A Nuffield Farming Scholarships Trust Report

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CATCH AND COVER CROPPING OPPORTUNITIES IN UK ARABLE AGRICULTURE

TOBY SIMPSON

JUNE 2023

NUFFIELD UK

This report is written by a farmer for farmers who want to better understand what place cover crops can have on their farms.

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Southill Farm, Staple Fitzpaine, Taunton, TA3 5SH
Tel: 01460 234012
Email: director@nuffieldscholar.org
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Date of report: June 2023

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

Title	Catch and cover cropping opportunities in UK arable agriculture
Scholar	Toby Simpson
Sponsor	McDonald's UK & Ireland
Objectives of Study Tour	To explore: • What place catch and cover cropping has in UK arable agriculture. • On-farm practicalities and best practices when adopting cover cropping. • The wider opportunities around catch and cover cropping practices.
Countries Visited	Norway, Sweden, Denmark, Germany, France, USA, Canada, UK
Messages	• Cover crops are the keystone to the biological, chemical, and physical function of the soil. • Growers need to understand the carbon and nitrogen ratios and cycles in the soil for successful outcomes. Feed the soils and they will feed the plants. • When growing cover crops, think FDD; **functionality, diversity, density**. • Build resilience into a farm business by farming layered, additional enterprises can create new opportunities. • It's important to consider individual context as it will vary between individual farms and fields.

EXECUTIVE SUMMARY

On many arable farms, modern agricultural production has seen the continual removal of residues and intensive tillage of the soil. In the UK during the post-war period, these soils were depleted of organic matter, requiring more horsepower and artificial inputs to keep producing food. But the tide has changed over the last few years, with farmers and the wider industry focusing on improving soil health. Reduction of tillage, livestock integration, no-till, and cover cropping is far more common now than 20 years ago. Regenerative agriculture has become a fashionable term, though dividing opinions on what it means, whether it's something new or simply going back to good mixed farming practices of previous generations. As more farmers are incentivised to adopt practices like cover cropping, it's pertinent to look at the practicalities of this system and explore what wider opportunities arise as a result.

The public and private sectors are looking at farmers to help sequester carbon in soils and reduce agricultural emissions in the fight against climate change. At the same time, farmers face ever more challenging growing conditions with more erratic weather patterns, simultaneously navigating unstable commodity prices and high agricultural inflation.

By improving the function of the soil, farmers can help build resilience against these challenges while creating wider farm business opportunities which can add diverse income streams and generate employment opportunities. This is even more relevant when farmers want to fill the hole that Basic Payment Scheme farm subsidies have left in their income following their removal.

Cover crops are the keystone to the biological, chemical, and physical function of the soil; a living root will physically structure, biologically feed, and chemically alter the soil around it. Cover crops form part of a more extensive system of soil health which farmers must look at in the context of their own soils and climate. Understanding the carbon and nitrogen cycles in the soil will help farmers manage their cover crops, residues, and inputs. While helping increase the soil's organic matter and associated benefits.

To succeed in the adoption of cover cropping, farmers need to set clear, achievable objectives. These objectives will help when considering the choice of the cover crop's functionality, diversity, and density. The function will inform the species selection, establishment, management, termination, and following crop performance. Cover crop diversity will provide a plethora of above and below-ground residue that will feed a multitude of microbes and help cycle soil nutrients. Plant density will influence the function in several ways, from weed suppression and water management to CO_2 cycling.

When leaving fields empty, we are essentially farming naked; cover crops provide the opportunity to not only add cover but layer the soil with new enterprises and diverse income streams—improving not only public engagement but farm business resilience. All of this should be viewed in the context of a farmer's own soil, climate, and business, as this will vary significantly, and what works for someone might not always be the solution for all.

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DISCLAIMER

The opinions expressed in this report are my own and not necessarily those of the Nuffield Farming Scholarships Trust, or of my sponsor, or of any other sponsoring body. They are written from the point of view of a farmer, not an academic.

CONTACT DETAILS

Toby Simpson

Holme Wood Lodge
Old North Road
Stilton Fen
Stilton
Peterborough
PE7 3SB

07851003312
Toby_simpson@ymail.com

Nuffield Farming Scholars are available to speak to NFU Branches, Agricultural Discussion Groups and similar organisations

Published by The Nuffield Farming Scholarships Trust
Southill Farmhouse, Staple Fitzpaine, Taunton TA3 5SH
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Chapter 1. Introduction

As a feral child who mostly lived outdoors, I never realised how fortunate I was growing up on a family farm until I left to study politics at The University of Leeds in 2007. I'd always harboured the desire to join the army, which I duly did and thoroughly enjoyed. In 2015 I moved back to the farm with my now wife, Imogen, where my parents, Ann and James, had diligently stewarded the land for over 30 years. With little understanding of running a farm, I completed a Graduate Diploma in Agriculture at The Royal Agricultural University in Cirencester. I spent the next few years learning everything I could from my father, whose attention to detail and knowledge of the soil knows no bounds. I live on our family farm in Cambridgeshire with my wife and two children, Matilda (4) and Teddy (2).

Off the farm, I enjoy attempting 'silly' challenges; it could be on a bike, in a kayak or simply on foot; each time it seems to escalate slightly, and I'm not sure I'll ever be content to sit still. I'm therefore incredibly grateful to my wife and family for allowing me to indulge in the mental ultra marathon that is a Nuffield Farming Scholarship.

Figure 1 - Silly challenges. Source: Author

Chapter 2. Background

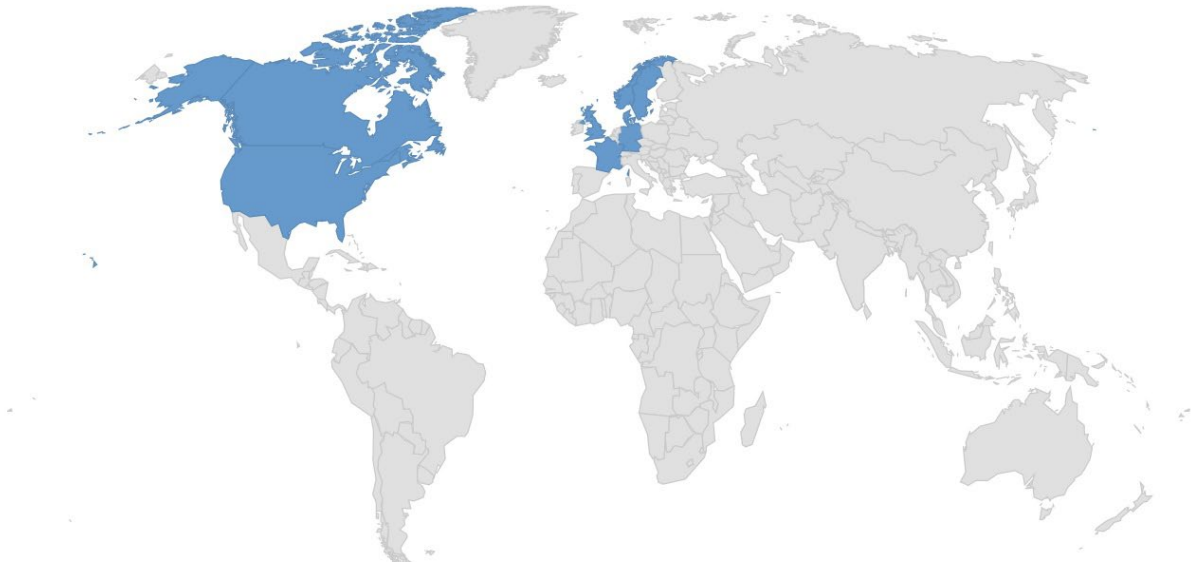
Dad's been soil health focused for 20 years. He reduced tillage and incorporated residues to save fuel and labour while increasing soil organic matter (SOM). It worked; SOM in the clay loam soils increased by a total of 2% over 15 years. Spring cropping was introduced with stale seedbeds to kill slugs and grassweeds, leaving the soil bare overwinter. As the soil improved, we adopted no-till in 2019; I felt we lacked cover crops during this change, but with no evidence, I needed to prove their value.

