency by using plants which can tolerate a wide range of conditions, so making use of non-prime land e.g. flood prone areas, exposed areas


Sheep grazing
Crops fertilised with manufactured nitrogen
Rotational N fixing ley
Crops fertilised with nitrogen from rotational ley
Buffer Strip
Flood plain
Present day agricultural landscape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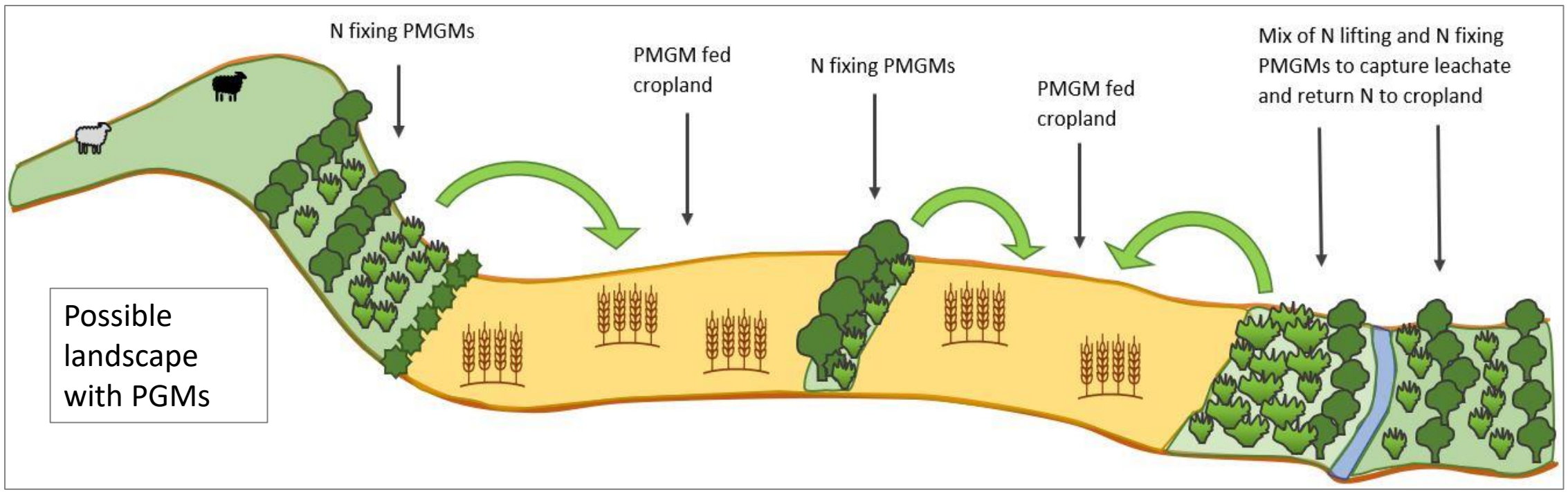
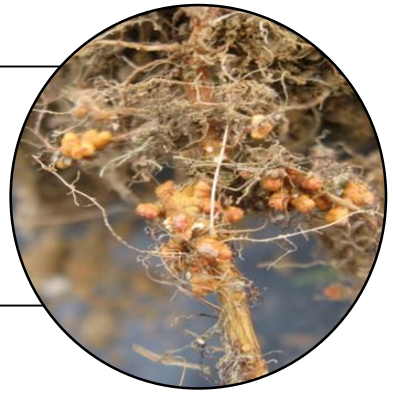
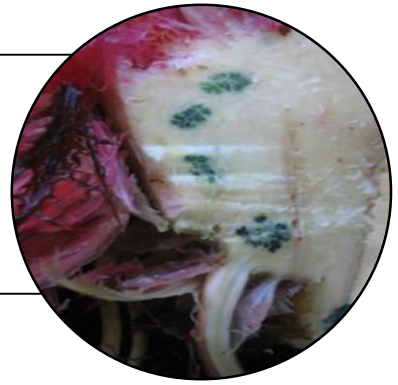

N fixing PMGMs
PMGM fed cropland
N fixing PMGMs
PMGM fed cropland
Mix of N lifting and N fixing PMGMs to capture leachate and return N to cropland
Possible landscape with PGMs

At **Bangor University** we researched three perennial nitrogen fixing plant species to see if they could supply N to crops, and measured the yields, soil nitrate and nitrous oxide emissions.