Two things happened when direct drilling in the wet season of 2020; firstly, we drilled wheat into OSR stubble where high slug pressure convinced Dad the crop would not survive. The OSR volunteers acted as a catch crop, the slugs ate them instead of the wheat. Secondly, we planted spring barley on the green in the form of a strip of oats and radish cover. The soil was fantastic at drilling but the spring barley yielded 1t/ha less. Suddenly there was more to cover cropping and no-till than I'd envisaged, a spark of curiosity was ignited that led me to explore the topic as part of a Nuffield Farming Scholarship.

With cover cropping in vogue and part of the new Sustainable Farm Incentive and Countryside Stewardship payment options, I wanted to investigate the practicalities of cover cropping in an arable rotation and the opportunities that come with it, particularly integrating livestock and public engagement.

Figure 2 - Allelopathic effect of oats on spring barley (biochemicals produced by one plant affecting the germination and growth of another) Source: Author

Chapter 3. My Study Tour



Date	Location	Comment
March 2022	Norfolk & London	Pre-CSC & CSC hosted by Nuffield UK
Spring 2022	UK	Conducted numerous farm visits with UK farmers
September 2022	Norway, Sweden, Denmark, Germany	Drove to Norway and worked my way back home meeting advisors, seed companies, farmers and carbon trading companies.
Autumn 2022	UK	Travelled around the UK meeting farmers, seed companies and advisors
November 2022	France	I met farmers and seed breeders in northern France and joined an Agrii study tour
Spring 2023	UK	Continued to meet UK farmers
April – May 2023	USA, Canada	Drove around the North East States of the USA and Canada

Chapter 4. Cover Crops – the keystone to a healthy living soil

A cover crop is planted without the intention of harvesting. The term refers to several practices: a catch crop is planted between summer and autumn, an over-winter cover crop or summer cover crop which are self-explanatory. While cover crops are primarily intended to protect or enhance the soil, they are different from a companion crop planted with a cash crop to help the crop's health but are not harvested, and from an intercrop or bi-crop which is harvested.

Figure 3 - Blake Vince, Ontario, a matter of life and death. Cover crops protecting the soil next door to land left with minimal crop residue over winter. Source: Author

4.1 Why plant a cover crop?

The answer will depend on who you ask. Nutrient cycling, building organic matter, and carbon sequestration feature highly, sometimes legislative reasons or environmental stewardship. Cover crops can be important to water quality, erosion prevention, moisture retention, livestock forage, weed and pest management, soil structuring, habitat creation, or maybe just for the pretty flowers. Cover crops can be everything and nothing.

So why plant cover crops? The answer is simply to keep the soil alive. There are more living organisms in a spade of soil than humans on Earth. Biologically, living roots feed fungi and bacteria in exchange for nutrients; dying plant residues are a feast for the soil microbes, themselves turning into organic matter. Structurally, plant roots shrink and swell creating aggregation, while penetrating compacted layers with up to 300 psi of pressure alongside worm burrows helping the soil to breathe. Soil chemical elements such as nitrogen, potassium and phosphorous can be accessed and cycled through plant roots making them less prone to leaching and more available to the subsequent crop.

Plants form part of the Earth's carbon, nitrogen, and phosphorus cycles, along with oxygen and water. A soil without plants cannot assist in these cycles and is essentially dead.

4.2 Cover crops are part of a bigger system

You can't change one thing in isolation. Call it conservation or regenerative agriculture, or good farming practice; it doesn't matter. If we take Groundswell's five principles as a handrail, we can see where cover crops fit.

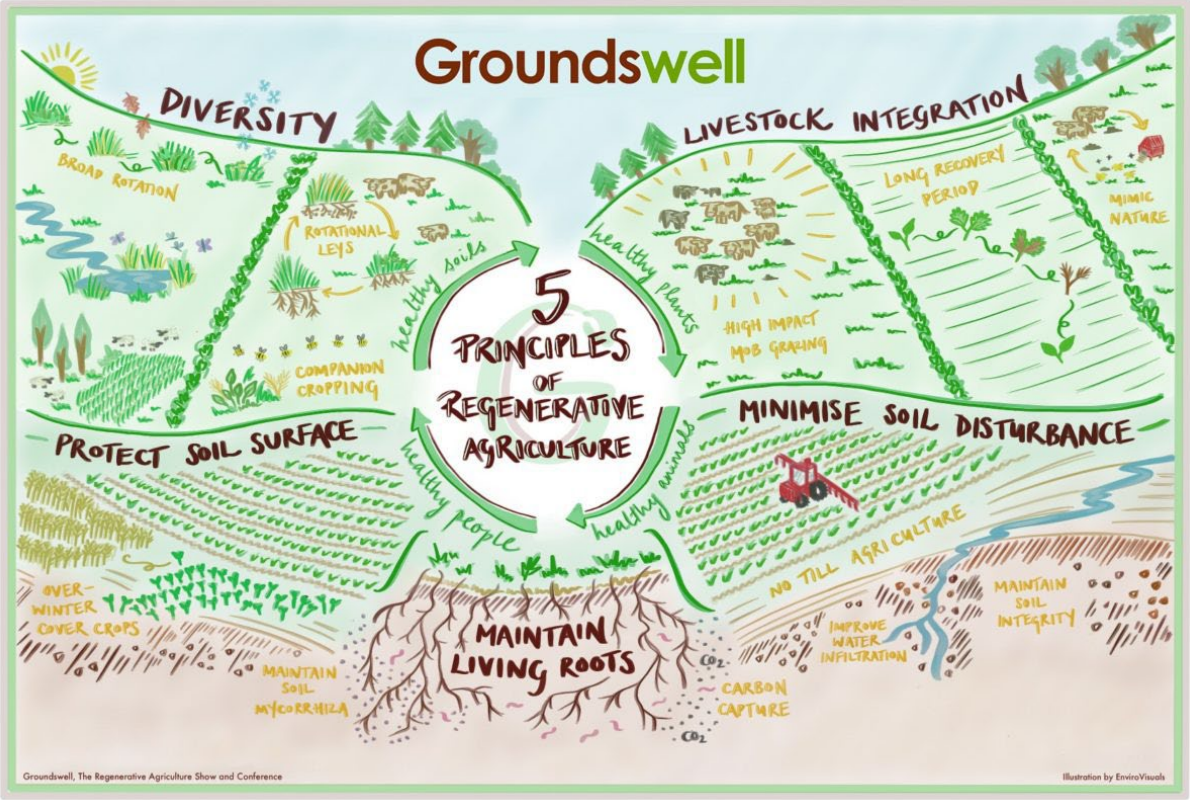


Figure 4: Five Principles of better soil health. Source: Groundswellag.com

1.	**Minimise soil disturbance;** roots structure while shoots feed the workforce.
2.	**Maintain living roots;** by filling the gaps between crops.
3.	**Protect soil surface;** roots are the foundations, while shoots put a roof over the soil.
4.	**Diversity;** multiple species roots and biomass are a feast for soil biology.
5.	**Livestock integration;** providing grazing opportunities in arable rotations.
6.	**Context;** you wouldn't plant a palm tree in the artic; every farm is different.

4.3 Maintain living roots

On my travels, I have seen the importance of living roots. Nature doesn't like space, filling it with plants and organisms. Jim Hoorman in Ohio introduced me to the rhizophagy cycle; seedlings and younger plants excrete exudates that promote bacterial growth, absorb bacteria into the roots and extract nutrients before the surviving bacteria are recycled at the root tips. Plants will also form fungal root associations such as arbuscular mycorrhiza fungi (AMF); nutrients are extracted from the soil by the fungi and exchanged for plant-produced sugars in the rhizosphere. These bacterial and fungal networks can provide a plant with most of its needs, but are easily damaged taking time to recover. Cover crops keep this network alive and fill the space.

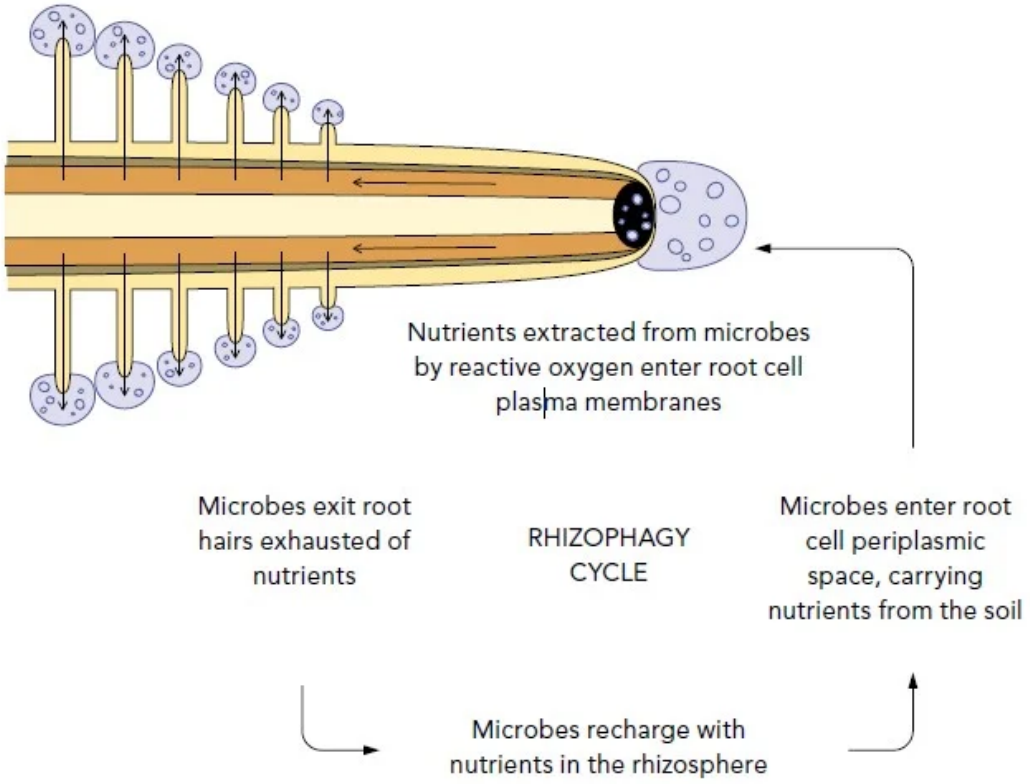


Figure 5 - Rhizophagy Cycle. Source: Teaming With Bacteria, Jeff Lowenfels

Figure 6 - The living root. Source: Author

4.4 Carbon to nitrogen

To avoid poor crop establishment through nutrient lockup, it's essential to understand how carbon and nitrogen flow through the soil. All residues have an amount of carbon (C) and nitrogen (N) which can be expressed as a ratio. Typically, soils have a C:N ratio of about 10kg C to 1kg N. Generally, a C:N ratio of 24:1 is optimal for decomposition; soil microorganisms typically have a ratio of 8:1, but require another 16 parts carbon for energy. At 24:1 they can both maintain and digest fresh organic matter without needing excess from the soil. Generally, residues over 30:1 can cause nitrogen immobilisation. Under 20:1 can mineralise nitrogen and force microbes to seek out existing soil carbon.

Chopped wheat straw residue of 80:1 requires microbes to use existing nitrogen to digest it, making it temporarily unavailable to the plants. When direct drilling, soil organic matter is not mineralised so nutrient immobilisation can occur. The C:N ratio of the growing plant will change over time, a low C:N ratio while it's green and leafy; as it matures it becomes woody with a higher C:N ratio. Different plants have different ratios and percentages of nitrogen, meaning plant selection, maturity, termination timing, and method are essential in planning a cover crop. Figure 7 sets out the C:N ratio for crop residues and other organic materials.

Table 1. Carbon to nitrogen ratios of crop residues and other organic materials

Material	C:N Ratio
rye straw	82:1
wheat straw	80:1
oat straw	70:1
corn stover	57:1
rye cover crop (anthesis)	37:1
pea straw	29:1
rye cover crop (vegetative)	26:1
mature alfalfa hay	25:1
Ideal Microbial Diet	**24:1**
rotted barnyard manure	20:1
legume hay	17:1
beef manure	17:1
young alfalfa hay	13:1
hairy vetch cover crop	11:1
soil microbes (average)	8:1

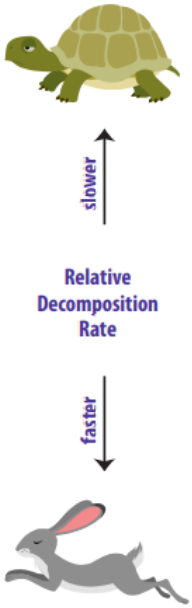


Figure 7 - C:N ratios. Source: nrcs.usda.gov

The decomposition rate and carbon cycle of plant residues depend on the material, termination method, microbial populations and climatic factors like temperature and moisture. Like nitrogen carbon is cycled, fresh organic materials containing carbon are simultaneously digested by multiple microbes in differing ways; when they die, their microbial necromass is repeatedly digested until CO_2 is released and respired back into the atmosphere. There is a microscopic residual stable fraction of carbon hidden in the soil that microbes cannot access. Cover crops can help build long-term carbon, though this varies hugely depending on climate and soil mineral types.

Figure 8 – Cover crops showing different rates of decomposition and nutrient cycling in New York State
Source: Author

Chapter 5. Foundations of cover cropping

When exploring the practicalities of cover cropping, thinking about the **functionality**, **diversity**, and **density** (FDD) of the plants in a cover crop is useful. Thomas Björkman from Cornell University and Frederik Larsen from Denmark spoke about functional diversity, that is having the right plants in the right place performing to their best. Björkman likens it to selecting the best players for a team and he uses the phrase *'fast start, no gaps, kill on time'* for a cover crop strategy. Density should be considered as well as type and diversity of the cover crop; it will often assist the function of the cover crop. I will explore FDD in detail in the following chapters.

Cover Crop Chart

Key to Symbols: = Excellent = Very Good = Good = Fair = Poor

	Species	When To Plant	Min Germ Temp	Seeding Depth Inches	Seed Per 1000 sq ft	Pounds Of Seed Per Acre	Hardiness To Zone	Legume N Source	Nitrogen Recycler	Chokes Out Weeds	Pounds Organic Matter Per Acre	Forage Or Hay	Attracts Beneficial Insects	Erosion Control	Nematode/ Symphylan Control	Soil Builder
Legumes	Summer Alfalfa	Late Summer	45°F	¼–½	½ lb	15–20	5				2000–4000					
	Hairy Vetch	Early Autumn, Spring & Summer	55°F	1½–2½	1 lb	25–40	4				2300–5000					
	Common Vetch	Early Autumn, Spring & Summer	55°F	1½–2½	1 lb	25–40	4				2300–5000					
	Austrian Field Peas	Autumn	40°F	1–3	2–4 lbs	75–100	7				4000–5000					
	Crimson Clover	Anytime	45°F	¼–½	1–2 lbs	30–40	7				3500–5500					
	Mammoth Red Clover	Early Autumn	40°F	¼–½	½ lb	20	4				4000–6000					
	Miniclover®	Spring to Autumn	40°F	¼–½	1–2 lbs	8–10	4				2000–6000					
	New Zealand White Clover	Spring to Autumn	40°F	¼–½	¼ lb	6–10	4				2000–6000					
	Berseem Clover	Early Autumn	42°F	¼–½	1 lb	15–20	8				6000–10,000					
	Fava Beans	Autumn	55°F	1–3	5 lbs	200	7				3500–7000					
	FIXatioN Balansa Clover	Early Autumn	40°F	⅛–¼	1–2 lbs	5–8	4				6000-10,000					
Brassicas	Mustard	Spring & Summer	40°F	¼–¾	¼–½ lb	15–20	7				5000–12,000					
	Radish	Late Summer	45°F	¼–½	½ lb	10–12	8				4000–7000					
	Turnips	Spring to Late Summer	45°F	¼–½	¼ lb	5–7	6				8000–12,000					
Cereal Grains & Grasses	Annual Rye Grass	Early Autumn	40°F	½	1 lb	20–30	5				2000–9000					
	Buckwheat	After last frost	48°F	½–1½	2–3 lbs	75–100	Not Frost Tolerant				2000–4000					
	Sudangrass	Late Spring to Late Summer	60°F	½–1½	1–2 lbs	30–50	Not Frost Tolerant				8000–10,000					
	Winter Rye Grain	Autumn	34°F	½–2	3–4 lbs	75–150	3				3000–10,000					
	Winter Barley	Late Summer to Autumn	37°F	¾–2	2–3 lbs	75–125	7				2000–10,000					
	Winter Triticale	Autumn	34°F	1½–2	2–3 lbs	60–120	6				6000–8000					
	Winter Wheat	Autumn	38°F	½–1½	3–4 lbs	70–150	4				3000–8000					
	Winter Oats	Autumn	38°F	¾–2	2–3 lbs	100–120	8				2000–10,000					