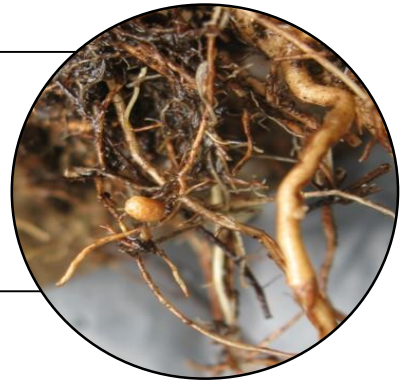
Alder
Alnus glutinosa

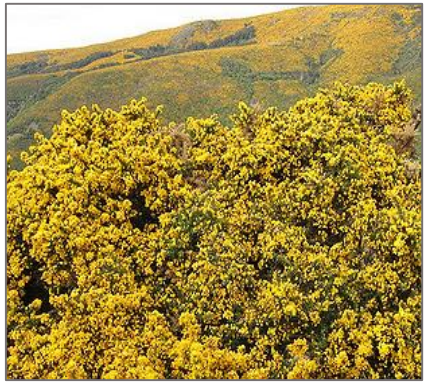


Gunnera
Gunnera x cryptica



Gorse
Ulex europaeus





But any perennial plant that grow fast and would be ecologically beneficial could be a PGM species

e.g. other N fixing perennials:

Clovers, Vetches, Trefoils, Lathyrus, Lupins, Broom, Tree lupins, Italian alder, Laburnum, Wisteria, Eleagnus, Acacias, Myrica, Genista, Robinia, etc.

and nutrient lifting/accumulating species

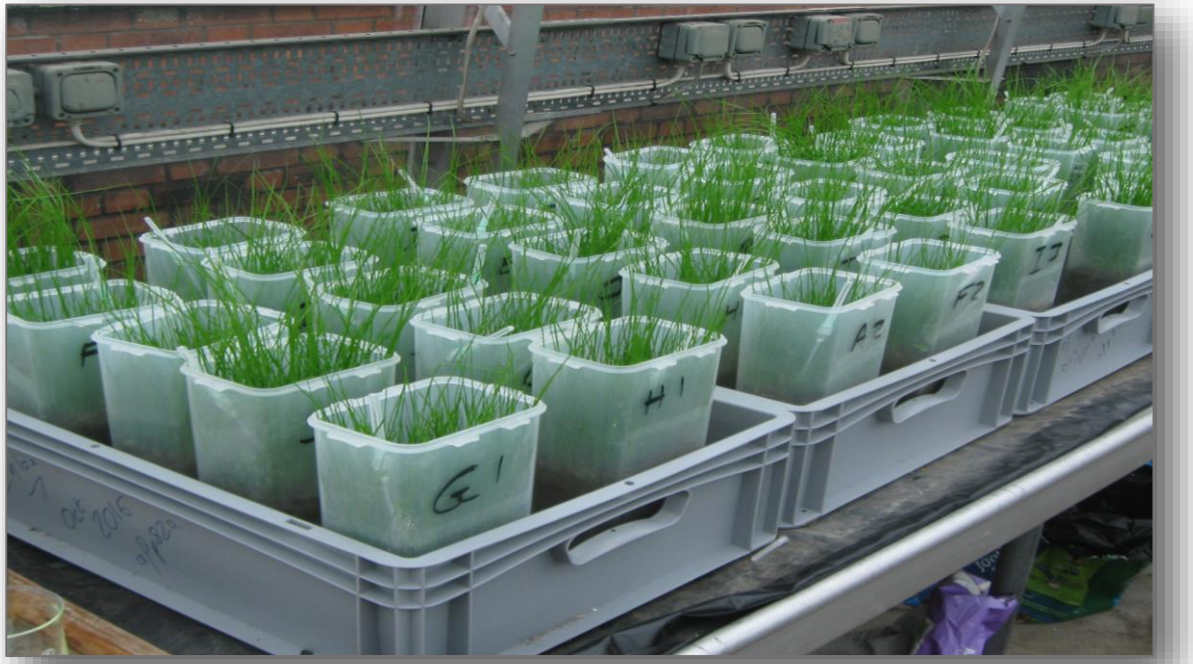
Grasses, Comfrey, Hops, Honeysuckle, Vines, Brambles and Rubus species, Jerusalem artichokes, Willows, Hazel, Hawthorn, Dogwood, Viburnums, Prunus, etc