Figure 9 Cover Crop Chart. Source: Table 1 - territorialseed.com

In North America, cover crop charts like Figure 9 help to understand each plant's functional roles. The publication *'Managing Cover Crops Profitably'* and many other resources at https://www.sare.org/ provide knowledge on cover cropping. Still, they must be taken in the context of different climates and rotations to the UK.

Chapter 6. Functionality of cover crops

6.1 Objectives

First, identify where a catch or cover crop can be grown in the rotation, then plan the objective you want to achieve as it will determine the subsequent management strategy. For example, if nutrient cycling for the following crop is the objective, the cover crop might be a mix of legumes and scavengers, aiming for fast-growing biomass, terminated while the C:N ratio is low, usually around flowering. Timing of the termination should be planned so the residue has time to break down and release nutrients to the following crop.

If building soil organic matter and sequestering carbon is the main objective, a dense rooting, high C:N ratio residue with predominantly grasses would be preferable. However it is not straightforward as the following crop might suffer nitrogen lockup, so a legume or combining cereals with a starter fertiliser might be appropriate in this situation.

Pest reduction is another matter. In Germany, I visited the seed breeders P.H. Petersen. Matz Petersen showed me the breeding process, where they specialise in radish cover crops that reduce specific nematode populations in the soil. I learnt that in targeting a specific nematode, nothing planted in a cover crop should be a multiplier; variety selection is critical.

When grazing livestock, a cover crop needs to supply adequate palatable forage. Martin Lines in Cambridgeshire aims to have something for the sheep to stand on (clovers) and something to graze.

Erosion and run-off prevention requires covers to have multi-layered root architecture and some above-ground canopy protection for weed suppression, where a dense cover including allelopathic plants such as buckwheat or oats could be used.

These examples show different management approaches; objectives don't need to be exclusive, a well-established cover crop will add multiple benefits to the soil and environment, but the primary objective should always be considered when planning a cover crop.

6.2 Species selection

When choosing species and variety traits of cover crops, there are many UK information resources in addition to the North American charts (Figure 9). The Cotswold Seeds website shows detailed knowledge of the whole root and plant architecture. NIAB TAG and Kellogg's Origins have produced a guide to cover cropping in the UK https://www.c-l-m.co.uk/wp-content/uploads/2017/07/NIAB-TAG-Cover-Crops-A4-guide-lo-res.pdf. I've visited seed breeders and distributors, all providing excellent knowledge and insight into sourcing and selecting cover crop seed. Ian Gould from Oakbank has given me sound advice over the last few years while doing exciting research. It's always worth seeking advice regarding cover crop species selection.

Seed sourced from the continent isn't always subject to the same quality assurances you would expect from a cash crop. It may have been grown in an environment entirely different from your farm, and the seed won't be naturally primed with endophytes favourable to your soil. Where possible, test and home-save seed which also reduces the risk of importing weeds. When buying seed, understand its origin, variety traits and, if possible, the thousand-grain weight and germination. A compromise I've noticed is farmers home saving the larger seeds and buying in the

small seeds to reduce cost. As more cover crops are grown in the UK, the same standards should be expected as cash crop seed. The farmer has the ultimate responsibility to do a thorough assessment before planting anything.

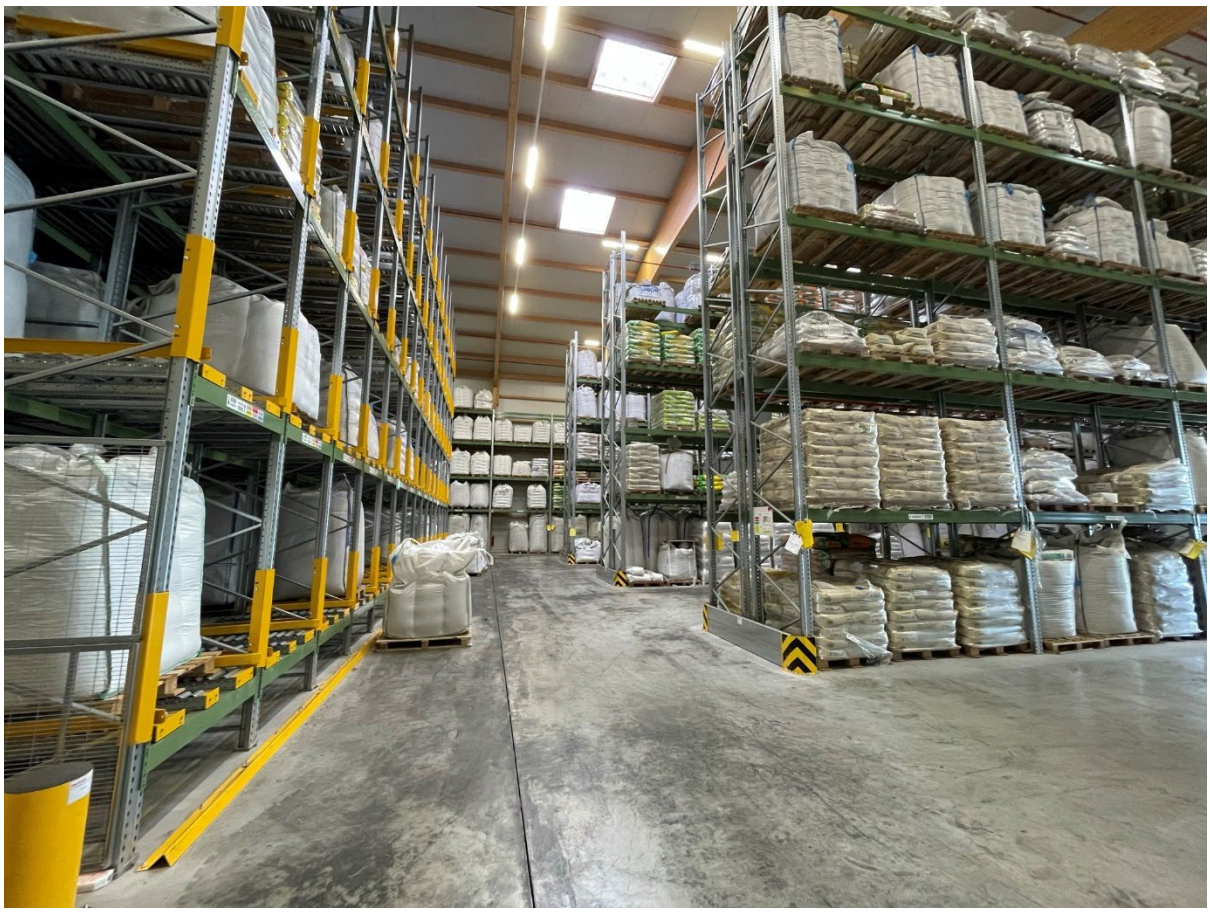


Figure 10 - One of several cover crop seed warehouses at P.H. Petersen, Germany. Source: Author

6.3 Establishment

Good cover crop establishment is key to success. It can be challenging due to time and moisture but conditions must be favourable, with good seed-to-soil contact essential.

I have seen many ways to establish cover crops; being able to drill soon after harvest and into moisture seems the most consistent. Cultivators or straw harrows fitted with seed applicators are fast and convenient, while a combine harvester with an auto-caster is very timely.

In Scandinavia, the growing season is short; farmers often broadcast a high seed rate ahead of harvest to maximise the summer growing conditions. Some farmers under-sow a cover in the growing crop, usually consisting of low-growing clovers, chicory, or Lucerne, which are often kept as a continuous understory. Where cover crops have been broadcast into corn in North America, farmers found surface residues stopped good soil contact, and dense crops prevented light from getting to the young plants. So under sowing success depends on the nature of cover given by the crop due to be harvested.

In Norway Else Villadsen introduced me to her 'Else mix' consisting of **1kg chicory**, **1.5kg birds-foot trefoil**, **2kg Red clover**, and **8kg cocks-foot** per hectare. This was sown into spring oats; although it

limited herbicide choice, it provided a well-rooted winter cover immediately after harvest, making a good grazing platform, while creating good soil structure quickly. See Figure 11.

Figure 11 - Else Mix. Source: Author

To summarise on establishment, cover crops need to be treated like any other crop. Timely establishment into moisture, drilling at slow speeds, rolling straight after and aiming for good seed-to-soil contact. Residual chemicals from the previous season can inhibit some cover crop species. Equally chopped crop residue can have a suppressive effect on germinating plants. Like with drilling anything, there is no right or wrong way – just different challenges.

6.4 Management

Due to the lack of immediate financial return, cover crops tend to be neglected once they have been planted. Uneven establishment may carry a legacy into subsequent crops; it may even show up in poorer-performing areas where covers take up nutrients left behind from the previous cash crop. If cloud cover is favourable NVDI satellite data showing the distribution of plant growth is helpful to assess the consistency of a cover crop.

Cover crops face the same pest pressures as any crop; applying slug pellets and spraying out competitive volunteers can help a cover crop to achieve its objective. I saw trial work in Scandinavia and Europe that suggested using 20kg N/ha increased initial plant biomass and could return more nitrogen to the next crop. However, this was not certain as it might be a short-term visual benefit, encouraging more biomass and discouraging rooting or legume nitrogen fixation.

I met farmers who use cover crops post cultivation or subsoiling to maintain the soil structure. Having a network of roots swiftly occupy the fractured soil helps mitigate the initial damage done by tillage. This was important in reducing subsequent tillage passes in root rotations.

6.5 Termination

Some methods include desiccating, grazing, cultivation, crimping, mowing, and frost kill, all useful in different circumstances. The timing and method will influence a cover crop's ability to achieve its objectives; most legacy problems can be solved at termination. One consideration is that cover crop residue can cause lockup and limit seed-to-soil contact reducing the following cash crop's yield potential. Timing is everything, it determines the fresh organic material's C:N ratio and ability to cycle nutrients. As a farmer in France said, '*worms can't climb trees'*; for a residue to be broken down and the process of cycling nutrients to begin, it needs to be accessible to the soil's microbes.

Where allelopathy and nutrient lockup are unlikely to impact a crop, many farmers drill on the green which works well with a low C:N ratio catch crop. For early drilled spring cereals on heavy land in the UK, I have found the consensus is that early termination of a cover crop helps mitigate any lock-up while aiding the soil moisture conditions. However, later drilling on lighter drought-prone soils will suit drilling on the green, especially if planting larger seeds.

In a conventional system, herbicide is a common termination method, helping reduce initial competition from weeds and reducing the need for tillage. Glyphosate is a popular choice given its low cost and effectiveness, but responsible use is essential. In North America, I met many farmers who cautioned on genetically modified crops; Donn Branton spoke of a farmer creating glyphosate-resistant weeds in just eight years of continuous GM corn. As glyphosate is phased out in much of Europe, French farmers are lobbying to keep it for cover crop and no-till situations. In the UK we should not be complacent and alternative methods of termination may need to be sought in the future. Blake Vince, NSch 2013 and chair of Nuffield Canada, explained how he and a friend had a corn crop perform poorly one year following a glyphosate-terminated cover crop. After some research, they concluded that the systemic nature of glyphosate had adversely affected the mycorrhizal fungi populations via the cover crop roots. Farming is complicated and involves many compromises.

At the Rodale Institute in the USA, the development of a crimper roller, see Figure 12, has been crucial for organic no-till; variations of crimper rollers are becoming more widely used in the UK with grants available. They rely on the plant having a mature stem that can be broken in several places but will not kill small grass weeds, whose destruction relies on cultivation or herbicide. Rollers need the right soil conditions, either dry enough or frost. This is where species selection and maturity timing play an important role. At Cornell University, I saw important ongoing trial work into the maturity timing of vetches paired with cereal rye to best aid timely destruction.

Figure 12 - Crimper roller in New York State used for non-herbicide cover crop termination Source: Author

Frost kill can't always be relied upon, but plants can be selected to naturally die off over winter, Angus Gowthorpe practices this in the UK. Donn Branton and his son Chad use 'bio strip till' in New York State before planting corn. Alternative rows of diverse cover crop mixes are planted. The row destined for corn will die off over winter, aiding strip-tilling ahead of planting. The other row containing winter hardy plants will survive, providing roots and biomass until terminated. In Brittany, Pierre-Yves Donval plants a double cover crop before maize, first a diverse mix that's crimped in November while simultaneously planting beans.

Figure 73 - Bio strip-till. A frost hardy cover crop mix shown surviving the winter where the frost sensitive cover crop mix has died off in alternate rows, leaving the field ready for strip-till corn Source: Author

Livestock grazing can terminate and reduce biomass, while providing more available nutrients to future crops and helping the biological function of the soil. To avoid compaction, frequent moves, back fencing and leaving 1/3 of the above-ground plant help. Timely removal of livestock will give the soil a chance to recover, while using cultivation or a tine drill can remedy shallow compaction. Integrating livestock into arable cover crops creates opportunities for those without land to expand while adding new enterprise opportunities to the farm. A good relationship between grazier and farmer is key, ensuring all stakeholders' expectations are met. Regarding the question of animals taking more nutrients off the field than if it was left un-grazed, a useful Canadian study called *'Integrating green manure and grazing systems: A review'* concluded livestock may remove no more than 25% of a cover crop's nutrients, and the biological benefit of increased microbial diversity the livestock bring outweighs any removal of nutrients. The benefit is retained if the livestock are already an existing on-farm enterprise.

Cover crop termination will depend on a farm's individual objectives; however, being flexible is advantageous. As an example of multiple termination strategies, in France, Frederic Remy will roll or mow his pre-spring barley cover crop down at flowering in the autumn, ideally, when it's reached the optimum biomass and C:N ratio, to avoid nutrient lockup and begin cycling nutrients. Subsequently, a dry or frost spell is used to lightly incorporate the residue with discs, further aiding breakdown. Before spring beans, he grows cereal rye and drills on the green, creating a weed-suppressing mulch; the scavenging nature of cereal rye encourages the beans to fix their own nitrogen. This practice is common in North America, where cover is required until at least May and

large seeds like corn or soybeans seem less affected by allelopathy.

Figure 14 - November terminated cover crop in France, early termination gave the residue time to decompose and cycle nutrients ready for the spring crop Source: Author

6.6 The following crop

When planning a cover crop it must complement the following cash crop. Establishing spring cereals on heavier land is particularly challenging in the UK, with many farmers finding it more complex to get right. Consider nutrient immobilisation; if there's high carbon residue still being decomposed by the soil microorganisms then soil available nitrogen may be unavailable. Placed starter fertiliser such as Di-ammonium Phosphate can help young crops, especially in colder, less biologically active soils. Allelopathy might be an issue following certain cover crops; increasing the seed rate and ensuring several weeks between termination and drilling can mitigate this. Oats, buckwheat, hairy vetch, and crimson clover all have an allelopathic effect on weeds but potentially on cash crops too. This is less of a problem during autumn establishment of the following cash crop as the allelochemicals released by these plants are not as potent as plants enter dormancy and are biologically broken down quicker in the wet.