1 year pot experiment and 2 year field experiment:

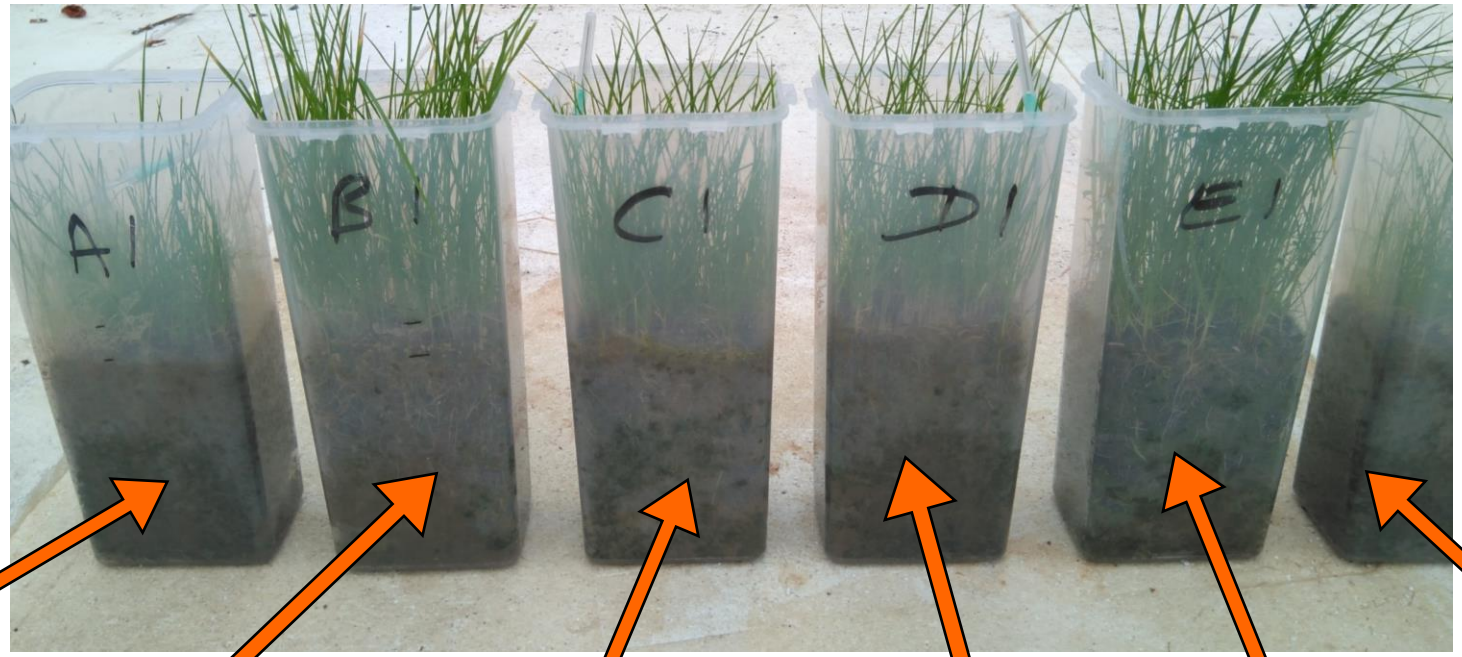
How do PGMs perform compared to traditional green manures and manufactured fertiliser?

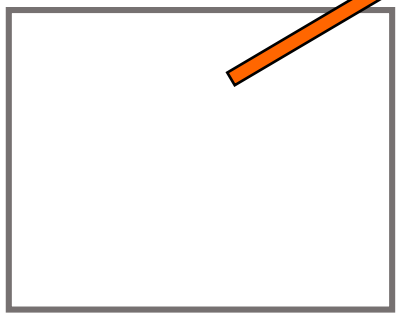
Fertilised crops with fresh or dried leaves of alder, gunnera and gorse compared to red clover and ammonium nitrate fertiliser and measured:

- Crop yields
- Crop N uptake
- Nitrate concentrations in soil
- N_2O emissions



Treatments were incorporated into soil and crops sown
Samples taken of crop biomass, soil solution and gases emitted from soil





No addition

Ammonium nitrate

Clover C:N 10:1

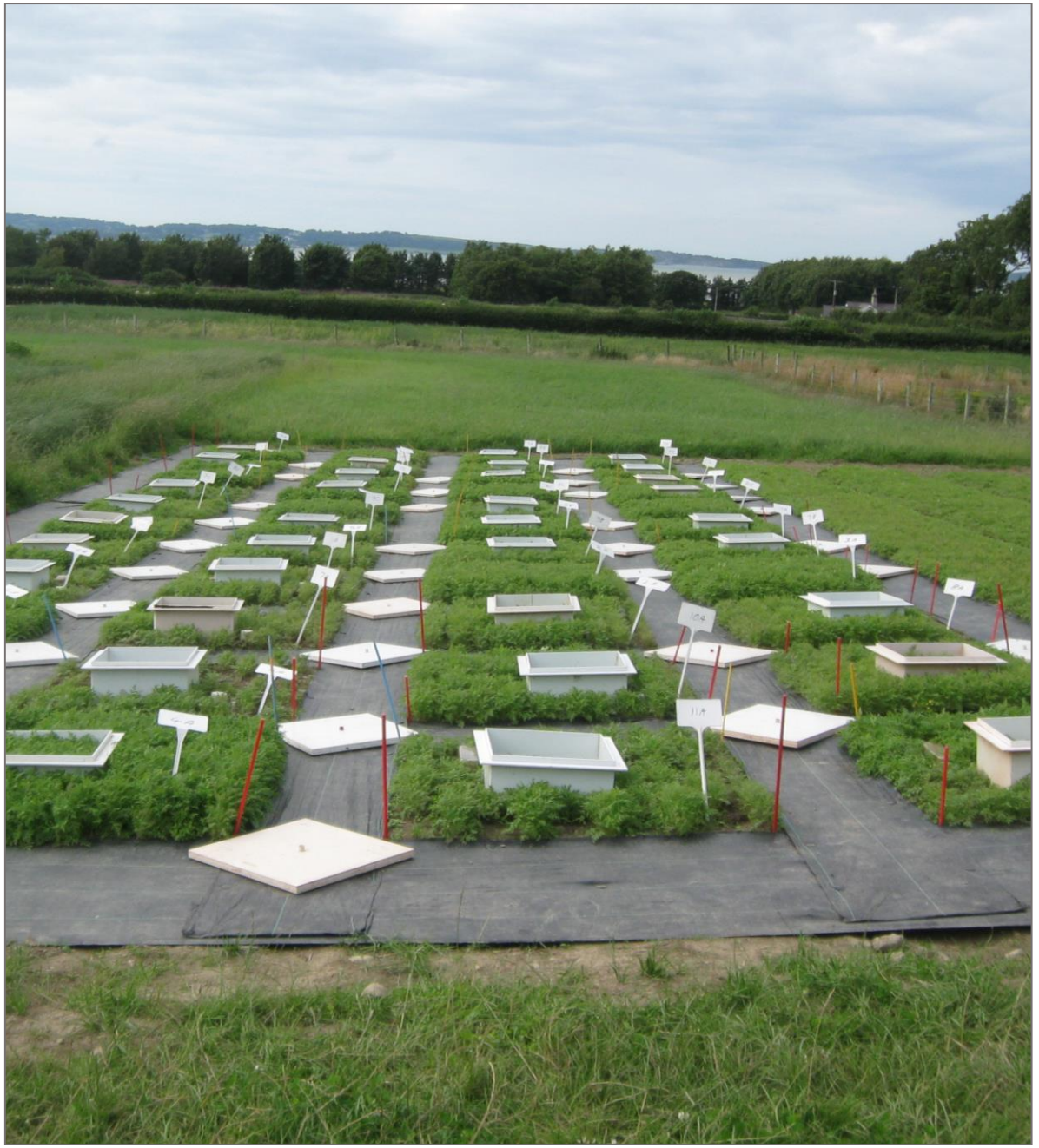
Gorse C:N 26:1

Gunnera C:N 20:1

Alder C:N 15:1

Bangor research conclusions:

- PGMs resulted in **a slower, but effective supply of nitrogen**, which became more effective the second year of addition in the field
- PGMs resulted in **lower nitrate in soil solution**
- **In a pot experiment - lower N_2O** emission factors from alder of 0.60 % and gunnera of 0.34 % of N added, compared to > **5 % of clover N and > 3 % of ammonium nitrate N**. NB, in warm, moist conditions optimal for N_2O.
- Possible allelopathic effect on crop growth from gorse.



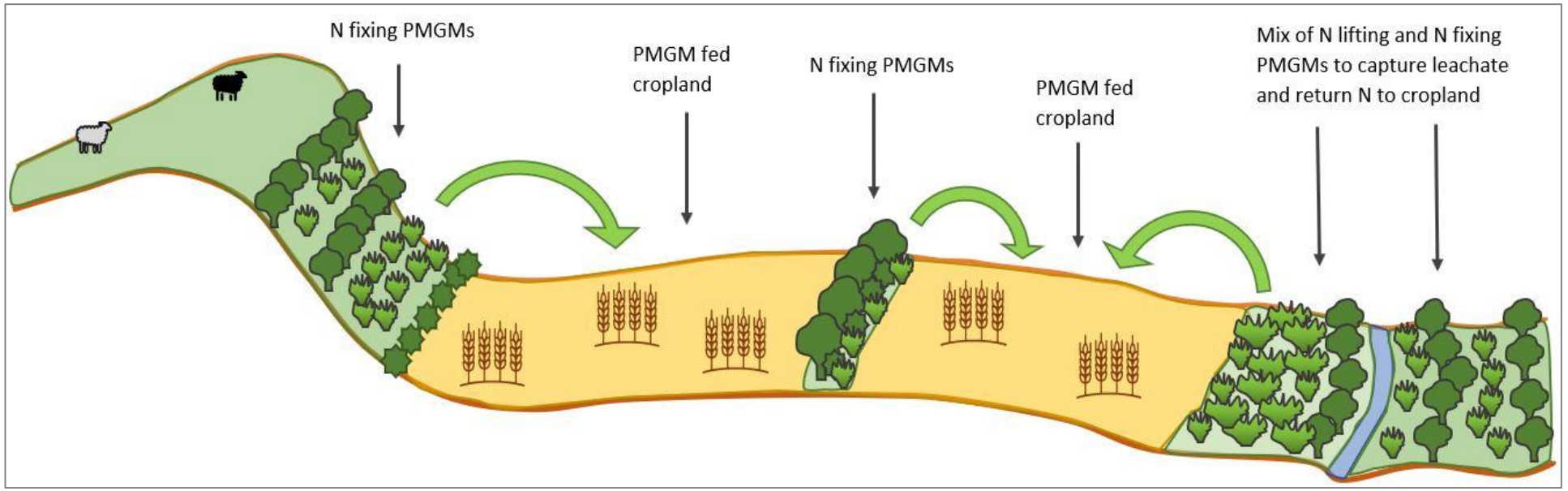
The Perennial Green Manure Project

Conversations and on-farm trials of dried and pelleted PGMs using:

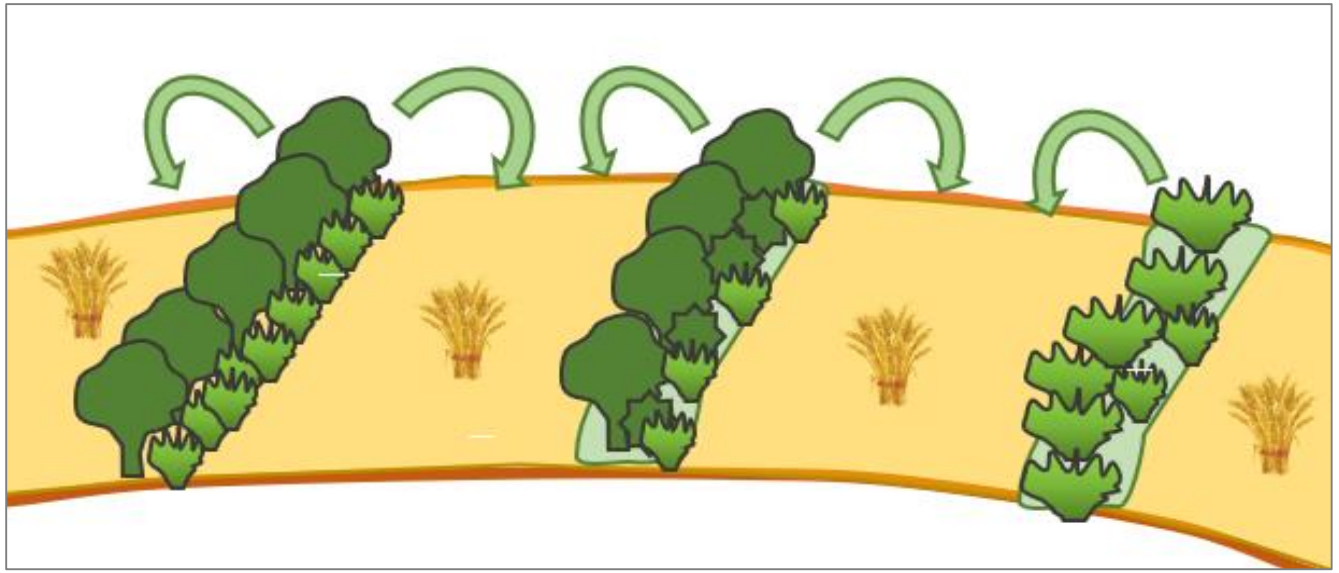
N fixers:	N lifters:
Alder	Willow
Clover	Comfrey
Gorse	Grass

Could PGMs work on a farm scale?

Integrated into the landscape



An alley system?



As a processed product?