With nutrient cycling, the million-dollar question is how much is available to the subsequent crop; the answer is 'it depends'. When considering nitrogen availability, consider the C:N ratios described in Chapter 4.4. Will the cover crop avoid or create nitrogen immobilisation based on the fresh organic carbon being broken down simultaneously? In the early years of cover cropping, the 'piggy bank', as Frederic Thomas puts it, will be empty, meaning initially cover crops can tie up existing soil nitrogen before they start to cycle it back. Over time as more carbon and nitrogen are cycled

through the soils, the piggy bank will fill up, and the soil will provide more of the crop's needs. Thus, aiding a reduction in inorganic nitrogen.

I met farmers who take a biomass sample to measure a cover crop's dry matter and nutrient content. In France, the 'Merci' lab gives a detailed breakdown of the nutrients in a cover crop, and depending on the management practice, it estimates quantities of nutrients available over time. We can make our own basic analysis of a cover crop's nutrient availability. Plant dry matter contains circa 45% carbon, so 1000kg/ha of DM contains 450kg of carbon. If the C:N ratio is 12:1, we know there is approx. 37.5 kg of nitrogen. Not all of that will be plant available; some will leach or be used by microbes in the short term to sequester carbon. Trials in the USA estimate that between 1/3 to 1/4 of nitrogen will be plant available within a few months, depending on tillage and climate. So between 8-12 kg of N per 1000kg of DM per ha could be expected back in the first year. As time passes, we see a diminishing return from that cover crop as it is cycled within the soil. The more years of cover cropping, the bigger the piggy bank and increased nutrient cycling potential.

There are many variable factors to the cycling of nutrients; it's worth measuring cover crop biomass and taking soil mineral nitrogen samples, in conjunction with on-farm nitrogen rate trials, helping to build up a picture over time to gain the confidence to adjust inorganic nitrogen application rates appropriately to the crops need. *SARE Managing Cover Crops Profitably*, https://www.sare.org/wp-content/uploads/Managing-Cover-Crops-Profitably.pdf is an excellent resource on nutrient cycling and cover crops.

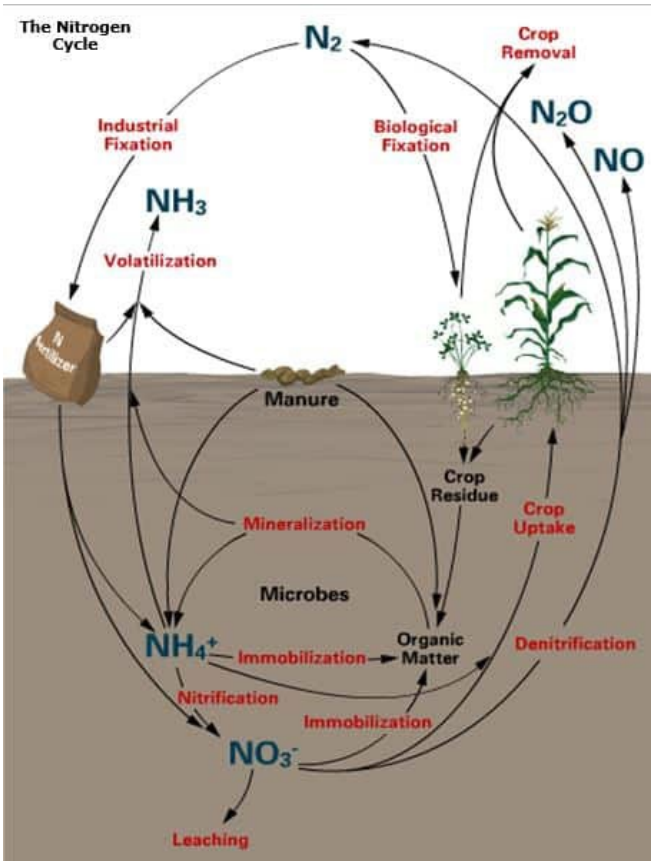


Figure 15 - The Nitrogen Cycle- showing the complexity above and below ground

Source: Cornell Small Farms Program

Chapter 7. Diversity of cover crops and mixes

During my travels I've come across several compelling reasons to include plant diversity in a cover crop mix, where the plants don't detract from the function of the cover crop and are selected to complement each other. For example, scavengers act to capture soil nitrogen encouraging legumes to fix their own. Conventional wisdom suggests plants don't interact or exchange nutrients and only serve to compete for resources. But if we look at the biological interactions with plant roots in the soil, we see how the right plants can share the space while nutrients are moved between root systems by bacteria and fungi.

Structurally, different root and shoot architecture causes plants to complement the use of space above and below ground. Phacelia and vetch have a dense network of roots that can create an ideal shallow soil structure, while brassicas can penetrate compaction creating good drainage. Likewise, above-ground vetch stays low, climbing taller plants around it, like oil radish that grows upwards and outwards. Multi-layered rooting and canopy structure is critical in several functions such as creating soil structure, suppressing weeds, protecting the soil from weather erosion and heat, providing forage for grazing, accessing nutrients etc. It also provides the living organisms in the soil with a buffet of residue and root matter to feast on, promoting a diverse mix of microbiology and helping to keep the soil ecosystem in balance, never creating space for any one thing to dominate.

Figure 16 - Bean and oat roots entangled Source: Author

Companion crops play an important role maintaining root diversity and enhancing biological interactions in the soil. OSR companions can make the mycorrhiza fungal associations that brassicas can't. Legumes and cereals planted together can fix and scavenge nitrogen respectively: it's why they make such good intercrops that require very little input, the main challenge being at separation. In France, I saw trial work on the benefits of different companions in wheat, such as buckwheat used to suppress weeds. This practice will be rewarded in the Sustainable Farming Incentive standards as part of ELMS.

Diverse cover crop mixes act as an insurance policy, as, given the unpredictability of the weather, not everything will grow equally every year: having a mixture of plants will increase the chances of something establishing well. That said, with companions and understories, there is a fine line between too little and too much, so there should be a plan to manage the additional plants before they become too competitive.

Crop diversity may not always be appropriate in relation to the required cover crop function. For example, nematode-reducing radish covers must be free of plants whose roots act as nematode hosts and multipliers. Or when a dense buckwheat cover is used to suppress weeds through its allelopathic effect at the same time increasing phosphate availability through its ability to cycle P better than most other plants ahead of a high-value cash crop. But in general, if every species in a mix can perform its role to the best of its ability and complement the cover crop's function then they have earnt their place on the team.

Figure 17 - Root architecture Source: Cotswold Seeds

Chapter 8. Density of cover cropping

8.1 Plant density

We plan and plant cash crops by plants per m² but tend to plan and buy cover crops by the £/kg. I found most farmers and seed merchants who calculated cover crop by plant numbers aimed for 180-220 per m². Jim Hoorman suggests taking individual component seeding rates and assigning them a percentage of the mix. Knowing the thousand-grain weight or seeds per kg is key as the danger is that one species dominates - on my Nuffield journey another key aspect I learned was to seek good advice and use trial and error in perfecting inclusion rates.

Root density is an excellent way to build soil organic matter; the more root exudates, the more chances of soil biological interactions. Although modest above ground, clovers and vetches can have incredible root biomass; a cover crop should never be judged on how it looks above ground. Low density may be desired if trying to encourage weeds to germinate. Alternatively, a dense cover crop won't leave space for them to grow. At Lamport in Northamptonshire, UK, trial work suggests a lower density black oat and berseem clover cover crop will lead to lower blackgrass plant counts than an autumn fallow or other cover crop mixes.