Summer/autumn 2022: Collected and dried/pelleted perennial green manures

Spring/summer/autumn 2023: Growers' trials

Winter 2023/4: Planting of new bio-service areas

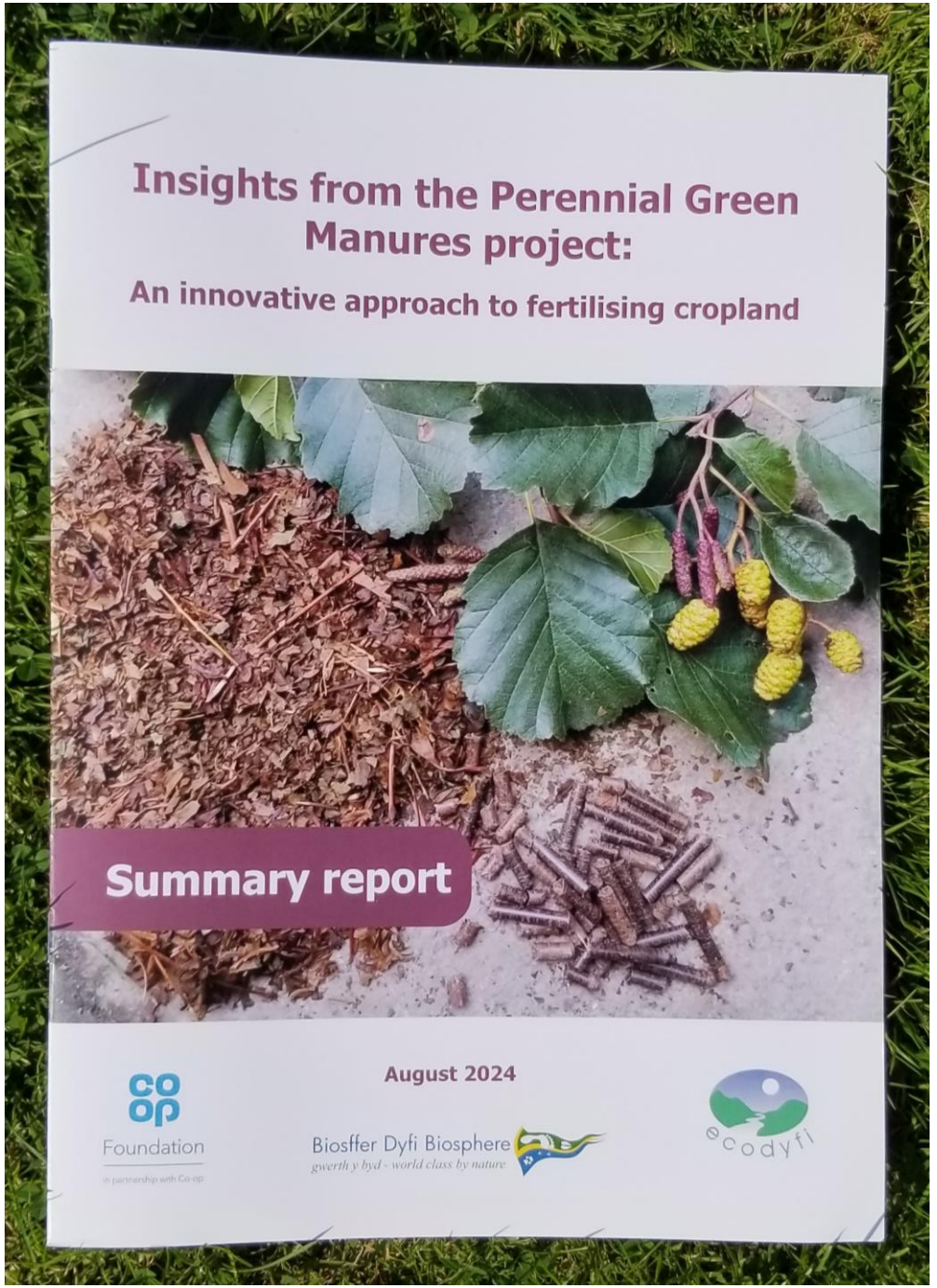
PGM 1	PGM 2	Crop	Usual soil addition
Alder	Clover	Potatoes	Horse muck
Alder	Clover Grass	Potatoes	Horse muck
Gorse	Comfrey	Courgettes	Green waste compost
Alder/ Willow	Comfrey	Beetroot/Kale	Bagged compost
Alder	Clover	Kale	Own made compost
Alder	Clover	Wheat	Chicken manure pellets

Insights from the Perennial Green Manures project

- Small scale growers are adding a lot of nitrogen in manures and composts (between 300 and 800 kg/ha)
- PGMs performed well considering the lower amounts of N added
- Five bioservice areas planted for future PGM production

Future research needs include:

- collating a **database** of characteristics and nitrogen release rates of a wide range of potential PGM species
- the **long term impact of PGMs** on soil health
- **quantify nitrogen fixing** in diverse bioservice areas including trees and shrubs
- **efficient methods** to harvest, process and apply PGMs
- **the effect of long-term continued harvesting of PGMs** on the bioservice areas, for example possible depletion of phosphorus or potassium