In France, Thierry Tétu presented high-density cover cropping. Thierry explains the soil must be in good functional health with appropriate organic matter levels. This was part of a 12-year transition to 'nitrogen autonomy' where autumn green manures or catch crops provide N to the following crop; the key to this is to have a low C:N and high biomass catch crop. Thierry puts fast-grown biomass success down to the plants per m², around 250-300. Ideally, a mixture of 70% legumes with 30% scavengers to create a multi-layered canopy. An example he gave was to establish: **30 bean**, **75 pea**, **62 hairy vetch**, **100 berseem clover**, and **20 radish** plants, a total of 287 plants per m2, given establishment losses this could be up to 400kg/ha of seed. The denser plants can smother weeds and access more nutrients for themselves in the soil; crucially to the creation of biomass, the dense canopy could create a CO_2 fertilisation effect as it captures and recycles the CO_2 respired from the soil and plants.

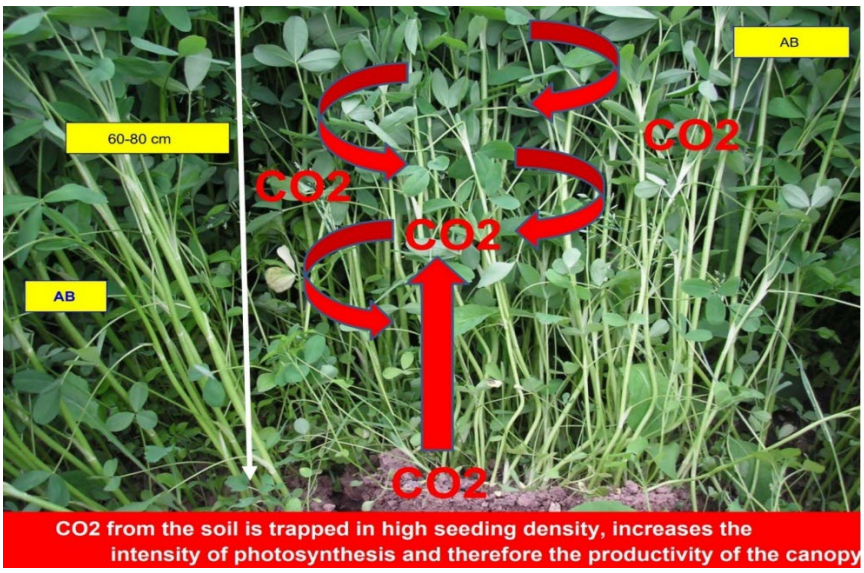


Figure 88 - High density cover crop Source: Thierry Tétu

8.2 Co2 Fertilisation for biomass

I was fascinated by the concept of CO_2 respiration and recycling combined with the rhizosphere priming effect, a process where soil organic matter is mineralised by interactions with living plant roots, the result is a subsequent release of nitrogen and CO_2 from the soil that can then be used by the plant. A plant not only absorbs CO_2 through photosynthesis but will also respire CO_2. In a greenhouse, CO_2 can be added to create a high-growth environment alongside adequate water and sunlight. Atmospheric CO_2 sits around 400ppm, but by increasing the CO_2 within the canopy to 550ppm, the plant will increase its growth upwards of 30%. This is illustrated in the graph in Figure 19 at the end of this chapter Thierry has managed to get catch crop biomass of 8t/ha above ground and 2t/ha below ground, equating to a potential 300kg/N in the dry matter with 100kg/N available to the following crop.

When I met Jim Hoorman in Ohio, he'd calculated that a 200 bushel/acre corn plant needed to absorb 100lb of CO_2 per day on average; he felt O_2 and CO_2 were the limiting factor in corn growth. There's 3000 – 10,000 ppm of CO_2 in the soil; it is nearly 3 x higher at night due to root and microbial respiration. In the morning, there's plenty of CO_2 for the plants to absorb through their stomata, most of which reside on the underside of the plant leaf. Jim thought that if we increased the efficiency of photosynthesis, it would help improve crop yields. Growing high biomass might not always be needed, but understanding how important the roots are in soil function is essential when investigating cover cropping.

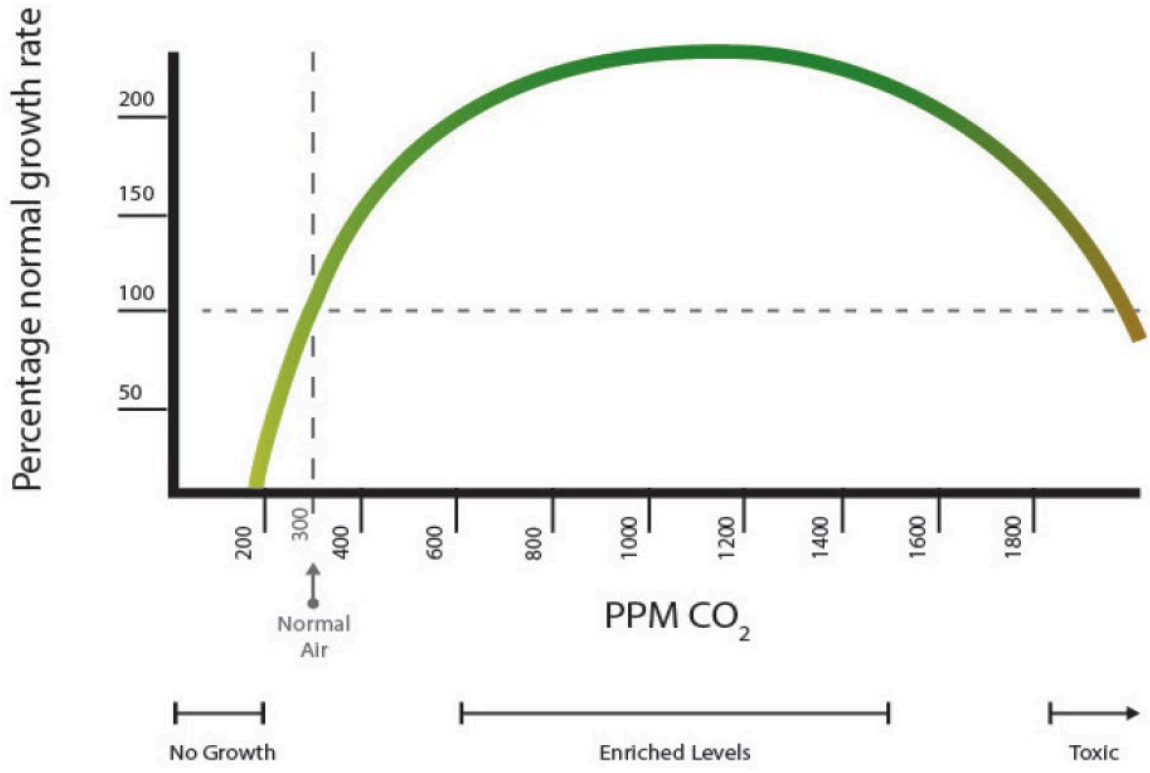


Figure 19- CO_2 fertilisation, illustrating the impact on growth of higher CO_2 absorption.
Source: Table 2 extension.okstate.edu

Chapter 9. Opportunities for cover crops

9.1 Naked farming

On my travels I was privileged to meet numerous farmers, not constrained by conventional thinking. My first visit was to see Ed Horton in the Cotswolds, I saw his hybrid system which was somewhere between organic and conventional. Using sheep grazing, inter-row hoeing and organic manures, Ed has reduced his reliance on artificial inputs while enterprise stacking his sheep within an arable rotation. Doing so has improved the soil on his farm while reducing his business's exposure to risk. Ed wasn't the only one making the most of the land. Stephen Briggs did a Nuffield Scholarship on agroforestry. By having fruit trees in the organic crops, he is farming in 3D, or 4D; the longer into the system he gets, the better his soils are. Farmers like Ed and Stephen show that we are only limited by our imagination. If cover crops are part of a broader system change, the opportunities that come from changing the system are limitless; enterprise stacking, direct marketing, and public engagement can add additional value to a business.

Figure 20 - Enterprise stacking- cover cropping providing additional income, increased natural fertility for following cash crops and protection from erosion. Source: Author

Leaving fields bare is farming naked, we might begin to cover them up with cover crops that protect the soil from some environmental risks, but if we layer our fields with multiple enterprises, it could add a level of financial protection. This layered approach can regenerate a rural community and create job opportunities; it may sound twee, but even on a small scale, it could be a welcome addition to a farm business.

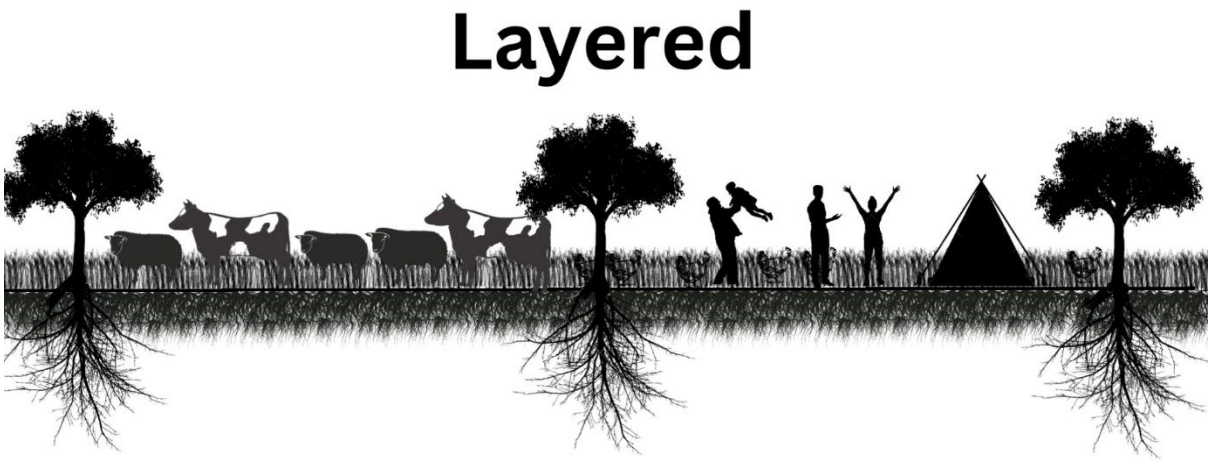


Figure 21 - Are you farming naked or layered? Source: Author

9.2 Other opportunities

Local communities can benefit from cover crops which can lead to improved air and water quality and a reduction in flooding. There is public and private sector financing to reward farmers for such benefits. In the UK, cover crops are publicly funded through the agri-environment schemes, and privately many water companies will pay and advise farmers to improve water upstream. The Landscape Enterprise Networks Scheme (LENS) puts stakeholders together in parts of the UK to identify where interests overlap. Farmers are invited to bid for on-farm outcomes using more flexible but similar practices to Countryside Stewardship.

I came across several policy approaches, especially in Europe. In Denmark and France, where cover cropping is mandatory with little financial reward, it has created an inflexible system leading to poor practice. In Norway, where water quality is an issue, a carrot-and-stick approach is being phased in consisting of high financial incentives (circa £400/ha for no-till and cover crops), with rules restricting ploughing.

Carbon trading and biodiversity offsets are hot topics; rightly or wrongly, farmers are being approached by corporate polluters to sell offsets. In the vacuum following BPS, private markets are a tempting alternative for farmers with tight margins, especially in the early years of adopting cover cropping when it can be hard to see immediate financial benefits. However, it turns out that private or public contracts may limit the flexibility of a farmer and so should be treated with caution. Cover cropping should make sense financially on its own and be done for the right reasons.

Chapter 10. Discussion

Cover cropping is a vast topic and when linked to soil health there is plenty to unpack. My report scratches the surface of the practicalities and opportunities of which there is inevitably nuance.

There's no right or wrong way to improve soil function, only different challenges. Farmers need a profitable and sustainable business; direction of travel is more important than prescriptive practices. Our knowledge of the carbon and nitrogen cycles is constantly evolving; while it's helpful to understand nutrient cycling and management, expecting soil to behave consistently is naive. Ratios are only a guide, but soils are incredibly variable and complex. Don't expect them to behave differently after one year.

Practically, expectations must be balanced with reality: every year is different, having flexibility and experience will help navigate these challenges. No rain between harvest and autumn means a decent cover crop won't be realistic. There's no silver bullet to cover cropping: it's incumbent on growers to put the time and research into understanding their objectives and how to achieve them.

Enterprise stacking and public engagement opportunities can arise from changing the system, but the basics must be done well first. Individual farm context is key; some things will be more suited to specific soil, climate, and rotations. Speak to other farmers and go and try it, see what works and continue to learn. BASE UK is a great independent organisation where like-minded farmers can share ideas. Events like Groundswell are helpful to meet and listen to experienced farmers and industry experts. The AHDB have good resources along with local Monitor Farm meetings and events.

Figure 22 - David Brandt. An inspirational no-till and cover cropping pioneer in Ohio, USA. His soils have changed beyond recognition over his lifetime through the use of cover crops over winter. David sadly passed away 3 weeks after my visit. Source: Author

Chapter 11. Conclusions

Following my travels, I've peered in depth into many topics, I've come to some simple conclusions that will hopefully help to inform on farm decision making around cover cropping.

- Cover crops are the keystone to the biological, chemical, and physical function of the soil. They form part of a wider system that works to build healthy soils, this change takes time and patience.

- Growers need to understand the carbon and nitrogen cycles in the soil for successful outcomes. Avoid nutrient immobilisation while better managing artificial inputs. Feed the soils, and they will feed the plants.

- When growing cover crops, think FDD, **functionality, diversity,** and **density**. Set out with clear objectives and a management plan. Treat the cover crop with the same care and attention as any cash crop.

- Build resilience into a farm business by farming layered, not naked. If cover crops are part of a broader system change, then the opportunities that come through changing the system are only limited by our imaginations.

- Always consider individual context as it varies between farms and fields.

Figure 23- On farm direct marketing and enterprise stacking in the UK. Cover crops are used to enhance the livestock enterprise while on farm products are sold alongside other things in a farm shop. Source: Author

Chapter 12. After my study tour

Doing a Nuffield Farming Scholarship has changed the way I look at our soils and business. I've met incredible people and have been inspired to try new things on the farm working towards improving the function of our soil and resilience of our business. These are all listed in the figure below.

I've travelled to stunning countries and had the space away from daily life, allowing me to evaluate new ideas and develop my thinking. I've made friends for life and discovered a desire to keep learning and sharing ideas; my Nuffield is only just beginning.

Practices adopted or being tested on farm
Integrated livestock grazing
Agroforestry
Intercropping
Johnson Su Composting
Clover understories
'Cide' free crops for Wildfarmed
Efficient and reduced nitrogen strategy
Reduced fungicide strategy
Inter-row hoeing
Public engagement through a pop-up shop
Use of dense catch and cover crops

Figure 24 – On-farm changes following my Nuffield journey. Source: Author

Figure 25 - Norwegian exchange. The Author standing in a cover crop mix including radish, vetch, and phacelia alongside Norwegian soil advisors. Source: Author

Acknowledgment and thanks

A Nuffield Farming scholarship is a real team effort, there is no way I could have entertained the idea of spending so long away indulging in cover crops if it wasn't for my incredibly supportive wife and family. Taking up the slack of work and family life was a challenge for everyone involved, especially with two young children. My friends and family at home have been invaluable when sharing and processing ideas, while also helping me to proofread and provide valuable feedback.

The Nuffield Farming Scholarship community is like a family; in the UK and worldwide I have been blown away by the generosity people have shown with their time and friendship. The kind hospitality of international Nuffielders has really enhanced my experience. My fellow 2022 scholars and mentor Matt Swain have been great sounding boards over the last few years and will undoubtedly be lifelong friends.

The numerous inspiring people I have met along my travels have been at the core of my Nuffield. Travelling to new places in remote destinations to spend hours talking to strangers about cover crops, soil health, and farming is fantastic and by the end, strangers become new friends.

Finally, I would like to thank my generous sponsors, McDonald's UK & Ireland, and the Nuffield Farming Scholarships Trust for making all the above and more possible.

Toby Simpson

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Southill Farm, Staple Fitzpaine, Taunton, TA3 5SH
T: 01460 234012 | E: director@nuffieldscholar.org