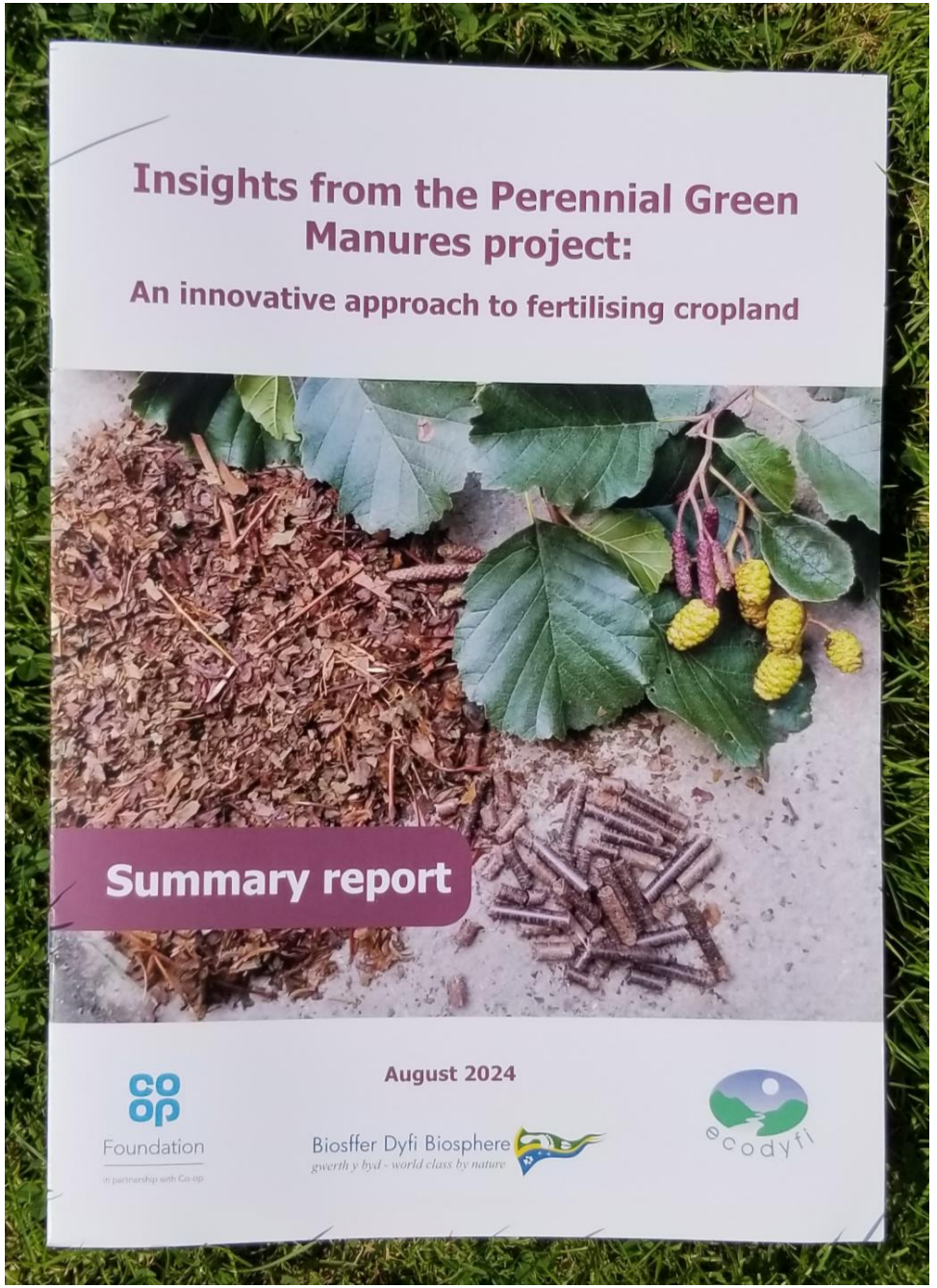
Future possibilities for maximising efficiency of organic nitrogen use:

- In well functioning soil, nitrogen cycles in and out of soil organic matter. Do we need to shift away from conventional measurements of efficiency such as nitrogen recovery efficiency and consider **nitrogen use efficiency over a greater scale in time and space?** (Congreves et al 2021)

- **Uptake of intact organic nitrogen molecules:** Evidence that plant roots and mycorrhizal fungi are capable of taking up amino acids and small peptides - therefore bypassing the risk of N loss from soil. Plant breeding to restore affinity for organic uptake into new crop varieties could therefore increase organic nitrogen use efficiency. (Farzadfar et al. 2021).

Congreves KA, Otchere O, Ferland D, Farzadfar S, Williams S, Arcand MM (2021) Nitrogen use efficiency definitions of today and tomorrow. Front Plant Sci. https:// doi. org/ 10.3389/ fpls. 2021. 637108

Farzadfar, S., Knight, J. D., & Congreves, K. A. (2021). Soil organic nitrogen: an overlooked but potentially significant contribution to crop nutrition. *Plant and Soil*, *462*, 7-23. https:// doi. org/ 10. 1007/ s11104- 021- 04860-w



Download our reports from:
www.dyfibiosphere.wales/perennial-green-manures

Thanks to:

The grower trialists:
Enfys Veg, Einion's Garden, Gardd Afon, Centre for Alternative Technology, Ash and Elm Horticulture, Dan yr Onnen

The Beacon Project at Aberystwyth University
Paul Hill and the team at Bangor University